Hydrogen Council McKinsey & Company

Global Hydrogen Compass 2025

Industry progress and lessons learned from the first wave of mature clean hydrogen projects

September 2025

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The Hydrogen Council's inaugural Global Hydrogen Compass report builds on five years of detailed reporting in collaboration with McKinsey & Company via the "Hydrogen Insights" series and examines where the hydrogen industry stands today, unpacks lessons learned from the first wave of mature clean hydrogen projects, and explores the impact clean hydrogen can have across the energy sector as the industry navigates the current challenging environment.

Representatives from the Hydrogen Council member companies were instrumental in delivering the report through ensuring project data is fully up to date, sharing insights around how companies are facing challenges and progressing projects, and volunteering to showcase how a representative sample of projects have come to fruition.

Analysis in this report includes unique qualitative and quantitative insights derived from interactions with over 70 Hydrogen Council members gathered through a sentiment survey and direct conversations with CEOs across the value chain. In the Hydrogen Leaders' Perspective that opens the report, insights from these interviews and survey results are distilled down into key emerging themes, bringing to light how leaders in the ecosystem are navigating the industry's opportunities and challenges today. The analytical body of the report that follows examines the state of the project pipeline, the progress of supply projects, the development of firm demand, and lessons learned from the first wave of mature clean hydrogen projects.

Unless otherwise cited, analytical findings in this report are based on the Hydrogen Council & McKinsey Project & Investment Tracker – a comprehensive database on clean hydrogen projects that span the value chain from production to distribution to end use. Additional insights throughout the report are based on research delivered in collaboration with McKinsey & Company.

The authors of the report confirm that:

— 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; and

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

The calculations in this analysis were conducted based on regulations as formulated in law and drafts as of August 1, 2025. This analysis does not include calculations or hypo–thetical ranges based on future regulatory uncertainty or transitory trade measures (e.g., tariffs), nor does it seek to make any specific policy recommendations.

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, based on robust life–cycle analysis–based methodologies for greenhouse gas (GHG) emissions assessment.

This includes i) hydrogen produced using natural gas as a feedstock with steam methane reforming (SMR) or autothermal reforming (ATR) coupled with carbon capture and storage (CCS); ii) hydrogen produced through pyrolysis of natural gas into hydrogen and solid carbon; iii) hydrogen produced through gasification of coal with CCS; iv) hydrogen produced through electrolysis using electricity of non–renewable origin as feedstock. Renewable and low–carbon hydrogen are collectively referred to as "clean hydrogen". Unabated hydrogen refers to hydrogen produced from unabated fossil fuels.

We recognize the varying national and regional approaches to GHG emissions intensity thresholds or bands and the criteria for qualifying hydrogen as 'clean,' 'low–carbon,' 'renewable,' 'sustainable,' 'low–emission' adopted across jurisdictions.

While 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 European Union (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

Steering members

Supporting members

Investors

As of July 2025.

In this report

Reflecting on industry progress: a letter from the Hydrogen Council Co–Chairs

The first wave of mature clean hydrogen projects is coming online. Today, about $110 billion in committed investment supports more than 500 projects past final investment decision, in construction or operation across the globe – up $35 billion in the past year alone. In just five years, our sector has scaled at a remarkable pace, with investment growing over 50% year–over–year. The total committed capacity now exceeds 6 million tonnes per year (mtpa), of which 1 mtpa is already operational.

But this progress has not come without turbulence. The sector is navigating through the hype cycle and moving from a surge of announcements in 2022–2023 to a more disciplined era of maturation, similar to the solar, wind, and battery industries. Over 1,700 projects have been announced globally since 2020, a 7.5 increase, but a pipeline clean up is underway – a natural attrition phase where the projects with the strongest business cases get selected, win regulatory support, and close financing, while projects that lacked commercial viability inevitably get cancelled. A challenging macroeconomic environment with structurally higher interest rates, elevated energy and equipment costs, and delayed implementation of climate policies in some regions is exacerbating this selection process.

What is emerging is a stronger, more credible foundation of projects built on solid business cases and growing offtake certainty. Including the projects that are already committed, the current supply pipeline could support a total of 9–14 mtpa by 2030. However, how much of that capacity materializes still hinges on demand and only those projects that secure offtake will ultimately come online.

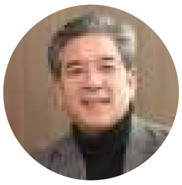
Demand is our next great test. Roughly 3.6 mtpa of binding offtake has been secured globally. In key markets such as the EU, US, Japan, and Korea, implementation and enforcement of existing policies could enable a total of up to 8 mtpa of clean hydrogen demand by 2030, although there is still more work to do. A further 13 mtpa could be unlocked through targeted infrastructure investment and continued cost reductions, but without timely implementation, much of the supply opportunity will remain unfulfilled.

CEOs from Hydrogen Council member companies who were interviewed in preparation for this report acknowledged that the environment remains challenging for clean hydrogen, but shared a sense of optimism, particularly those leaders accustomed to the development cycles that come with large–scale industrial sectors. Leaders also pointed to demand, backed up by policy stability, as the lynch pin for future growth, with most anticipating additional regulatory clarity in the near term.

Realism, pragmatism and focus will be key to success in the next phase of hydrogen build–out. We are therefore proud to introduce this inaugural Global Hydrogen Compass – a unique report that provides much needed clarity on what is really happening in hydrogen through a combination of comprehensive industry data, direct insights from global CEO leaders, and case examples of projects that demonstrate what it takes to advance despite a challenging environment. Like a compass, we hope it will guide business, policy and other decision–makers through this pivotal moment in our important collective effort to build a clean, secure, and resilient energy future.

Sanjiv Lamba

CEO, Linde



Jaehoon Chang

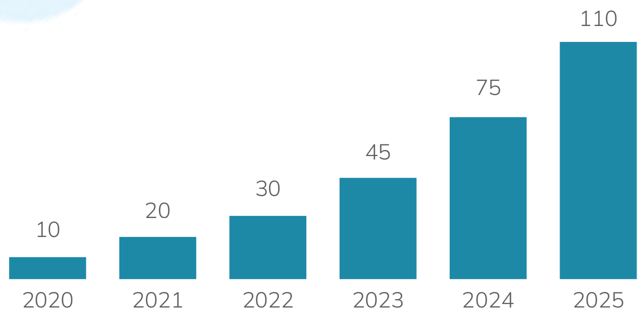
Vice Chair, Hyundai Motor Group

Key analytical findings: State of the global hydrogen industry

The first wave of mature projects is coming online

Committed[1] investment in clean hydrogen has now surpassed $110 billion across 510 projects, up $35 billion from last year and growing on average over 50% year–over–year since 2020. There are now more than 1,700 clean hydrogen projects announced globally across the value chain, although maturation of the project pipeline[2] has meant fewer new announcements. As part of the ongoing pipeline clean up, at least 50 projects have been publicly cancelled in the last 18 months, 80% of which were early–stage renewable hydrogen projects. Advancement of projects with the strongest business cases is expected to be coupled with cancellations of less viable projects as the pipeline continues to mature.[3]

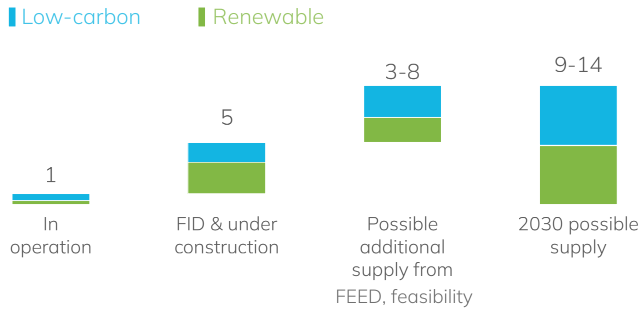
Global cumulative committed (FID+) investment in clean hydrogen projects by 2030, $ billion



Supply is ready to scale

Of the 6 mtpa of committed clean hydrogen capacity today, 1 mtpa is already operational. After accounting for delays and expected attrition, the current project pipeline could support up to 9–14 mtpa of clean hydrogen capacity by 2030, depending on how much supply secures offtake. Currently, China is the global leader in electrolysis deployment with over half of global committed renewable hydrogen capacity, while North America leads for low–carbon hydrogen. The majority of recent operational capacity additions have also been in China, which has increased operational capacity sixfold since 2022.

