Hydrogen Insights 2022

An updated perspective on hydrogen market development and actions required to unlock hydrogen at scale

September 2022

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Executive summary

The pipeline of hydrogen projects is continuing to grow, but actual deployment is lagging. 680 large-scale project proposals worth USD 240 billion have been put forward, but only about 10% (USD 22 billion) have reached final investment decision (FID). While Europe leads in proposed investments (~30%), China is slightly ahead on actual deployment of electrolyzers (200 MW), while Japan and South Korea are leading in fuel cells (more than half of the world's 11 GW manufacturing capacity).

The urgency to invest in mature hydrogen projects today is greater than ever. For the world to be on track for net zero emissions by 2050, investments of some USD 700 billion in hydrogen are needed through 2030 – only 3% of this capital is committed today. Ambition and proposals by themselves do not translate into positive impact on climate change; investments and implementation on the ground is needed.

Joint action by the public and private sectors is urgently required to move from project proposals to FIDs. Both governments and industry need to act to implement immediate actions for 2022 to 2023 – policymakers need to enable demand visibility, roll out funding support, and ensure international coordination; industry needs to increase supply chain capability and capacity, advance projects towards final investment decision (FID), and develop infrastructure for cross-border trade.

The pipeline of hydrogen projects is continuing to grow, but actual deployment is lagging. In 2022 some 680 large-scale hydrogen project proposals, equivalent to USD 240 billion in direct investment through 2030, have been put forward – an investment increase of 50% since November 2021. Yet, only about 10% (USD 22 billion) have reached final investment decision.

Europe is home to over 30% of proposed hydrogen investment globally. However, other regions are leading the implementation on the ground: 80% of operational global low-carbon hydrogen production capacity is in North America, while China has surpassed Europe in electrolysis with 200 megawatts (MW) operational, versus 170 MW in Europe, driven by strong government support. South Korea and Japan, in turn, are leading on fuel cells, driven by strong government and corporate ambitions: more than half of the 11 gigawatts (GW) of global fuel cell manufacturing capacity is located there, and Japan has ramped up deployment of hydrogen-ready combined heat and power (CHP) plants, with 425,000 such systems installed.

The urgency to invest in mature hydrogen projects today is greater than ever. The rebound of carbon emissions to above pre-COVID levels, the invasion of Ukraine, and the growing concerns around energy security resulting from the war in Europe make one thing clear: our economies need clean hydrogen, and action is needed to convert proposals into actual deployment. Out of the more

than 680 projects announced, 45 projects worth USD 29 billion are in the front-end engineering design (FEED) phase and 120 projects worth USD 80 billion are undergoing feasibility studies.

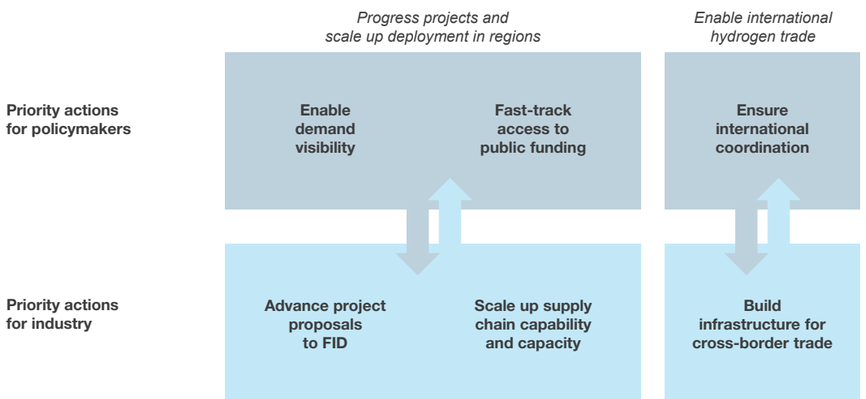
However, only USD 22 billion (about 10% of proposals) have reached final investment decision (FID) or are under construction or operational. This number has only grown by USD 2 billion in the last half year, significantly slower than growth in project announcements.

The key barrier that project developers face today is a lack of demand visibility – many are awaiting decisions on the enabling regulatory frameworks and funding to incentivize offtakers to enter long-term hydrogen supply contracts. Such long-term offtake is key to unlocking project finance and support from financial investors.

Capturing the maximum climate value of hydrogen to deliver the 2050 net zero target requires a tripling of investment in hydrogen by 2030 to USD 700 billion – in other words, additional investments of USD 460 billion into hydrogen projects through 2030. This sounds enormous but in fact is equivalent to less than 15% of the investment committed to upstream oil and gas in the past decade. Across the value chain, investment in infrastructure connecting supply and demand is particularly lagging as visibility on demand is lacking, with an investment gap of more than 80% between project proposals and what is needed to reach net zero.

Joint action by the public and private sectors is urgently required to move from project proposals to FIDs. For policy ambition and project proposals to materialize into actual investments and start delivering environmental and socio-economic benefits, enabling conditions are necessary today. Below, a set of mutually reinforcing priority actions for policymakers and industry for 2022 to 2023 to progress from proposals to investments, scale up hydrogen deployment in regions and enable global hydrogen trade (Exhibit 1). These are critical for moving from ambition to action, accelerating hydrogen deployment.

Exhibit 1 – Synchronizing the efforts of governments and the industry



Policy - Priority actions for 2022-2023:

1. **Enable demand visibility and regulatory certainty by adopting legally binding measures.** Create demand visibility through measures such as targets or quotas for hydrogen consumption across end-use sectors, alongside public procurement measures or competitive bidding for (carbon) contracts for difference. This will bridge the gap to cost competitiveness, boost investor confidence and have a ripple effect throughout the value chain, enabling investments in hydrogen supply, equipment manufacturing, and infrastructure.
2. **Fast-track access to public funding for hydrogen projects.** Introduce measures such as grants, loans, tax credits, as well as funding support schemes based on competitive bidding. Policymakers across geographies have put forward plans to roll out the relevant instruments designed to stimulate hydrogen uptake. Right now, it is crucial to move from vision to action, and proceed with the implementation of these instruments. Rapid rollout of support schemes for hydrogen will lift mature projects off the ground and accelerate hydrogen deployment to support global climate goals within this decade, while bringing the costs further down.
3. **Ensure international coordination and support credible common standards and robust tradeable certification systems.** A common standard methodology for assessing all hydrogen production pathways is essential to allow the hydrogen with the lowest carbon footprint to reveal its climate benefits. Robust certification systems are instrumental in building consumer trust and paving the way for global hydrogen trade, which in turn will support scale-up and minimize hydrogen cost.