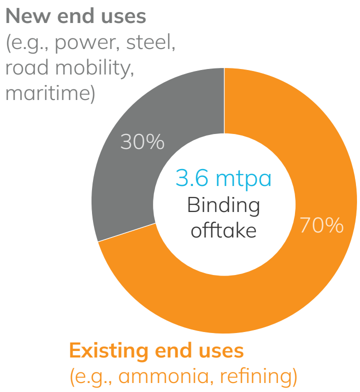
Global clean hydrogen capacity by 2030 by pathway and status, mtpa



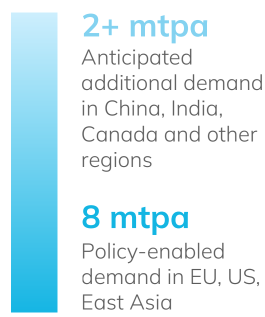
Demand is critical, but relies on enabling policy

Locking in offtake remains the critical element for most supply projects to move forward. Approximately 3.6 mtpa of binding offtake is in place today globally, representing about 60% of committed project capacity. Existing use cases comprise 70% of current offtake with the biggest pockets of demand in decarbonization of refining and ammonia, particularly in the European Union, followed by co–firing clean ammonia for power in Japan and Korea. Looking ahead to 2030, about 8 mtpa of 2030 clean hydrogen demand could materialize in the European Union, US, Japan, and Korea,[4] but requires that existing policies are implemented and enforced.[5] About 2 mtpa of FEED+ projects in China are anticipated to serve growing Chinese demand.

Binding offtake by end use sector, %



Potential 2030 demand in key regions, mtpa



[1] Throughout this report "committed" refers to projects that have taken final investment decision (FID), are under construction, are commissioned, or have started operations; [2]The project pipeline refers to the full portfolio of hydrogen projects at various stages of development, from announced through operational; [3]Not all project cancellations are publicly announced–additional projects have likely been stalled or cancelled either temporarily or permanently; [4]Hydrogen Council & McKinsey: Closing the Cost Gap report, 2025; [5]As of the publication of this report, key hydrogen–supportive policies including the EU's RED III, CBAM, Japan's CfD, and Korea's CHPS program are still either being transposed at country levels, have not yet fully gone into enforcement or are still awaiting upcoming clarifications or actions that could affect the overall impact on hydrogen demand.

Key analytical findings: Progress across leading regions

China

$33 billion — Committed investment by 2030

Global leader in electrolysis deployment, supported almost exclusively by domestic market

China currently accounts for 19 GW (1.6 mtpa) of committed renewable hydrogen capacity (approximately 55% of global), with Chinese projects in some cases four to ten times larger than European and American renewables projects. Supply predominately serves growing domestic demand on the back of a push to diversify away from dependence on fossil–based energy sources. Current offtake is focused in ammonia, refining, and power with growing deployment of commercial fuel cell vehicles. Top–down policy directives, centrally–supported lower cost of capital, and strategic alignment of state–owned enterprises appear to contribute to rapid growth in the sector.

North America

$23 billion

Global leader in low–carbon production and exports, with limited domestic demand–side policies

About 2.2 mtpa of low–carbon capacity is committed in North America (85% of the global total). US production in particular is enabled by structural advantages including low–cost natural gas, existing CCS and export infrastructure, and supportive policy (e.g., the 45Q CCS tax credit). Most US low–carbon volumes are expected to serve exports in the near term given uncertainty around or limited availability of domestic demand–enabling policies (e.g., LCFS). Renewable capacity in the US has been curtailed due to a shortened eligibility timeline for the 45V production tax credit. Meanwhile 97% of Canada's committed capacity is low–carbon, but significant wind resources could be harnessed for renewable production for export.

Europe

$19 billion

Policy–backed renewable demand center with emerging regulatory clarity in the European Union

Europe ranks third in committed investment (USD 19 billion), while accounting for nearly two thirds of expected 2030 global demand.[1] By 2030, nearly 5 mtpa of clean hydrogen demand could emerge if policies like the Renewable Energy Directive (RED) III and the Carbon Border Adjustment Mechanism (CBAM) are implemented alongside the Emissions Trading Scheme (ETS). The EU is expected to supply near–term demand locally via small to mid–size projects before transitioning to a net importer, assuming trade infrastructure falls into place. In the last year, committed capacity has doubled as early signs of regulatory clarity emerge (e.g., RED III transposition drafts for transport), but firmness of potential demand still hinges on full policy implementation (e.g., RED III industry targets).

India

$14 billion

Cost leader in renewable ammonia production with emerging export market

Nearly all of India's committed renewable hydrogen investment is dedicated to ammonia production projects, bolstering its already substantial base of domestic ammonia production. India has set record low renewable ammonia prices in recent Solar Energy Corporation of India (SECI) auctions under the National Green Hydrogen Mission's (NGHM) Strategic Interventions for Green Hydrogen Transition (SIGHT) scheme, which could position India as a potential exporter of ammonia although the domestic fertilizer market is a likely offtake vector in part to alleviate reliance on imports.

Middle East

$11 billion

Growth through industrial–scale renewable production with a focus on exports

The 0.5 mtpa of committed capacity across Middle Eastern countries is split 55% renewable, 45% low–carbon. Low–cost renewable energy, advantageous access to financing, and a focus on large–scale projects enable globally competitive renewable hydrogen production costs, positioning the region as a key exporter. Abundant natural gas resources could also enable competitive low–carbon exports, however, energy diversification and budding demand in Europe appear to be driving current renewable hydrogen investment.

Japan, Korea

$6 billion

Policy–backed demand for ammonia in power, majority served via imports

Approximately 1–1.5 mtpa of 2030 policy–supported low–carbon demand could materialize in Japan and Korea for co–firing ammonia to partially decarbonize a relatively young coal powerplant fleet. Limited domestic renewable and natural gas resources creates an import opportunity for majority of supply, particularly for low–carbon molecules. Nearly all of committed investment is in distribution and end–use projects.

South America

$2 billion

Ample renewable energy and policy support enable progress towards future export hub

Although South America has limited committed capacity, a growing pipeline of earlier stage projects, of which 98% are renewable, is enabled by abundant renewable resources including hydro–power in Brazil and Paraguay, and solar and wind in Chile and Argentina. Hydrogen policy frameworks like Chile's National Green Hydrogen Strategy set ambitious production and export targets and Brazil's National Hydrogen Program (PNH_2) provides a strategic roadmap across six pillars to accelerate clean hydrogen development.

Oceania

$1 billion

Promising project pipeline hindered by lack of international trade economy

Approximately 50% of committed investment in Oceania is directed towards renewable hydrogen production projects. However, with limited demand centers in Oceania, realizing the region's production potential depends on establishing international trade infrastructure. While many large–scale projects remain in the feasibility stage, policy support and financing mechanisms, such as Australia's recently passed Hydrogen Production Tax Incentive beginning in 2027, create a strong foundation for future progress.

[1] Of the 0.7 mtpa of production capacity committed in Europe, 95% is in the European Union (EU).

Note: Select country and regional details are elaborated in each region without aiming to provide an exhaustive overview of every country's hydrogen profile.

Chapter 01

Hydrogen Industry Leaders' Perspective

It can be challenging to keep pace with the many dynamic developments in the hydrogen industry today. Understanding how businesses and investors across the value chain are navigating the challenges of scaling up and capturing the value in hydrogen requires hearing directly from their top leadership.

In this chapter, we go beyond data from our global project pipeline analysis and add a unique layer of insight by distilling down the perspectives of over 70 leaders from Hydrogen Council member companies, gleaned through a combination of CEO sentiment survey and direct CEO interviews.

Participating members include companies across industries, regions, and the hydrogen value chain, including industrial gas companies, power utilities, infrastructure players, technology suppliers, project developers, fertilizer producers, oil & gas majors, and automotive OEMs.

NEOM Green Hydrogen Company (NGHC) | Aerial view of renewable hydrogen production facility| image provided by thyssenkrupp nucera

Hydrogen Industry Leaders' Perspective

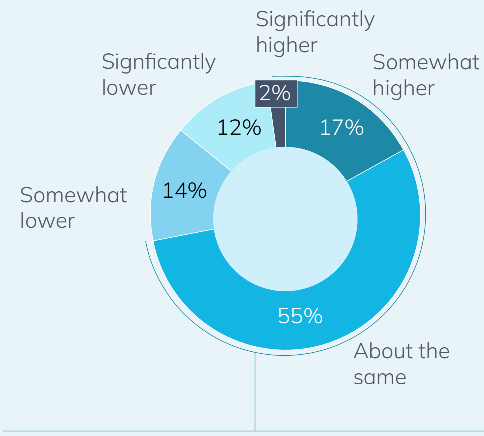
#1 | CEOs show confidence in hydrogen's continued growth despite a challenging environment

Consistent with the Global Hydrogen Compass report's finding that committed investment has surpassed $110 billion today, 83% of surveyed leaders indicated that they see mature clean hydrogen projects advancing and believe that the industry will continue to grow. Furthermore, 74% of respondents said their investment appetite for clean hydrogen has either remained stable or increased over the last two years.

In interviews, CEOs recognized that project attrition is a natural part of the continued maturation of the global project pipeline because in any project portfolio, developers will inevitably focus resources on the projects with the strongest business cases. CEOs indicated that the 500+ projects past FID that have emerged in the "first wave" of committed investments are the result of this prioritization process. Finally, CEOs also noted that many committed projects today include players with a track record of successfully developing large–scale industrial projects whose experience is key in successfully navigating the significant challenges of scaling up new technologies.

Clean hydrogen investment appetite

How does your investment appetite into clean hydrogen and derivative projects compare to two years ago?, % of respondents

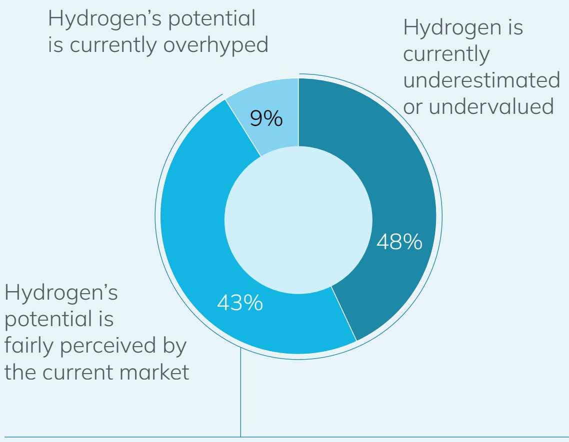


74%

indicated their investment appetite in clean hydrogen has either remained stable or increased in the last two years

Current public narrative around hydrogen

Do you think the current public narrative around hydrogen accurately reflects where the industry is today? % of respon-dents



90%

believe hydrogen is either fairly perceived by the current public narrative or underrated

#2 | CEOs call for focus and pragmatism amid shifts in public narrative and priorities

Leaders acknowledged a "cooling off" in the public narrative following the surge in project announcements in the last few years as the industry confronts challenges. This narrative shift has been partially driven by the ongoing cleanup of projects with less viable business cases, including headline–grabbing announcements of project cancellations. However, that has not changed their views on hydrogen's importance. 97% believe hydrogen will be a critical decarbonization solution for hard–to–abate sectors, with over 65% believing it could also play a significant role across the energy system more broadly.

When asked about how the current narrative captures the reality on the ground, 90% of CEOs indicated that hydrogen is either undervalued or perceived fairly – only about 10% indicated it is overhyped. In interviews, CEOs drew parallels to other cleantech industries like solar and wind, where an early ambition and "hype" ultimately gave way to realism and pragmatism, leaving the strongest projects to build more resilient industries.

Finally, CEOs suggested that the calibration of government priorities to energy security, industrial competitiveness, and affordability alongside decarbonization further strengthens the case for hydrogen, although decarbonization is expected to remain the primary strategic driver.

Source: Insights derived from interviews and surveys conducted with over 70 leaders from a subset of Hydrogen Council member companies from across the hydrogen value chain; analytical findings sourced from Hydrogen Council & McKinsey Project & Investment Tracker.

#3 | CEOs point to demand as the key market unlock and suggest near–term flexibility on low–carbon hydrogen use to bring down cost and enable infrastructure build–out

Leaders from across the value chain agreed that demand is now the single most critical factor determining how quickly the ecosystem will scale. In interviews, CEOs were optimistic that once demand firms up, the supply pipeline could capably support that demand, but that supply alone would not necessarily drive further uptake. This sentiment is borne out in the data where a risk–adjusted project pipeline could support an estimated 9–14 mtpa of supply by 2030, while for now, closer to about 8 mtpa of demand could carry a policy–supported positive business case assuming existing regulations are implemented and enforced in key regions.

In interviews, CEOs suggested the most concrete demand today is in refining and ammonia, particularly in policy–driven markets like the European Union, Japan and Korea. Early signs of progress are emerging in pockets where mobility ecosystems have been established (e.g., in South Korea and China), and CEOs frequently pointed to International Maritime Organization (IMO) guidance as an indicator that maritime uptake may be on the horizon.

When asked about other potential avenues for enabling uptake of clean hydrogen, about 90% of survey respondents indicated that flexibility to use low–carbon hydrogen could be at least a near–term enabler of broader adoption by cost–effectively serving end–use sectors and providing necessary scale to develop and utilize additional infrastructure, with 30% believing it is a prerequisite for industry take–off.

Main success factors for clean hydrogen projects

What are the main factors that make or break a successful clean hydrogen project?, top 5 responses

#1 Certainty of offtake/demand, including captive

#2 Favorable financing terms and investor confidence

#3 Ease of doing business, including regulatory clarity

#4 Reliable and resilient supply

#5 Proven track record of technology providers

Certainty of offtake seen as the key driver for hydrogen projects

with CEOs suggesting in interviews that developing at–scale demand is the most critical priority for the industry today

#4 | CEOs point to negative impacts of regulatory uncertainty but note that clarity is starting to emerge in some markets

Leaders noted that a landscape of hydrogen–supportive policies has emerged over the past few years, however, uncertainty around their implementation has contributed to project delays and in some cases, cancellations.

As in other growing cleantech sectors, policy remains crucial for clean hydrogen's foundational development and CEOs shared a cautious sense of optimism that the near future would bring more certainty. This includes the latest updated guidance on US energy tax credits, anticipated, at least partial, transposition of Renewable Energy Directive (RED III) at European Union Member State level, and the progression of Japan's contract for difference (CfD) funding allocation alongside both Japan and Korea's next rounds of clean power generation auctions. The upcoming International Maritime Organization (IMO) greenhouse gas reduction guidance could be another signpost for clarity around maritime demand.

In interviews, multiple CEOs also suggested that while the combination of these core policies could indeed be enough to support a successful first tranche of uptake, particularly in the decarbonization of existing refining and ammonia sectors, additional work remains to activate emerging end use sectors in particular. CEOs also noted that even existing regulations still carry some uncertainty in how they'll be implemented. For instance, several mentioned that while draft transposition guidance for RED III transport targets is emerging, guidance for industry targets is still outstanding in most Member States.

When asked what types of policies could bolster additional uptake, 88% of survey respondents indicated demand–side support as most impactful. Cost/price offsetting mechanisms (i.e., contracts–for–difference) and carbon pricing instruments (e.g., emissions trading schemes, carbon intensity standards) were also seen as potentially more impactful than additional supply–side support.

Source: Insights derived from interviews and surveys conducted with over 70 leaders from a subset of Hydrogen Council member companies from across the hydrogen value chain,; analytical findings sourced from Hydrogen Council & McKinsey Project & Investment Tracker.

Macro drivers of clean hydrogen uptake

For the following macro forces/priorities driving uptake of clean hydrogen, which are critical, possible or non–significant drivers?, top 5

#1 Government decarbonization policies

#2 Energy system diversification and resilience

#3 Corporate commitments

#4 Strengthening regional energy security

#5 Driving economic growth and job creation

Emerging regulatory clarity

anticipated in regions with key hydrogen–supportive policies like the EU, Japan, Korea and the US seen as critical for continued industry momentum

88%

Indicated demand–side policies as most impactful for bolstering further clean hydrogen offtake

#5 | CEOs recognize China's momentum but believe that long–term global leadership remains open and are split on whether lessons are replicable

Leaders agreed there is clear momentum around hydrogen in China where operational electrolysis capacity has grown sixfold since 2022–outpacing all other markets globally. Observing a hydrogen playbook similar to the one used in solar, wind, and battery development, 97% of respondents indicated that China would continue to be one of the leading forces on hydrogen, however, views remain split on whether China will maintain its current market leadership long–term.

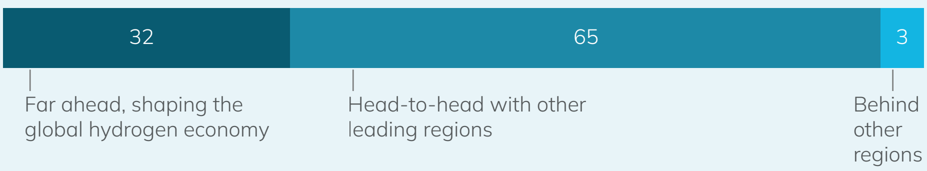
CEOs were equally split on whether China's experience is replicable elsewhere. In interviews, however, they, pointed to a combination of factors that appear to have contributed to rapid growth, including long term top–down policy directives as part of China's 2035 hydrogen development plan, local government incentives and mandates, and favorable financing terms realized by some state–owned enterprises. In addition, several mentioned that flexibility on sourcing of hydrogen used downstream (i.e., supplementing renewable hydrogen with unabated hydrogen) has allowed for more consistent molecule availability and infrastructure utilization.