Industry - Priority actions for 2022-2023:

1. **Advance project proposals to FID by committing to funding and resource deployment.** As regulatory certainty is being strengthened and funding support starts rolling out, industry should commit to deploying resources to mature projects towards FID by conducting feasibility and FEED studies to realize the USD 240 billion project proposals. Furthermore, new projects must continue to be developed to bridge the USD 460 million investment gap to net zero toward the end of this decade. Project developers should focus on building long-term relationships between hydrogen suppliers and offtakers, and actively mitigate the perceived risk of investing in hydrogen projects by staging projects and by working with established partners with strong track records.
2. **Scale up hydrogen supply chain capability and capacity.** As government targets translate into regulatory action and confidence in a sustained demand outlook, commit to increasing supply chain capability and capacity. The industry should start ramping up capacity to enable deployment at scale. Alignment and synchronization between the policy, infrastructure, and end-use applications is essential. The industry needs to ensure the project proposals and equipment (e.g., electrolyzers) are available as the industry scales. Supply chains must be readied, and only industry can do it. Increasing renewable power capacity at scale remains vital to scale up renewable hydrogen deployment.
3. **Build infrastructure for cross-border trade.** Global trade unlocks the full benefits of hydrogen as transportable, clean energy. But project proposals to develop hydrogen infrastructure are lacking, and industry should concentrate its efforts toward establishing infrastructure to enable cross-border trade (e.g., through building out terminals, large-scale storage, and hydrogen conversion technologies). As international cooperation between governments advances, the industry should actively help to prioritize actions to enable international trade flows match supply and demand in an efficient manner.

Context and objectives

The urgency to invest in mature hydrogen projects today is greater than ever

Climate change must be addressed, urgently. It is clearer than ever that climate change urgently needs to be addressed as highlighted in the most recent IPCC report published in May 2022. Stakeholders are making commitments to curb emissions rapidly: 131 countries covering 90% of global GDP have introduced net-zero targets,[1] and 46 countries have implemented or announced carbon dioxide emissions pricing or trading schemes. Globally, 40 national hydrogen strategies have been announced as countries set pathways to tap into hydrogen's potential to decarbonize, ensure energy security, and spur sustainable economic growth from stranded energy resources. Stakeholders from governments to industries to consumers themselves increasingly recognize that hydrogen is needed to achieve net-zero emissions.

The energy system needs hydrogen. Hydrogen can accelerate the energy transition by allowing clean energy to be stored and large volumes to be transported over long distances via pipelines and ships. It can foster greater resilience, cost-efficiency, and optimization at a system level. Hydrogen is a versatile clean[2] molecule that plays multiple roles across end-uses and goes hand-in-hand with other decarbonization levers such as direct electrification, carbon capture and storage, biofuels, and energy efficiency measures. For example, it can serve as a fuel directly usable in fuel cells used in mobility or stationary power, or for high-grade heat needed for cement production, or grid power generation. It is a feedstock to produce ammonia or synthetic fuels for use in the maritime and aviation sectors or other clean chemicals, and a reductant for processing iron ore for clean steelmaking.

Global political and economic trends influence hydrogen deployment. The pace of deployment is influenced not only by regulations, as critical as they are, and private sector commitments, but also by factors such as the state of the global economy, geopolitics, commodity prices, and the state of global supply chains. The world is recovering from the COVID-19 pandemic, resulting in rapid growth in economic activity with recent supply chain disruptions and high inflation rates. Economic development is uneven across geographies and the growth outlook is uncertain. These factors influence hydrogen deployment, but not necessarily in a negative fashion: recent developments suggest these shifts have strengthened the focus on hydrogen in the past months. However, on-the-ground deployment is not moving fast enough and needs to accelerate to realize the benefits of hydrogen.

Beyond its importance in decarbonization, hydrogen is gaining traction as a way to increase energy security. Countries are increasingly pursuing energy independence and diversification of energy supplies, particularly considering the current war in Europe and uncertainties in global politics. In the EU, the war in Ukraine has led to bolder ambitions for clean hydrogen to strengthen energy security and spur decarbonization beyond the "Fit for 55"[3] package. The EU's REPowerEU communication, announced just three weeks after the start of the Ukraine war, raised the ambition from 5.6 million metric tons (MT) of renewable hydrogen deployed by 2030 to 10 million MT of renewable hydrogen produced domestically and another 10 MT of imported clean hydrogen. Stakeholders have accelerated plans to develop hydrogen pipeline transmissions as laid out in the European Hydrogen Backbone initiative,[4] which now targets 28,000 km in 2030. For many countries, hydrogen is about monetizing decentralized energy resources like renewables in Chile, Brazil, Australia, and Egypt, or ensuring energy security and self-sufficiency, which are key components of the Chinese hydrogen strategy. They include building a domestic industry around technology for seaborne hydrogen trade and use in the power and automotive sectors, such as in Japan and South Korea.

Incentive schemes to accelerate hydrogen adoption are taking shape across the globe – these need to be rolled out, fast. In the EU, for instance, the first Important Projects of Common European Interest (IPCEI) pre-notifications were made at national level in 2021, with first approvals from the EU Commission received in July 2022. Furthermore, the development of a carbon contracts for difference (CCfD) scheme for renewable hydrogen has been announced on EU level. Countries in Europe are developing national support schemes for hydrogen. For example, Germany and Denmark are pursuing joint purchasing agreements and CfD schemes for clean hydrogen imports. Other regions are not standing still, with various incentive schemes emerging around the globe. For instance, the US has allocated USD 9 billion in funding to develop clean hydrogen hubs and advance and scale up electrolyzer technology while granting tax credits for carbon capture and storage, while Japan's Green Innovation Fund is allocation about USD 2 billion to develop carbon neutral projects, supporting development of liquid hydrogen value chains, amongst other technologies. Oman is waiving grid fees for renewable hydrogen production, while India is considering approaches such as grid tariff reductions, clean hydrogen blending mandates in refineries, and electrolyzer capital expenditure subsidies. But speed is of the essence – important controls and bureaucracy need to be adapted to match the urgency of the situation and the typical commercial product development rhythm.

Hydrogen's future is bright – right now, joint action is required to scale the hydrogen economy as fast as needed. Decarbonization is an urgent need as the world is expected to exhaust its remaining carbon dioxide emissions budget of about 400 gigatons (GT) by 2030 to remain within 1.5 degrees Celsius warming. The recent momentum in the hydrogen economy is positive, but ambition and proposals by themselves do not translate into a positive impact on climate change; investments and implementation on the ground are needed. Joint action by the public and private sectors is urgently required to move from project proposals to FIDs.