Overall, CEOs expressed some optimism that rapid Chinese deployment could ultimately facilitate lower renewable hydrogen costs. However, they noted that an acceleration is needed in other regions, particularly among OEMs in those regions, to achieve the scale and cost reductions necessary to mitigate single–region technology concentration seen in industries like solar and electric vehicle batteries.

What role do you see China playing in the hydrogen industry in the future?, % of respondents

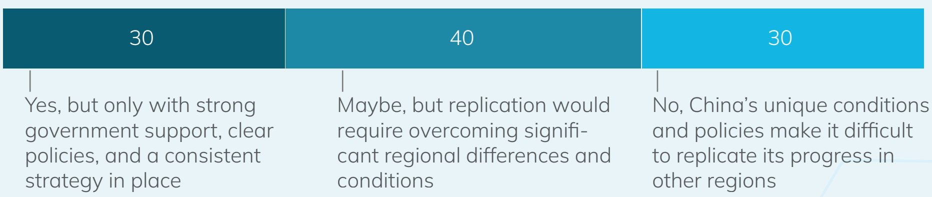
97%

believe China will continue to be one of the leading regions on hydrogen, with 32% believing it will maintain its current market leadership...



Is China's example replicable in other regions?, % of respondents

...however, there is still debate about how replicable the model is elsewhere



Source: Insights derived from interviews and surveys conducted with over 70 leaders from a subset of Hydrogen Council member companies from across the hydrogen value chain,; analytical findings sourced from Hydrogen Council & McKinsey Project & Investment Tracker.

Chapter 02

Analytical assessment of the state of the industry

In addition to reflecting on the perspectives of leaders across the value chain, a thorough examination of the industry requires unpacking and tracking progress on the ground through a data–driven assessment.

The insights in this chapter are organized into three core analytical sections focused on project development and the maturation of the overall project pipeline, clean hydrogen supply online today and projected through 2030, and uptake across demand segments, including the impact of policy on demand.

Roadrunner | Modular HYPRPlant skids on–site for Roadrunner| image provided by Electric Hydrogen

Project pipeline maturation

The first wave of commercial–scale clean hydrogen projects is coming online as committed investment continues to grow and the project pipeline matures

510 projects committed

out of a total global project pipeline of 1,749 projects

$110 billion committed

investment in clean hydrogen projects globally

50+ projects publicly cancelled

in the last 18 months with additional projects likely stalled or cancelled without public announcements

Of the total clean hydrogen project pipeline, 510 projects are committed, with more than 80 added in the last year

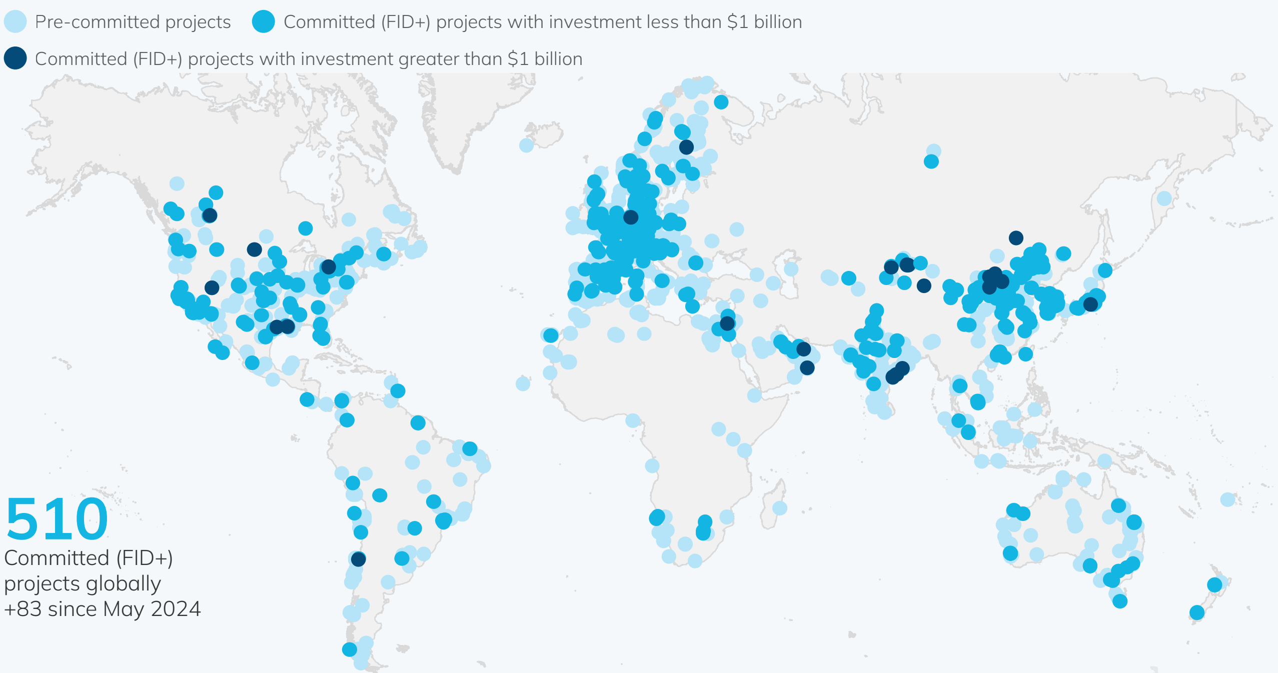
The total hydrogen project pipeline continues to grow, although announcements have slowed. The global hydrogen project pipeline has grown to 7.5 times its size since 2020. Although most of these additions took place between 2022 and 2024, there are 214 more projects in the pipeline, net of publicly announced cancellations, since May 2024. Of the 1,749 projects, 1,159 have publicly announced commercial operation dates (CODs) by 2030.[1]

The first wave of committed clean hydrogen projects has started to come online. Our research suggests that 510 projects (30% of all announced projects) are considered committed, having either taken FID, started construction, or begun operation.[1] Europe has the largest number of projects with CODs by 2030, followed by North America and China. By project number, approximately 70% of committed projects are renewable, of which just under half are in Europe. Although Europe accounts for slightly less than half of all renewable projects by number, the average size of Chinese renewable projects is 10 times that of European projects, as Europe is focused on developing infrastructure and demand centers for an import industry rather than producing giga–scale renewable hydrogen capacity domestically.

The Chinese pipeline has rapidly advanced compared to other regions. By project number, a larger percentage of the Chinese pipeline is FID+ (50%) compared to Europe (30%) and North America (35%). However, there is often less public visibility on earlier–stage Chinese projects, which potentially leads to an undercounting of projects in pre–FEED stages in China.

While pilot projects have been initiated across a range of other hydrogen pathways, including pyrolysis and geologic hydrogen (natural and stimulated) among others, the majority of production projects in the pipeline remain focused on electrolysis and methane reformation with carbon capture and storage (CCS).

Exhibit 1: Global clean hydrogen projects by project status



Committed projects, #

94	**198**	**94**	**38**	**86**
North America	**Europe**	**China**	**Japan/Korea**	**Rest of World**
Includes 5 largest low-carbon FID+ projects	95% of FID+ projects are 15 ktpa or smaller	Includes 6 out of 10 of the largest FID+ renewable projects	Half of FID+ projects are transport and infrastructure	Largest 3 projects are in Middle East and South America

[1] Project announcements below 1 MW are excluded.
Source: Hydrogen Council & McKinsey Project & Investment Tracker, as of December 2020, May 2022, May 2024 and July 2025.

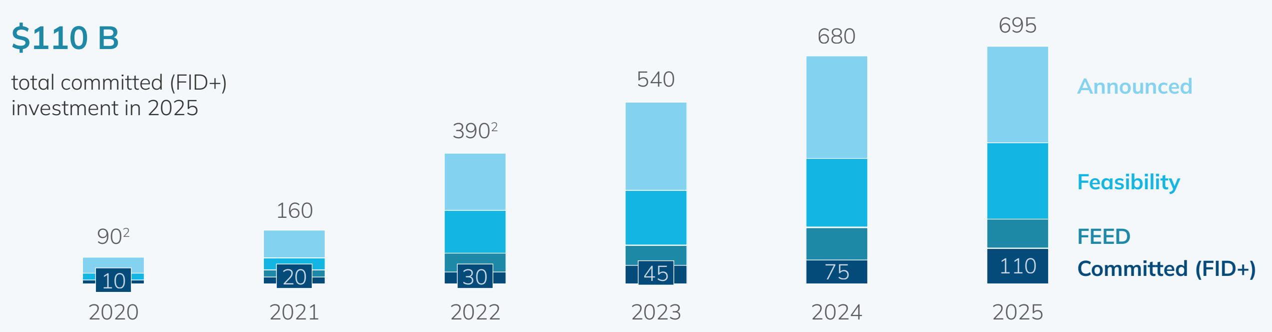
The clean hydrogen project pipeline continues to mature with committed investment growing over 50% year over year to $110 billion

Committed investments in clean hydrogen have grown to $110 billion, increasing by $35 billion in the last 12 months and about tenfold since 2020 despite a challenging environment for energy transition technologies. The investment size for projects in the committed stage has increased from an average of $5 million in 2020 to an estimated $260 million in 2025, demonstrating that projects have also increased in scale from small pilots to industrial–scale projects. About 80% of the total committed investment increase from 2024 is associated with renewable hydrogen projects.