Hydrogen Insights sheds light on the state of the industry – and what needs to be done for ambition and proposals to materialize into investments and deployment

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 offers a unique view into actual hydrogen deployment.

This publication has three sections:

Momentum: Industry announcements show current investment momentum in the global hydrogen industry.

Actual deployment today offers unique insights into the real deployment of hydrogen across sectors and geographies.

Priority actions for policymakers & industry suggest a set of priority actions for policymakers and industry for the coming year to overcome the key challenges preventing hydrogen deployment at scale.

This perspective is co-authored by the Hydrogen Council and McKinsey & Company and represents a collaborative effort to share an objective, holistic, and quantitative perspective on the status quo of the global hydrogen industry development. The Hydrogen Council counts 141 members (Exhibit 2), up from 60 in 2020, representing USD 8.2 trillion in market capitalization, 6.8 million employees, and revenues of USD 5.2 trillion in 2021.

[1] Includes 14 EU member states that have not announced targets but fall under the EU's overarching net-zero target by 2050, Purchasing Power Parity methodology used for GDP calculation, definition and list gathered from Oxford Net Zero Tracker
[2] Clean hydrogen in this publication defined as both renewable (from electrolysis and renewables) and low-carbon (from fossil fuel reforming with carbon capture and storage)
[3] The EU plan to cut greenhouse gas emissions 55% by 2030
[4] Initiative driven by 31 infrastructure operators

Exhibit 2 – Hydrogen Council Members

USD **8.2** trillion
market capitalization

6.8 million
FTEs worldwide

USD **5.2** trillion
revenues

Momentum: Industry announcements

While the number of project proposals continues to grow globally, less than 10% of hydrogen projects have reached FID

Globally, the industry has announced 680 large-scale hydrogen project proposals (Exhibit 3) as of the end of May 2022, an increase of more than 160 projects since our previous publication (Hydrogen for Net Zero, November 2021). Of these, 534 aim to fully or partially commission through 2030 and represent USD 240 billion of direct investments needed in hydrogen value chains by 2030 (up from USD 160 billion in the previous publication).

Of these 534 project proposals, about a third are undergoing feasibility and FEED (front-end engineering design) studies, representing USD 109 billion in investments. However, only USD 22 billion (about 10%) have reached a final investment decision (FID), are under construction, or are operational. This number has only grown by USD 2 billion in the last half year, significantly slower than the growth in announcements.

Giga-scale project proposals (over 1 GW of electrolysis for renewable or more than 200,000 metric tons a year of low-carbon hydrogen supply) account for 61 projects, of which 18 have been announced since the previous publication. Of these 61 proposals, 45 are renewable and 16 are low-carbon hydrogen. 51 of these are planning full or partial commissioning by 2030, while 33 are undergoing feasibility or FEED studies, and three have reached FID (linked to low-carbon hydrogen in North America). Giga-scale project proposals are found across all continents and are focused on exports to demand centers in Europe or Asia or on serving demand in large industrial hubs.

Europe is home to over 30% of proposed hydrogen investments globally (about USD 76 billion), with nearly 314 project proposals in total and 268 aiming for full or partial commissioning through 2030. Of this, about USD 32 billion is in the planning stages and USD 6 billion involves committed investment. In the past six months, about 50 new project proposals were announced in Europe, with most new additions focusing on the decarbonization of large-scale industrial uses.

North America and Latin America follow Europe in terms of announcements with about 20% each of proposed investments. In fact, since the previous publication, the proposed investments in these two regions have grown at the fastest rate, with USD 20 billion added in North America and USD 34 billion in Latin America. In Latin America, project proposals worth USD 30 billion are undergoing feasibility or FEED studies. In North America, project proposals worth about USD 13 billion are undergoing feasibility or FEED studies, and USD 8 billion is committed capital (mainly driven by existing low-carbon hydrogen projects).

Maximizing the climate value of hydrogen to deliver the 2050 net zero target requires a tripling of investment in hydrogen by 2030, to USD 700 billion. In other words, an additional USD 460 billion hydrogen project proposals by 2030 are needed, even if all current proposals are realized.

An increasing number of project proposals are undergoing feasibility and FEED studies, yet FIDs are lacking

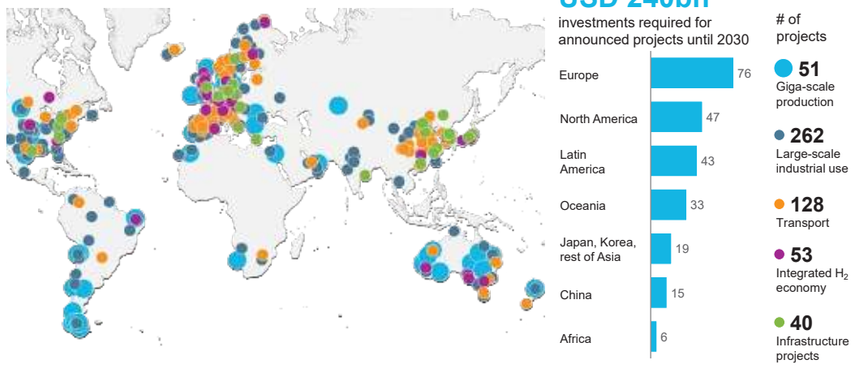
Of the USD 240 billion announced through 2030, nearly half is in the planning stage, i.e., undergoing feasibility or FEED studies (Exhibit 4). Since the previous publication, the number of project proposals undergoing engineering studies has increased from 115 to 165, an increase of 70% in terms of targeted investment, from USD 64 billion to USD 109 billion. Despite the momentum, many project proposals have not reached FID and are awaiting the development of supportive regulation and increased visibility on demand for clean hydrogen and its derivatives.

While there is positive momentum in further maturing projects, there is a slowdown when looking at the FIDs, which only grew by USD 2 billion (about 10%). The key barrier that project developers are

Exhibit 3 – Global hydrogen project announcements

As of May 8, 2022

Out of 534[1] large-scale projects worth USD 240 bn announced globally …



USD 240bn

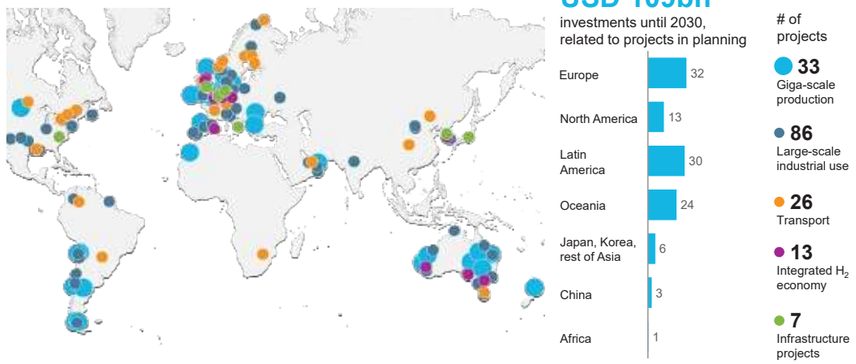
investments required for announced projects until 2030

Europe	76
North America	47
Latin America	43
Oceania	33
Japan, Korea, rest of Asia	19
China	15
Africa	6

# of projects

- **51** Giga-scale production
- **262** Large-scale industrial use
- **128** Transport
- **53** Integrated H_2 economy
- **40** Infrastructure projects

… 165 – about one third – are undergoing feasibility and FEED studies …



USD 109bn

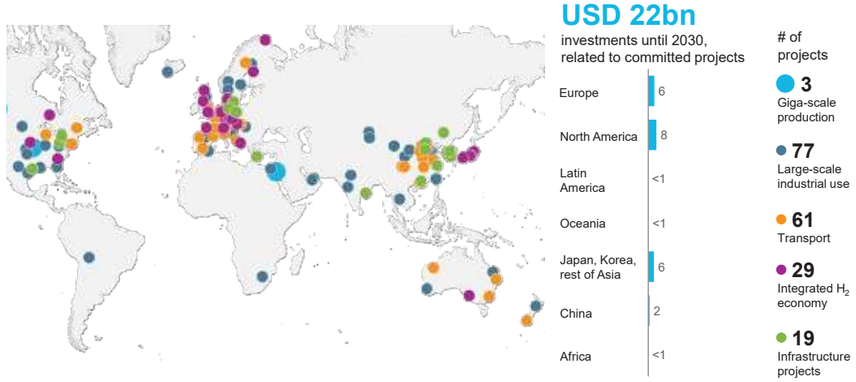
investments until 2030, related to projects in planning

Europe	32
North America	13
Latin America	30
Oceania	24
Japan, Korea, rest of Asia	6
China	3
Africa	1

# of projects

- **33** Giga-scale production
- **86** Large-scale industrial use
- **26** Transport
- **13** Integrated H_2 economy
- **7** Infrastructure projects

… and only about 10% of investments have achieved final investment decision



USD 22bn

investments until 2030, related to committed projects

Europe	6
North America	8
Latin America	<1
Oceania	<1
Japan, Korea, rest of Asia	6
China	2
Africa	<1

# of projects

- **3** Giga-scale production
- **77** Large-scale industrial use
- **61** Transport
- **29** Integrated H_2 economy
- **19** Infrastructure projects

[1] 680 projects announced globally of which 534 are (partially) deployed until 2030

facing today is the lack of demand visibility, as many are awaiting decisions on the enabling regulatory frameworks and funding (including the existing frameworks such as IPCEI in Europe or hydrogen hubs in the US) to incentivize offtakers to enter long-term hydrogen supply contracts. The largest volume of committed investment is in North America (about 35%, partially due to operational low-carbon hydrogen projects), followed by Europe (driven by a somewhat clearer regulatory environment and industry decarbonization targets) and Asia (excluding China and Oceania), both at about 25%.

Along the value chain, about 65% of the total announced investments of USD 240 billion focus on clean hydrogen supply, followed by end-use (25%) and transmission and distribution (10%).

Considering only project proposals in the planning stage, the share of hydrogen supply is above 70% of the total associated investment of USD 109 billion. However, the supply share of investments declines to about 50% when considering only committed investments, while the share of investments targeting hydrogen transmission and distribution increases to more than 20%. This is a doubling from about 10% share of investments when considering projects across all maturity levels. This could be due to the infrastructure component of a project maturing after the hydrogen supply aspect is clearer, or due to a significant current momentum around hydrogen supply specifically.

Hydrogen supply: Announcements reach one third of net zero target

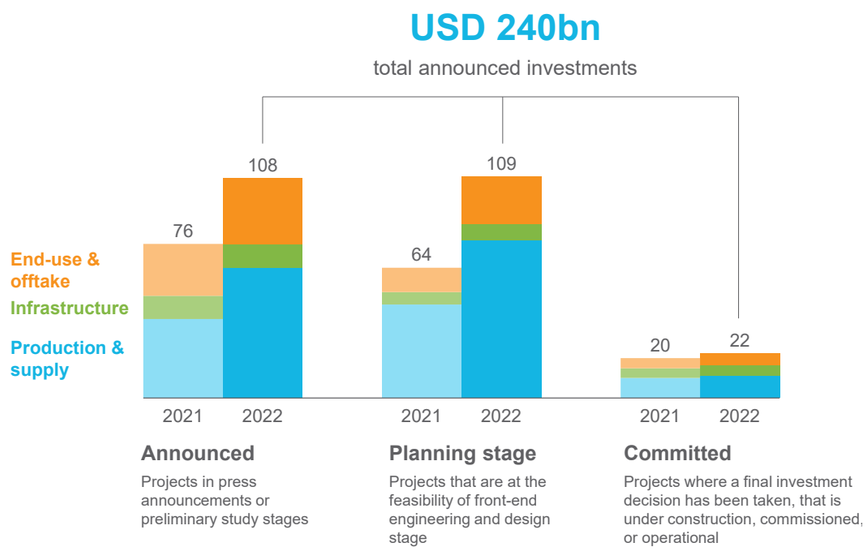
Companies have announced project proposals adding up to about 26 million MT of clean hydrogen capacity through 2030 (Exhibit 5), an increase of about 8 MT since the previous publication. This amounts to about a third of the 75 MT required by 2030 to be on track toward net zero (as laid out in the Hydrogen for Net Zero report). Announcements add up to 7.3 MT of clean hydrogen by 2025, up from 6.5 MT in the previous publication. About 60% of the announced volumes through 2030 feature renewable hydrogen, while about 40% consist of low-carbon hydrogen.