The overall investment pipeline has also grown since 2020, although new announcements have slowed. The investment pipeline across all project stages has increased eightfold since 2020 to an estimated $695 billion. A wave of new announcements took place from 2022 to 2024 as excitement around hydrogen's impact accelerated, but the rate of total increase slowed in the last year as the focus has shifted toward the mature end of the pipeline.

Taking final investment decision has typically been used as the marker by which to judge a project's likelihood of completion, given the stringent requirements usually needed to do so (e.g., securing firm offtake or targeting merchant volumes in policy–backed demand segment, vetting of project partners, successful completion of FEED). However, industrial projects in hydrogen and other sectors are not immune to regulatory shifts, cost escalations, or execution challenges, as evidenced by several examples of late–stage project cancellations. Nevertheless, committed investment remains the nearest barometer for tracking underlying industry development.

Exhibit 2: Investment pipeline in clean hydrogen projects by 2030, $ billion[1]



Committed investment increased 45% since 2024, driven by production and distribution projects

As seen in Exhibit 3, investments in production and distribution have driven the 45% increase in committed investment since last year, while committed end–use investments have remained relatively constant. Of the approximately $20 billion investment increase from 2024 associated with the production of hydrogen, China, North America, Europe, and India all account for roughly an equal split of the increase.

Distribution investments increased 130% from 2024, which corresponds with the storage and transport methods used for hydrogen (e.g., building pipelines as in the Hamburg Hydrogen Industry Network project), as well as derivative production such as ammonia.[3] The increase in committed distribution investments is driven by the maturation of existing ammonia projects in the pipeline (e.g., AM Green's renewable ammonia project in Kakinada, India), as well as several large Chinese ammonia production plants recently publicly announced as under construction.

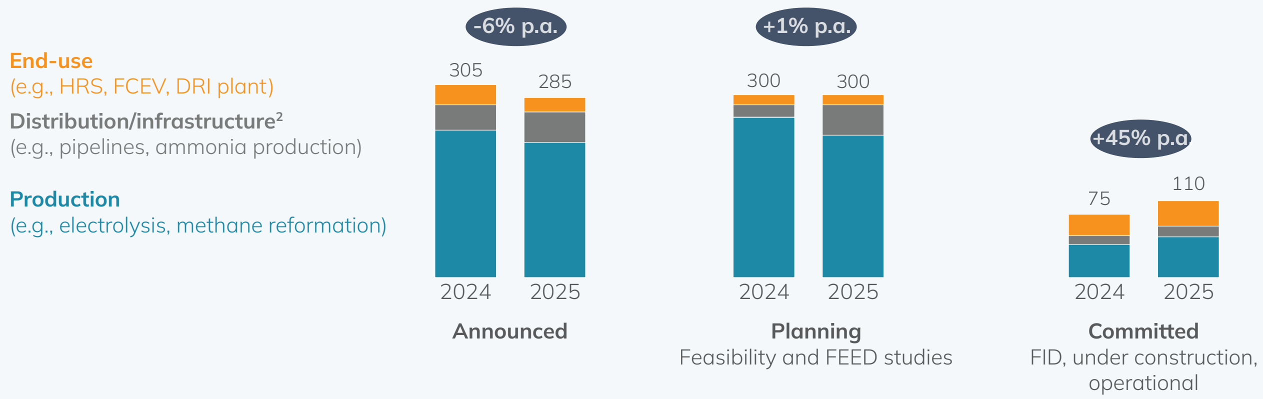
End–use investments correspond to the ultimate application of hydrogen, for example, the manufacturing of fuel cell electric vehicles (FCEV) or the construction of hydrogen refueling stations (HRS), where total investment numbers per project are generally lower than for production and distribution projects.

The composition of the pipeline suggests the industry is in a maturation phase, with committed investment as the fastest–growing segment and a slight shift in total pipeline composition toward more distribution investment. There have been modest shifts in investment associated with earlier–stage projects since 2024 (–6% and +1% in the announced and planning stages, respectively) driven by a combination of projects advancing to later stages and modest new additions.

Changing regulatory and market conditions have prompted a reassessment and streamlining of projects that no longer align with current industry realities, as well as a general maturation of the pipeline. Projects in the FEED and committed stages now account for 28% of total pipeline, up from 17% in 2020.

[1] Includes investment across all value chain steps from production through end use; [2]Report data is normalized based on updated capex numbers used from the December 2023 Hydrogen Insights report onwards as well as investments in deployments removed; [3]Distribution/infrastructure includes derivative production (e.g., ammonification)–in cases where a single project produces hydrogen that is then converted into a derivative, the investment for hydrogen production (e.g., electrolysis, methane reformation) is allocated to "production" and the investment for derivative production is allocated to "distribution/infrastructure".

Exhibit 3: Investment change by value chain step[1], $ billion



China and North America account for over 50% of committed investment today, with global growth driven by a few key projects

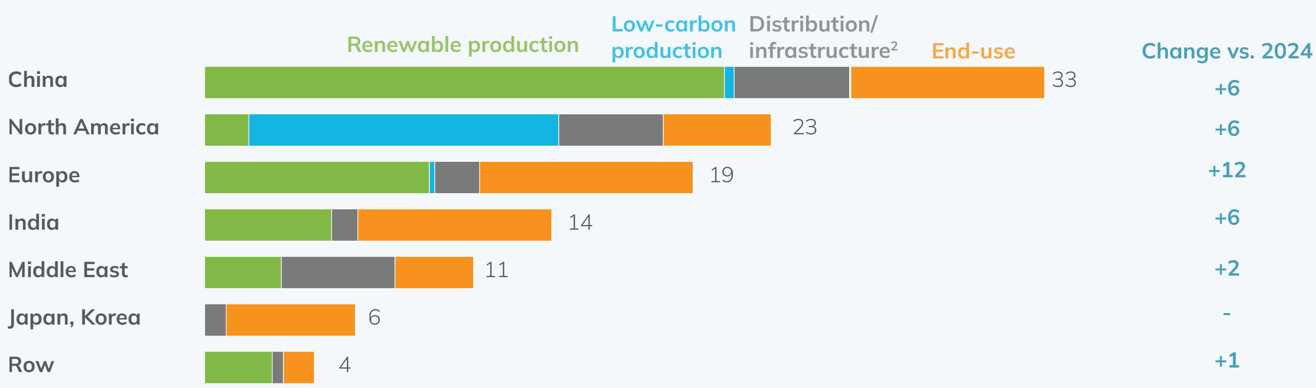
China has outpaced the rest of the world in committed hydrogen investments, with North America as the second–largest region by investment. A significant portion of Chinese investment is associated with renewable production, roughly equivalent to all other renewable production investment. Another quarter of China's committed investment is associated with end–uses, suggesting parallel investment efforts in both demand and supply.

While the majority of Chinese electrolysis is powered by renewable electricity, power from the grid is used to complement and increase load factors. Approximately $4.2 billion of North American low–carbon hydrogen investment is associated with legacy operational projects.

Other regions could see significant investments advancing through the pipeline soon. Europe and North America each have 3–4 times the investment in publicly announced FEED projects as China, which suggests that the next wave of committed investments could come from regions other than China. However, limited public visibility on the development of earlier–stage Chinese projects might lead to the undercounting of less mature investment in China.

A few large–scale projects are driving the majority of investment growth over the past year across several regions. $2.6 billion out of a $6 billion investment increase in China is due to a series of renewable projects under construction or that have taken FID (PetroChina Qinghai project, Shuangliao liquid sunshine project, Aohan Banner and Yuanbaoshan project). Blue Point low–carbon ammonia drives $4.5 billion of the total $6 billion increase in North America and is highlighted as a case study in Chapter 3. An estimated $4 billion of India's renewable investment increase is associated with the Hygenco & Ameropa Ammonia project, which will produce ammonia at a new facility at the Gopalpur port.