The majority of this capacity is at an early project development stage, with about 15 MT in the planning stage undergoing feasibility or FEED studies, and only 2 MT (about 7% of total announced

Exhibit 4 – Announced investments by maturity

Direct hydrogen investments until 2030, USD billion

As of May 8, 2022



capacity) at FID, under construction, or operational. Considering the proposals currently in the planning stage, about 55% of capacity is renewable and 45% is low-carbon hydrogen. For the projects with committed capital, the majority is low-carbon hydrogen (about 70% of total volumes), driven largely by operational low-carbon hydrogen projects in North America.

From a regional perspective, Europe, North America, and Latin America account for over 70% of the total announced clean hydrogen supply volumes, with the highest volumes found in Europe (about 8 MT in announced supply). Latin America has the largest announced supply of renewable hydrogen (4.8 MT by 2030), while North America has the largest volume of low-carbon hydrogen (4.7 MT). Latin America and North America are the regions with the highest growth in announced volumes since the previous publication, adding 3.6 MT and 2.8 MT, respectively. About three-quarters of project proposals focused on hydrogen supply are undergoing feasibility or FEED studies in Europe, Latin America, Oceania, and the Middle East, indicating that the industry is investing in maturing hydrogen supply projects further.

Beyond 2030, an additional 15 MT of clean hydrogen capacity has been announced globally, bringing the total to about 41 MT. If all the announcements were realized, it would reflect about 6% of the 660 MT required by 2050 to reach the net-zero target. More clean hydrogen supply project proposals are needed to be on track to net zero.

Hydrogen transmission & distribution: Largest gap to net zero

Companies have announced approximately USD 24 billion in investments in hydrogen infrastructure through 2030, encompassing refueling stations, pipelines, terminals, and ships, for example, up from about USD 22 billion reported in the previous publication. About half of these announced investments target the Asia-Pacific region, while Europe accounts for about 25%, followed by the Middle East at 15%. About a third is currently undergoing feasibility or FEED studies, with the majority in Europe (about 30%), followed by China and Oceania (each about 20% of volumes). Despite this positive development, infrastructure is the value chain step that sees the largest gap in investments required to be on track to net zero, with project proposals covering less than 15% of the investment requirement.

Developers are considering multiple hydrogen carrier technologies for global hydrogen transmission, including ammonia, LOHC[5], and liquid hydrogen. Most of the projects announced through 2030 with defined hydrogen carriers have currently opted for ammonia (about 35% by volume hydrogen), followed by LOHC (about 10%), and liquid hydrogen (about 5%). However, about half of the projects have not yet selected technology, and even for those that have, the final decisions on concept, design, and investment have not yet been made.

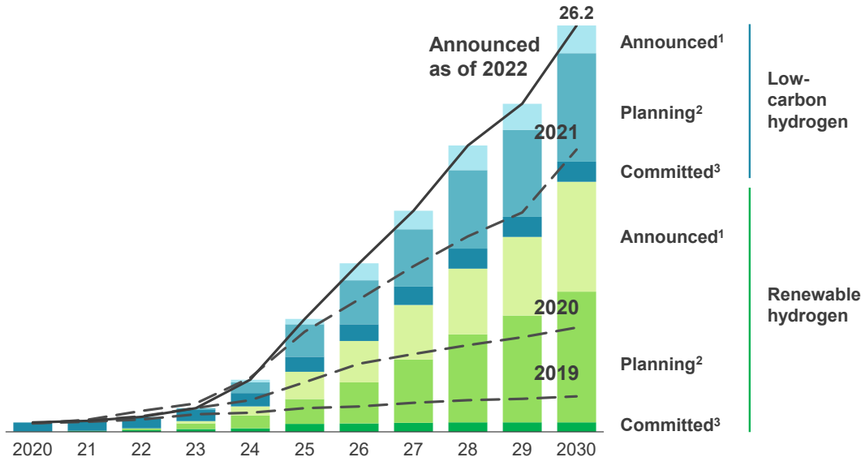
Hydrogen end-use: Mobility and steel are driving investments

Announced investments in hydrogen end-uses through 2030 account for about USD 60 billion and encompass, for example, fuel cell vehicles, the deployment of methanol and ammonia synthesis plants (of which some capacity is intended for export), or the use of hydrogen in clean steelmaking or power applications. Of this, about USD 23 billion is currently undergoing feasibility or FEED studies, while USD 6 billion is committed capital. Ground transport is the segment with the highest share of committed capital, with 25% of total investment proposals at FID or more advanced, followed by power where the share is about 15%.

Most announced investments target the mobility sector and new industry end-uses such as steelmaking, each at about 30% of investments, followed by existing industry uses, like ammonia and refining, at about 25% of announced investments. Announced investments in existing industry uses, where clean hydrogen directly substitutes for fossil-based (“grey”) hydrogen, have more than tripled since 2021 (from USD 5 to 16 billion). However, a large share of this growth is from additional ammonia production projects, many of which target energy export to demand centers in Asia and Europe, rather than substituting grey hydrogen in fertilizer markets. Investments in new industry uses

Exhibit 5 – Announced clean hydrogen production volume by pathway

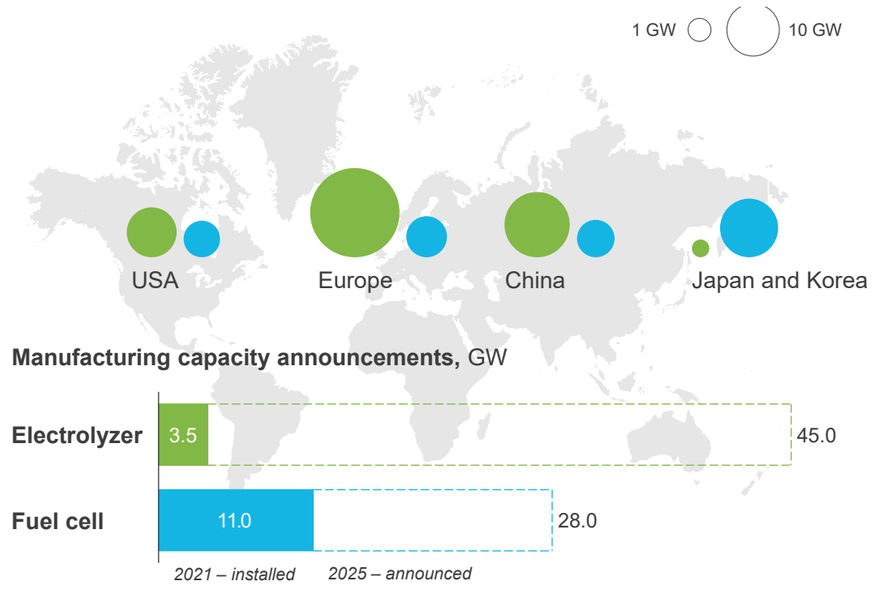
Cumulative production capacity, MT p.a.
As of May 8, 2022



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

Exhibit 6 – Global fuel cell and electrolyzer manufacturing capacity

Electrolyzer and Fuel cell manufacturer capacity, 2025 GW p.a. by HQ region
As of May 8, 2022



[5] Liquid organic hydrogen carrier

have grown by about 25% since the previous publication, primarily reflecting 26 steel projects (of which 20 are in Europe).