Exhibit 4: Committed (FID+) investment by region[3], $ billion



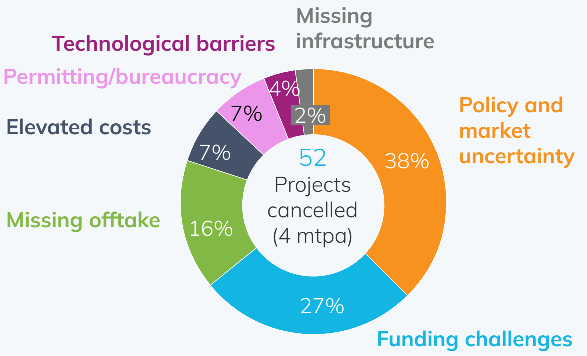
[1] As of May 2024 and July 2025; [2]Distribution/infrastructure includes derivative production (e.g., ammonification)–in cases where a single project produces hydrogen that is then converted into a derivative, the investment for hydrogen production (e.g., electrolysis, methane reformation) is allocated to "production" and the investment for derivative production is allocated to "distribution/infrastructure"; [3]Includes changes from both newly committed projects and investment adjustments to existing projects (e.g., ~$5 billion upward correction to Stegra green steel project investment).

As the project pipeline is maturing, several common themes emerge for hydrogen projects at risk of attrition or delays

The natural filtering out of some early–stage projects continues as part of the maturation and overall cleanup of the project pipeline. While committed projects are increasing, some earlier–stage projects are or will be selected out – some postponed, others publicly canceled.

As the hydrogen industry has advanced past the initial development phase and clarity has emerged regarding realistic cost and market estimates, a natural rationalization of projects has occurred. A large portion of these projects don't progress beyond early–stage plans and are often parts of larger development portfolios, out of which the projects with the best business cases are advanced.

Exhibit 5: Reasons for announced project cancellations[1],
% of # of projects



Count of cancelled projects does not include projects that have been paused or cancelled without public announcements, spotentially undercounting the total

Around 52 commercial scale clean hydrogen projects representing 4 mtpa of unrealized capacity have been cancelled publicly in the last 18 months with policy and market uncertainties cited as the primary drivers. However, this likely undercounts the actual volume of cancelled projects as often projects are paused or cancelled without a public announcement.

For 38% of publicly cancelled projects, developers cited policy and market uncertainty, including lack of regulatory clarity, as the primary contributing factors for cancellation (e.g., renewable projects in the US awaiting 45V clarification). About 27% faced funding challenges often associated with the bankruptcy, insolvency or insufficient execution capabilities of the developer or key project partner.

Considering the difference between the anticipated demand with a policy–supported business case in the near term compared to the overall announced capacity in the project pipeline, additional project attrition should be expected in the coming years as part of a continued clean up and streamlining of the project pipeline. Assuming realization rates comparable to solar and wind industries, only one in 10 announced projects ultimately come online.[2]

Particularly at risk are renewable hydrogen projects in the US (due to recent regulatory changes) and Europe (due to relatively high power costs in some areas). Very large (>500MW) renewable project concepts could also be at risk, as they often require additional connective infrastructure and commensurately more offtake. Low–carbon projects, while larger than renewable projects on average, may carry lower cancellation rates due to more advanced commitments from developers, many of whom have existing portfolios of industrial–scale projects, and earlier line of sight on offtake markets upon announcement.

Exhibit 6: Emerging archetypes of "at risk" projects

US renewable projects with CODs after 2027	Renewable projects in markets with constrained or high-cost renewable electricity	Giga-scale projects in emerging economies without existing export infrastructure	Projects involving complex infrastructure and lengthy value chains	Projects intended for demand sectors without a current positive business case
The eligibility window for the 45V clean hydrogen production tax credit has now been shortened, moving the cut-off for projects to begin construction to Jan 1, 2028, putting 60-70% of US renewable projects (0.55 mtpa) that could have otherwise been eligible under the original timeframe at risk based on currently announced project timelines.	Markets with high electricity prices due to limited renewable potential, high gas prices, and growing power demand result in renewable hydrogen projects that are highly dependent on policy support.	Challenges in emerging markets lie in high cost of capital, which has increased in the last 5 years, a significant need for net-new infrastructure (e.g., ports, grid connection), and a skills gap in some local workforces.	Inherent complexities in infrastructure and supply projects can compound when the two depend on each other to move forward. This increases the cancellation and delay risk of projects with complex infrastructure and long value chains (e.g., molecules produced in remote areas far from demand centers with additional distribution and conversion steps required).	Certain projects targeting non-regulated demand sectors (e.g., not subject to RED III quotas in the EU) or industries with a strained financial outlook, could be less likely to move forward. This includes sectors with either low end-user value-in-use (e.g., residential heating), or high anticipated cost to serve (e.g., due to additional process steps like reconversion).

[1] Total publicly announced project cancellations is 52. Ratio of project cancellation reasons excludes 7 projects across Europe, North America, Oceania, and South America with no announced cancellation reason; [2]Ranges of project success rates are based on historical project completion rates in the renewables sector (e.g., solar, wind) and align with risk methodology applied to estimate feasible 2030 capacity (see appendix).
Source: Hydrogen Council & McKinsey Project & Investment Tracker, as of July 2025; Press search conducted to map cancellation reasons where publicly available.

Supply

The supply pipeline is ready to scale and is projected to provide adequate supply to meet policy–supported 2030 demand

1 mtpa operational

capacity with 300 ktpa renewable (2.7 GW), 700 ktpa low–carbon

6 mtpa committed

clean hydrogen capacity, including 35 GW (3.3 mtpa) renewable

9–14 mtpa clean supply

potential by 2030,[1] which is 3–8 mtpa of additional annual production capacity

[1] Projection of feasible supply given expected attrition and delays of projects–capacity that moves forward still depends on amount of demand that materializes.

1 mtpa clean hydrogen capacity is operational in 2025 with China accounting for about half of online renewable capacity

New clean hydrogen capacity has increased by 40% since 2021. The majority of newly deployed capacity is coming from renewable projects, growing eight–fold since 2021. Of the roughly 1 mtpa of operational capacity, about 30% is renewable, and the other 70% is low–carbon – a significant shift from the 6%/94% pathway split in 2021.

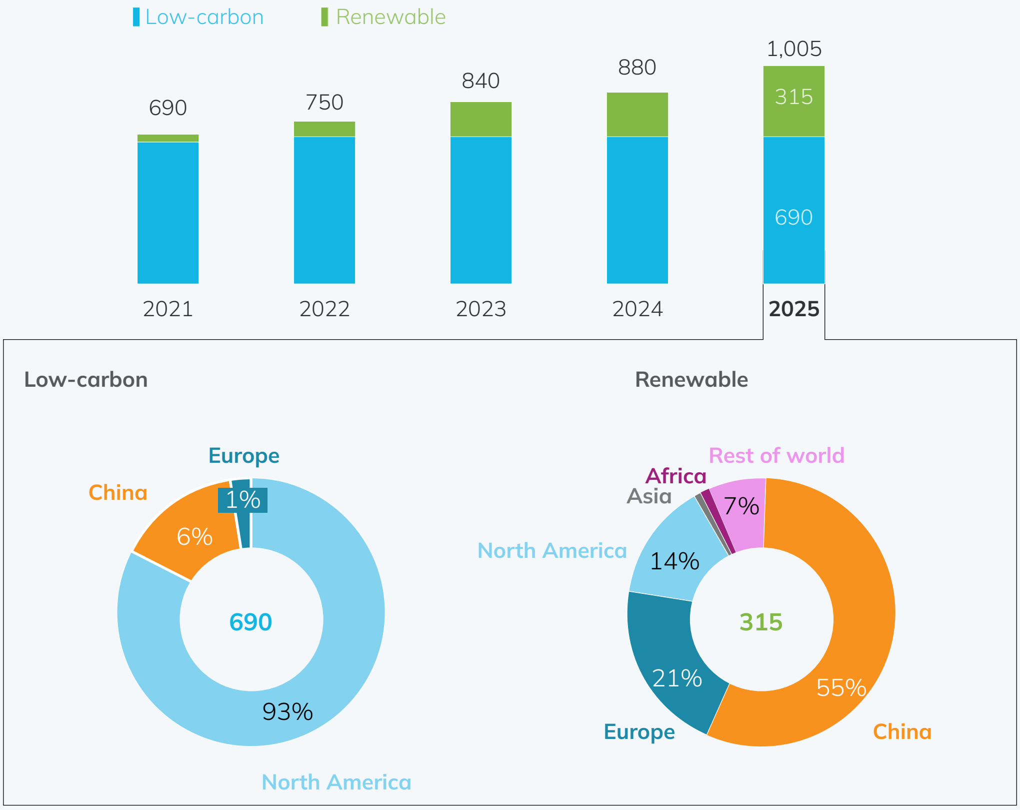
China is the key region in operational renewable growth. The deployment of Chinese renewable capacity is currently outpacing other markets with about 56% (180 ktpa) of operational capacity today, an estimated 60 ktpa increase from 2024, which equals the growth from the rest of the world combined. The primarily electrolysis technology in China continues to be alkaline. Approximately 80% of all global alkaline electrolyzers are in China and it is expected that nearly all capacity additions since last year in China have been alkaline based. As regulatory support in other regions falls into place, a broader range of regional renewable leadership could develop.