Momentum around proposed projects targeting hydrogen end-uses is strongest in Europe, where half of the proposed investments have been announced, followed by the Asia-Pacific region and North America (each about 15%). There is significant variation in the focus segments across regions. In Europe, most end-use investments focus on steel (60%), whereas Latin America sees 60% of investments related to ammonia production (majority of which is intended for export). The Asia-Pacific region focuses on power and transport (about 40% each), while in North America about half of the investments target mobility (ground transportation and sustainable fuels).

Hydrogen technology supply chains are preparing for a rapid scale-up

Anticipating hydrogen market growth, technology providers are planning to ramp up fast (Exhibit 6) – if demand materializes and regulatory frameworks are put in place. For example, electrolyzer OEM announcements worldwide add up to 45 GW of annual manufacturing capacity by 2025, more than ten times the capacity installed by end of 2021. European OEMs are the most ambitious, accounting for 40% of the announced capacity. Chinese OEMs follow with about 35% of announced capacity, potentially driven by supportive government policies toward clean hydrogen supply.

Fuel cell OEMs have announced 28 GW installed capacity until 2025, up from 11 GW installed today. About 60% of existing capacity is concentrated in Japan and South Korea, where some of the world's leading vehicle OEMs are based.

Actual deployment today

Clean hydrogen deployment is increasing across the value chain

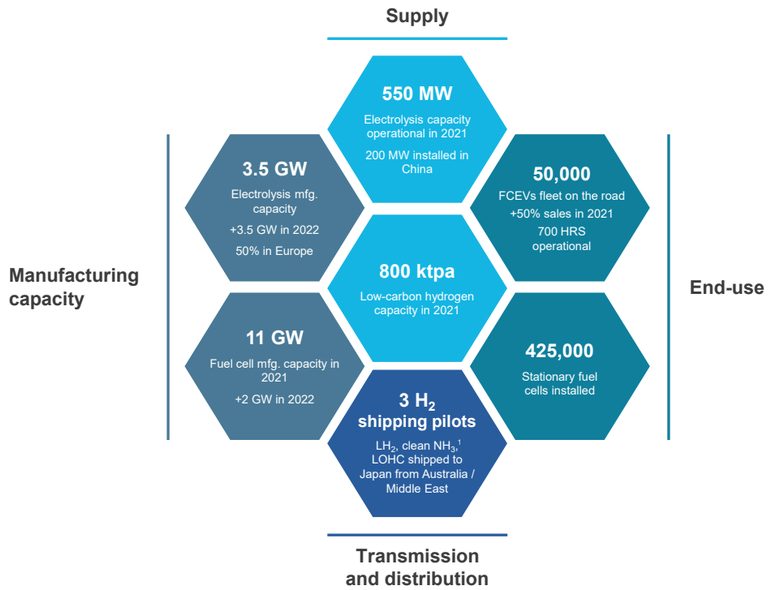
The deployment of hydrogen technologies and projects is gradually growing across the value chain, with progress in hydrogen supply, transmission and distribution, and end-uses in the past year (Exhibit 7)

Hydrogen supply: 800 kt low-carbon, 550 MW electrolysis deployed

Up until now, the global industry has installed about 800 kilotons (kt) per annum of low-carbon hydrogen capacity and about 550 MW of water electrolysis for renewable hydrogen supply. Operational low-carbon hydrogen volumes are spread across 18 projects, with about 90% of the capacity in North America. Installed electrolyzer capacity grew about 80% from 2020 to the end of 2021, with most of the growth (160 MW) in China. China is currently the world's largest market for electrolysis, with about 200 MW capacity installed (most of which involves a 150 MW plant commissioned in 2021). Europe is the second-largest market with about 170 MW of electrolyzers installed (with 40 MW added in 2021). About two-thirds of this serve demand from industrial end-uses such as ammonia plants or refineries, followed by mobility at about 10% of total capacity.

About 75% of the installed electrolyzers are alkaline technology, followed by proton-exchange membrane (PEM) solutions, which account for most of the remaining 25%. Most PEM electrolyzer capacity is installed in Europe, while other regions have higher shares of alkaline technology.

Exhibit 7 – Hydrogen deployment across the value chain



[1] Note that grey ammonia (i.e., produced from natural gas without carbon sequestration) is shipped today at scale

Hydrogen transmission and distribution: Initial steps to develop a hydrogen trade system are being taken

Regional and global hydrogen infrastructure is gradually developing and maturing, and this is happening across pipelines, refueling stations, and global hydrogen shipments.

Global seaborne hydrogen trade is slowly evolving. Small-scale deliveries of clean hydrogen by ship have taken place. Three pilot projects carrying clean ammonia, liquid hydrogen, and liquid organic hydrogen carriers (LOHC) have already sailed in the past three years, delivering hydrogen from Australia and the Middle East to Japan. The Japanese government focuses on hydrogen as a clean energy vector, and is taking steps to, for instance, develop the world's first international value chain for transporting liquid hydrogen between Japan and Australia.

Other regions are starting to focus more on hydrogen trading as well. European countries are considering imports from several potential export countries in the Middle East, Northern Africa, and elsewhere, while Singapore is considering importing hydrogen from Australia. Several regions are positioning themselves as exporters of renewable or low-carbon energy, including Australia, Latin America, North America, Northern Africa, and the Middle East.

Hydrogen pipelines are advancing. There is about 4,500 km of hydrogen pipeline installed globally, transmitting grey hydrogen to industrial end-users, showcasing the feasibility of transmitting hydrogen via pipelines. Several initiatives are currently exploring pipeline transmissions of hydrogen. For instance, pipeline exports of hydrogen from energy resource-rich areas in Northern Africa or Norway to continental Europe are being considered, while the UK and California, among others, are testing the blending of hydrogen in natural gas pipelines.

The deployment of hydrogen refueling stations continues to grow. About 700 hydrogen stations were installed globally by the end of 2021, reflecting about 25% annual growth from the end of 2020. About half of these are in Japan, South Korea, and China, with about 100 stations added in the past year, reflecting annual growth of about 35%. Europe accounts for about 230 stations, while the US has 80 operational stations concentrated in the coastal states. Annual growth in these two markets was about 20%, notably slower than in Asian markets.

Hydrogen end-use: 65% growth in vehicles, clean ammonia producers lead in industry segment

Hydrogen is advancing in mobility. Sales of fuel cell vehicles grew by about 65% from 2020 to 2021, with total sales of about 17,000 vehicles (up from 11,000 in 2020). Commercial vehicles account for about 10% of total vehicle sales, with about three-quarters consisting of fuel cell buses and the remainder of trucks. However, these two segments grow at different rates. Whereas sales of fuel cell trucks grew sevenfold in a year, mainly in China followed by Europe, bus sales declined by 30% driven by lower sales in China.

Sales of fuel cell passenger vehicles grew about 80%, totaling about 15,000 vehicles sold worldwide in 2021. Most sales were in South Korea (55% of sales), North America (20%), and Japan (15%). The highest relative growth occurred in North America (nearly quadrupled) and Japan (more than tripled), reflecting supporting regulatory schemes and available refueling infrastructure.

Progress is happening with off-road vehicles as well, where hydrogen has a role to play for heavy, long-duration uses in sectors like mining, construction, or rail. Multiple projects have retrofitted mining trucks with fuel cells, while OEMs have developed crawler excavators that run on hydrogen. Hydrogen-fueled trains were deployed in several countries in Europe and Asia. More than 10 trains currently operate globally, with orders for over 60 more in place.

Industrial hydrogen end-uses have high activity levels, but large-scale plants have yet to be built. 27 renewable hydrogen projects have reached FID, of which about 20 are in Europe, encompassing the production of clean ammonia, methanol, steel, and synthetic fuels. Among these, ammonia leads the way with seven projects having reached the FID stage and three operational projects (up to 20 MW electrolyzers). Meanwhile, clean methanol production projects are maturing, with seven at the FID stage and the largest operational plant having a 10 MW electrolyzer. Another five renewable hydrogen projects focus on refining, four small-scale projects target hydrogen-based steelmaking, and four others will produce synthetic fuels. Much of this momentum is driven by private sector commitments, even before regulatory frameworks and potential government support are clear. For instance, two large global container ship operators have placed the world's first orders for methanol-fueled oceangoing container ships, while automotive companies are committing to sourcing "green steel." However, no full-scale plants have reached the FID stage.

Energy and heating end-uses are progressing. Examples include the blending of hydrogen in natural gas turbines as well as the development of hydrogen-ready turbines and hydrogen for high-grade heat applications, as well as the replacement of coal with clean ammonia in power plants. Notably, Japan and South Korea have deployed combined heat and power (CHP) fuel cell systems that can run on hydrogen, with about 425,000 such systems installed across Japan.

Technology suppliers have ramped up manufacturing capacity

Hydrogen deployment is gradually evolving, and although demand visibility is limited, suppliers are readying and have installed manufacturing plants for equipment such as electrolyzers and fuel cells.

Electrolysis. Companies have installed about 3.5 GW of electrolysis manufacturing capacity globally by the end of 2021, with another 3.5 GW announced to be added during 2022. European OEMs have developed about half of the existing capacity, while Chinese OEMs have announced the most ambitious targets for 2022 and are planning to install an additional 1.5 GW this year. Two-thirds of existing capacity is atmospheric alkaline technology today, whereas the share of pressurized electrolyzer technologies should gradually increase as new manufacturing capacity rolls out.

Fuel cells. The currently installed fuel cell manufacturing capacity is approximately 11 GW, with about 60% of this capacity developed by South Korean and Japanese OEMs, followed by Chinese and American OEMs. Announced near-term growth is limited, with a target of 13 GW total installed capacity in 2023, and most growth will occur in South Korea.

Vehicle platforms. Vehicle OEMs have developed 87 fuel cell vehicle platforms to date, up from 61 in 2021 (about 70% are in China). Most of the current platforms are for fuel cell buses, followed by trucks and light vehicles. Most of the new platforms target fuel cell trucks, followed by light vehicles such as vans or passenger vehicles.

Developers and financial investors are investing in hydrogen

Companies are actively investing in hydrogen, both to develop projects to supply and consume clean hydrogen, and in hydrogen companies themselves (e.g., technology providers).

Companies are investing in maturing hydrogen project proposals. Stakeholders are investing about USD 4 billion in feasibility or FEED studies for projects that have yet to reach FID. About 40% of these investments are centered in the Asia-Pacific, followed by Europe (about 35%). Historically, companies have invested about USD 2 billion in such studies to develop projects that have already reached FID or have been deployed – these projects imply an estimated committed investment of USD 22 billion.

Financial investors are following suit. Globally, investors spent about USD 7 billion on fuel cell and electrolyzer suppliers in 2021, nearly doubling in a year. Both private and public markets are active, with significant growth seen across all types of investments. Notably, private investment in public equity (PIPE) doubled, while merger and acquisition (M&A) activity grew fivefold from 2020 to 2021. Average deal sizes increased by 60% year on year, with an average deal worth USD 41 million in 2021.

Priority actions for policymakers and industry

Joint action by the public and private sectors is urgently required

There is no climate solution without clean hydrogen. Scaling it up rapidly is crucial for staying on track to net zero but doing so will not happen by default. The two most important priorities for policymakers and industry in the next few years are: i) to progress from proposals to investments and scale up hydrogen deployment in regions, and ii) to enable global hydrogen trade (Exhibit 1).

1. Progress from proposals to investments and scale up hydrogen deployment in regions

Accelerating hydrogen deployment at scale is critical, and it will help push the costs of clean hydrogen further down. To do so, policymakers can create demand visibility and regulatory certainty as well as fast-track access to public funding for mature projects. In parallel, industry should mature projects towards FID and further increase supply chain capacity and capabilities.

Policy action 1: Enable demand visibility and regulatory certainty by adopting legally binding measures

Currently, about 680 large-scale hydrogen project proposals are on the table. To move these projects forward, investors are looking for visibility on future demand, which depends to a large degree on the regulatory framework for offtakers. Measures such as binding targets and quotas for the consumption of clean hydrogen (for instance in steelmaking, road mobility) and hydrogen derivatives (such as synthetic fuels and clean ammonia), contracts for difference (CfDs) and public procurement measures would increase this demand visibility.