Low–carbon online hydrogen capacity has remained stable since before 2021, at between 660 and 690 ktpa. About 90% of online low–carbon capacity comes from eight legacy projects located in North America: Great Plains synfuel, Valero Port Arthur Refinery, Coffeyville Gasification plant, PCS Nitrogen, Enid fertilizer, Quest CCS, North West Sturgeon refinery, and Nutrien's Alberta Project. However, another estimated 2 mtpa of low–carbon capacity is currently in FID or under construction, indicating significant new additions coming online in the next two to three years.

Exhibit 7: Operational clean hydrogen capacity by pathway and region, ktpa H_2e

8x
Growth in operational renewable capacity in the last five years, including 65% increase since last year

56%
Chinese share of operational renewable capacity today

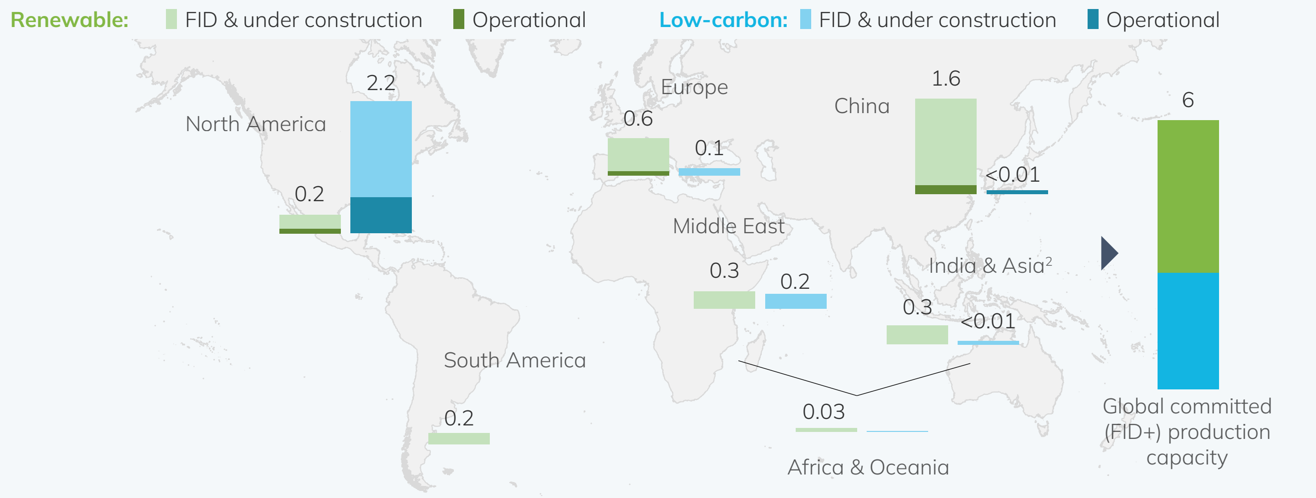


Approximately 6 mtpa of clean hydrogen capacity is committed, with the majority concentrated in North America and China

The first wave of projects, comprising about 6 mtpa of clean hydrogen capacity, has taken final investment decision, begun construction, or is already in operation. Of the approximately 6 mtpa of committed clean capacity, North America and China account for over two–thirds of the total, with North America leading in the deployment of low–carbon capacity and China on renewable capacity.

The concentration of committed low–carbon capacity in North America is driven by a combination of low–cost natural gas, existing CCS networks, the concentration of export infrastructure, and, in the US specifically, the $85 /t$CO_2$ 45Q tax credit for permanently captured carbon.[1] Together, these factors enable exported low–carbon hydrogen and derivatives from the US to be competitive or nearly competitive, even with unabated hydrogen in regions with relatively higher natural gas prices and carbon pricing mechanisms (e.g., Europe). Although carbon dioxide that is captured and used (e.g., for oil recovery), can now also qualify for the full $85 45Q credit, lifecycle carbon intensity considerations in offtake markets would still dictate whether projects qualify for certain international policies (e.g., Japan's Contract for Difference).

China leads in the deployment of renewable capacity. The expansion of renewable capacity in China is, at least partially, motivated by a combination of top–down policy directives as part of China's 2035 hydrogen development plan, local government incentives and deployment mandates, and favorable financing terms realized by some state–owned enterprises. Other factors include flexibility regarding hydrogen sourcing for end–users (i.e., allowing the supplementing of renewable hydrogen with unabated hydrogen to ensure downstream molecule availability and infrastructure utilization). Combined, these factors have underpinned the fastest regional growth of renewable capacity worldwide.



35 GW (3.3 mtpa) of renewable hydrogen capacity has passed FID, up 35% since last year, with approximately 55% in China

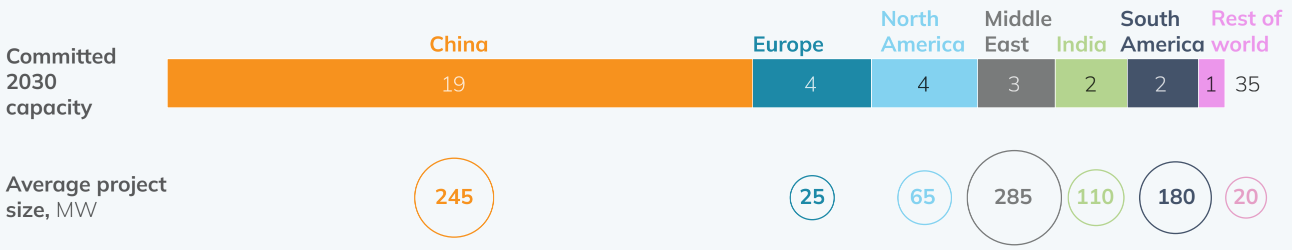
Commercial–scale renewable hydrogen projects are reaching maturity, with an increase of 9 GW committed since 2024. Over 35 GW (3.3 mtpa) of renewable capacity has passed FID, with about 2.7 GW (0.3 mtpa) already operational. China accounts for roughly 55% of total committed renewable capacity and Chinese projects are in some cases four to ten times larger than European and American projects.

Many hydrogen projects in China are developed alongside new onsite renewables capacity, highlighting the role of hydrogen in spurring additional renewable installations.

The average global size of all the renewable projects that were operational by 2024 (about 14 MW) is less than the size of the individual electrolyzers modules being installed every week today (e.g., the 20 MW modules being installed at Stegra green steel plant in Boden, which is highlighted as a case study in Chapter 3). The average project size in China is also outpacing the rest of the world, with the exception of the Middle East where a few giga–scale projects with minimal small demonstration projects skew the average.

[1] Global CCS Institute: U.S. Preserves and Increases 45Q Credit in "One Big Beautiful Bill Act"; [2] Japan, Korea, India, Vietnam, Uzbekistan, Malaysia, Singapore, Taiwan, Thailand.

Exhibit 9: Cumulative committed electrolysis capacity by region (announced)[1], GW



9–14 mtpa of announced clean capacity could feasibly come online by 2030 after adjusting for estimated project development timelines and attrition, if offtake is secured

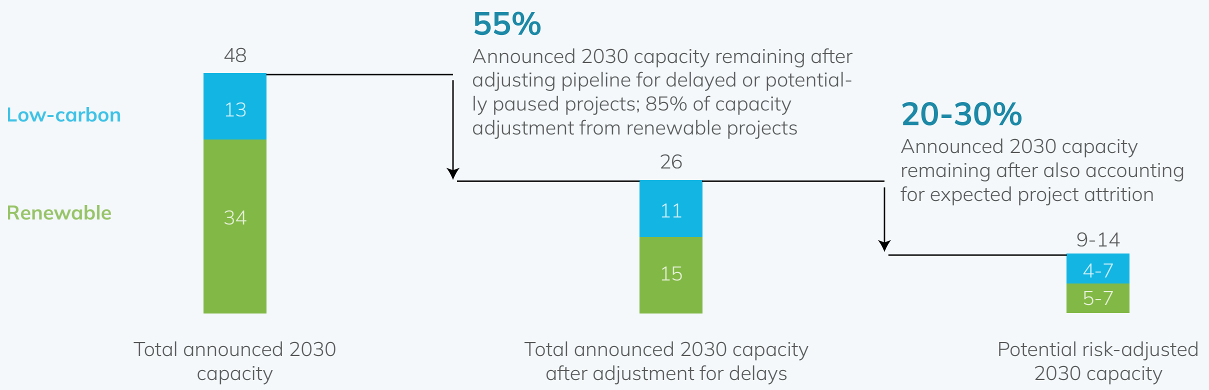
Roughly 20–30% of the 48 mtpa of announced clean hydrogen capacity could feasibly come online by 2030. About 75% of today's total clean hydrogen capacity was announced between 2022 and 2024. While projects with the most compelling business cases have progressed, other projects announced during this period may not come online by their stated timelines or be executed at all. Many renewable projects were announced with cost expectations and in a policy environment that has now shifted, which could suggest a significant portion of these projects are at risk.