If enacted, these policies will create a ripple effect through the value chain, enabling investments in hydrogen supply, equipment manufacturing, and infrastructure. With the increased scale, costs will come down, bridging the gap towards cost competitiveness. In electrolysis, for example, an estimated 70 GW of installed electrolysis is sufficient to bring down costs to be on par with grey hydrogen.[6]

Several countries have proposed schemes to increase demand visibility. The Netherlands have enacted SDE++, a carbon contract-for-difference scheme that provides a reliable and robust carbon price to support decarbonization projects. Germany is implementing the H2Global scheme to facilitate hydrogen imports by matching long-term supply contracts with shorter-term offtake contracts. In the United States of America, California's Low Carbon Fuel Standard (LCFS) has proven to be a cost-effective demand-pull measure incentivizing fuel switching from fossil fuels to low carbon alternatives in the transport sector. Meanwhile South Korea has, as part of its hydrogen roadmap, launched ambitious public procurement measures for fuel cell electric vehicles.

Policy action 2: Fast-track access to public funding for hydrogen projects

Governments have earmarked USD 80 billion to kickstart the hydrogen economy. The funding aims at supporting early hydrogen deployment, creating infrastructure and clusters, and speeding up cost reductions as hydrogen reaches scale. Such announced measures across different regions include:

— Funding program for regional hydrogen hubs and production technology development in the US (USD 9 billion), as well as production tax credits (PTC) for clean hydrogen production with support of up to USD 3 kg a kilogram depending on carbon dioxide content.

— Alongside funding from the Important Projects of Common European Interest (IPCEI) in the EU, from which first approvals from the EU Commission were received in July 2022, release funding for rolling out carbon contracts for difference (CCfD) scheme for renewable and low-carbon hydrogen at the EU level. Further, several national hydrogen strategies have pledged funding for growing hydrogen deployment (e.g., Germany, Spain).

— In Japan, the government has pledged about USD 2 billion for the development of a large-scale liquefied hydrogen supply chain.

Most of these funds, however, remain pledges to date, and only a small share has been assigned to specific projects. Following through with rapid implementation of these instruments to support hydrogen deployment is essential and will allow lifting mature projects off the ground. For instance, across Europe there are project proposals worth USD 32 billion undergoing feasibility or FEED studies – an acceleration of funding could help propel them forward.

Government action and support for clean hydrogen deployment today is critical to move from vision to action and accelerate hydrogen uptake, while helping industries that are decarbonizing to retain their competitiveness.

Industry action 1: Advance project proposals to FID by committing to funding and resource deployment

As governments increase regulatory certainty and funding support starts to roll out, mature projects will move toward FID. Investing in feasibility and FEED studies will be required to bring the USD 240 billion of project proposals closer to deployment. In addition, more projects – an estimated USD 460 billion of investments until 2030 – are needed to be on track to net-zero in 2050. Project developers would need to step up the development of more proposals spanning the entire hydrogen value chain, boosting hydrogen supply, investments in end-use, and the infrastructure that connects supply with demand.

To lower risks for both offtakers and suppliers, new partnerships across the value chain are already emerging. Project developers are eliciting demand from potential offtakers, for example, by way of organizing them in project consortia together with potential hydrogen suppliers and infrastructure players. As the project concept matures, binding offtake agreements are concluded, which in turn allow the suppliers and infrastructure players to raise funding and commit further investments. By coordinating across the value chain, sharing risks, leveraging existing infrastructure and building in phases, such projects are solving the chicken-egg problem in an iterative fashion.

Industry action 2: Scale up hydrogen supply chain capability and capacity

As demand visibility increases, the industry will be able to ramp up manufacturing and deployment capacity across all types of equipment. For example, electrolyzer OEMs need to expand capacity from the current 3.5 GW installed by end of 2021 to at least 50 GW a year by 2030 to be on track to net zero.

Furthermore, scale-up is required along the full value chain, starting with the materials that go into the components and ultimately the equipment to produce, store, convert, transport and use hydrogen. To succeed, companies need to deploy capital early to build manufacturing experience, prepare product designs, optimize manufacturing processes, and gain experience in building the plants. Projects require alignment and synchronization along the value chain, both in terms of regulations as well as with infrastructure and end-use applications. Partnerships along the value chain – for example between electrolyzer suppliers and project developers and between component manufacturers and fuel cell stack manufacturers – can be used to jointly develop products and synchronize scale up.

2. Enable global hydrogen trade

Global trade in hydrogen allows to bring clean hydrogen from regions with abundant energy resources to the demand centers thereby accelerating hydrogen uptake and reducing costs. This requires common global standards for hydrogen, robust tradeable certification systems and cross-border infrastructure.

Policy action 3: Ensure international coordination

To enable trade of hydrogen and its derivatives, international coordination, credible common standards and robust certification systems for hydrogen are required. A common global ISO[7] standard methodology for assessing the carbon footprint of different hydrogen production pathways

[6] See Path to Hydrogen Competitiveness, January 2020, and Hydrogen Insights, February 2021

[7] International Organisation for Standardisation

is essential to allow the hydrogen with the lowest carbon footprint to reveal its climate benefits. The Hydrogen Council is supporting the development of the said ISO standard, with the IPHE guidelines[8] serving as the seed document. Meanwhile, robust certification systems are instrumental in building consumer trust and paving the way for cross-border hydrogen trade, which in turn will support production scale-up and bring the cost of hydrogen further down. The upcoming Hydrogen Council publications on the global trade of hydrogen and on hydrogen certification will explore these topics in more detail.

Industry action 3: Build infrastructure for cross-border trade

The biggest gap between announced projects and projects required to achieve net zero is in hydrogen infrastructure. Only 10% of currently proposed investments focus on hydrogen infrastructure, highlighting an investment gap of about 85% to the required USD 200 billion in spending through 2030. The industry needs more proposals in these areas and should concentrate its efforts on establishing infrastructure to enable cross-border trade. Such proposals would involve terminals, large-scale storage of hydrogen, hydrogen carriers, conversion technologies, and refueling station networks. As international cooperation among governments advances, industry should actively help prioritize actions to enable trade flows that efficiently match supply and demand across borders.

[8] IPHE Working Paper, Methodology for Determining the Greenhouse Gas Emissions Associated with the Production of Hydrogen