To evaluate the feasible 2030 capacity, both project timelines and anticipated attrition rates were assessed, yielding 9–14 mtpa of potential supply. A combination of project size, pathway, status, and announced COD were analyzed to determine a realistic COD for each project based on typical development timelines and account for projects that have likely been stalled or paused. Expected attrition rates were then applied to this adjusted capacity, with earlier stage projects carrying lower success rates (e.g., 0–10% for announced projects vs 90–95% for FID+ projects–see appendix for further details).

The resulting risk–adjusted 2030 capacity is split evenly across renewable and low–carbon capacity. Between 5 to 7 mtpa (15–20%) of the announced 34 mtpa of renewable capacity could come online by 2030, with 55% to 60% from Europe and China. Between 4 to 7 mtpa (30–50%) of the announced 13 mtpa of low–carbon capacity is feasible by 2030, with 70% to 75% based in North America.

This estimated supply range indicates what the project pipeline could theoretically support by 2030, but the ultimate volumes that come online will depend on how much of that capacity can secure stable, likely policy–backed, offtake.

Exhibit 10: 2030 estimated feasible capacity after estimated delays and attrition[2], mtpa H_2e



[1] Announcements are based on publicly available data and 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; [2] Ranges of project success rates are based on historical project completion rates in the renewables sector (e.g., solar, wind). Relatively low announced and feasibility–stage success rates could potentially be more conservative than actual success rates once industry matures further, but currently reflect early–stage nature of the industry.

Demand

Demand is the critical unlock for how fast the industry can scale, but relies on enabling policy falling into place

>8 mtpa H_2e demand

for clean hydrogen in 2030 with a policy–supported business case,[1] largely in existing end–uses in the EU

3.6 mtpa binding offtake

secured either through captive or sales & purchase agreements

70% of offtake in conventional uses

such as fertilizers and refining

[1] Demand in key markets with existing hydrogen–supportive policies: EU, US, Japan, Korea; additional demand expected in other markets (e.g., in China where domestic production is expected to serve domestic supply).

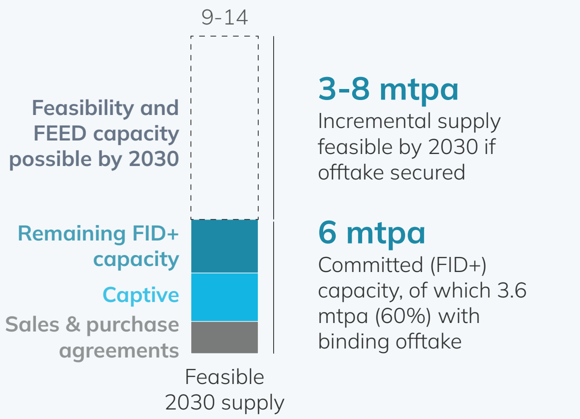
3.6 mtpa of binding offtake has been secured globally, with existing use cases making up 70%

Of the 6 mtpa of committed capacity, approximately 3.6 mtpa (60%) has secured binding offtake,[1] either via sales and purchase agreements or captive demand. A portion of the 3.6 mtpa in binding offtake could be overstated as it is assumed that captive offtake arrangements utilize the full production capacity of a project. Outside of binding offtake, additional FID+ volumes may be comprised of capacity intended to be sold on the merchant hydrogen or derivative market, as well as volumes with either non–binding or not yet disclosed offtake contracts associated.

The majority of offtake (70%) is concentrated in existing end uses like refining and ammonia. At about 43% of all binding offtake capacity, ammonia is the largest offtake sector. This segment is expected to maintain momentum going forward with several non–binding offtake agreements having recently been signed with Indian projects such as AM Green's renewable ammonia project in Kakinada and ACME Group's green hydrogen project in Odisha. Subject to transposition, RED III RFNBO quotas could drive approximately 0.8 mtpa in renewable ammonia demand in the European Union. RED III RFNBO quotas have the potential to also impact demand in refining, the second largest offtake sector, supporting up to 1.6 mtpa of demand for renewable hydrogen in the EU.

New and existing infrastructure has enabled offtake to occur at a greater distance from production than historically. Before 2021, offtake was located predominately near production, and while international offtake is still emerging, domestic output and offtake are increasingly enabled by new and existing infrastructure. For example, the recently approved €18.9 billion Hydrogen Core Network plan in Germany is focused on building nation–wide hydrogen infrastructure in Germany to connect production sites with storage and demand centers.[2] Ammonia import terminals, such as Yara International's terminal in Brunsbüttel, Germany, which is highlighted as a case study in Chapter 3, could likewise enable a significant increase in the import volume of low–carbon ammonia into Europe.

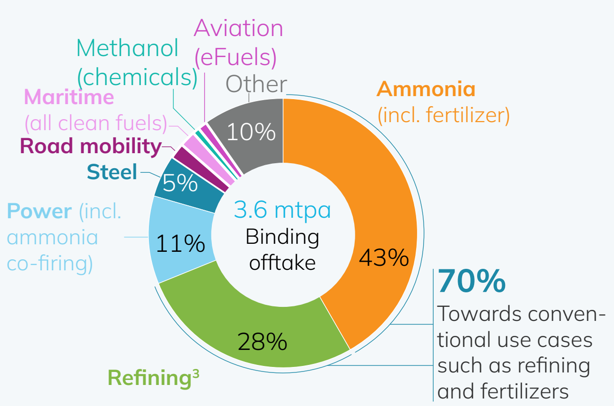
Exhibit 11: Potential 2030 clean hydrogen supply by type of offtake secured, mtpa H_2e



Emerging offtake sectors to watch in the future include steel, road mobility, and clean fuels for both maritime and aviation. Existing offtake in steel is supported by a few key projects such as the Stegra green steel production plant in Sweden, which is highlighted as a case study in Chapter 3, as well as the JSW Steel & JSW Energy MOU green hydrogen to steel plant in India. However, broader uptake of hydrogen for steel production is contingent on expanded use of direct reduced iron (DRI)–based manufacturing and utilization of hydrogen rather than natural gas in the reduction process.

Road mobility has seen recent momentum in China and South Korea with a shift towards commercial vehicle applications. Despite ammonia's potential future application as a decarbonized fuel for maritime, only about 1% of binding offtake is serving the maritime sector today, although final IMO guidance, in addition to both the FuelEU greenhouse gas reduction targets and RFNBO sub–quotas, could promote additional maritime adoption for either ammonia or methanol.

Exhibit 12: Clean hydrogen offtake by end use sector, mtpa H_2e



Holland Hydrogen | Aerial view of completed project rendering of Holland Hydrogen project which is intended to supply renewable hydrogen to the nearby Shell Energy and Chemicals Park Rotterdam to decarbonize its refining and petrochemical processes | image provided by thyssenkrupp nucera

[1] Binding offtake includes captive offtake and sales & purchase agreements for FID+ projects to reflect all projects that have confirmed, contractual offtake; [2] Offshore Energy: Green light for development of Germany–wide hydrogen core network; [3] Includes chemical intermediates as well such as offtake from the Path2Zero ethylene and derivatives plant.
Source: McKinsey Hydrogen Insights Clean Hydrogen Offtake Tracker, as of Q1 2025.

Low–carbon offtake concentrated in North America; majority of renewable offtake serving Europe and China

China and Europe have secured the majority of renewable offtake, with Chinese offtake sourced entirely from domestic production. All of China's offtake is served by Chinese supply, across both renewable and low–carbon. A small portion of Chinese production also has international offtake associated with the Envision Green Hydrogen Ammonia Project in Chifeng City where there is an agreement with Marubeni for use in the wider Asian region. Europe currently has the largest capacity of binding renewable offtake agreements, with a portion fulfilled by production in the Middle East and the rest sourced domestically.

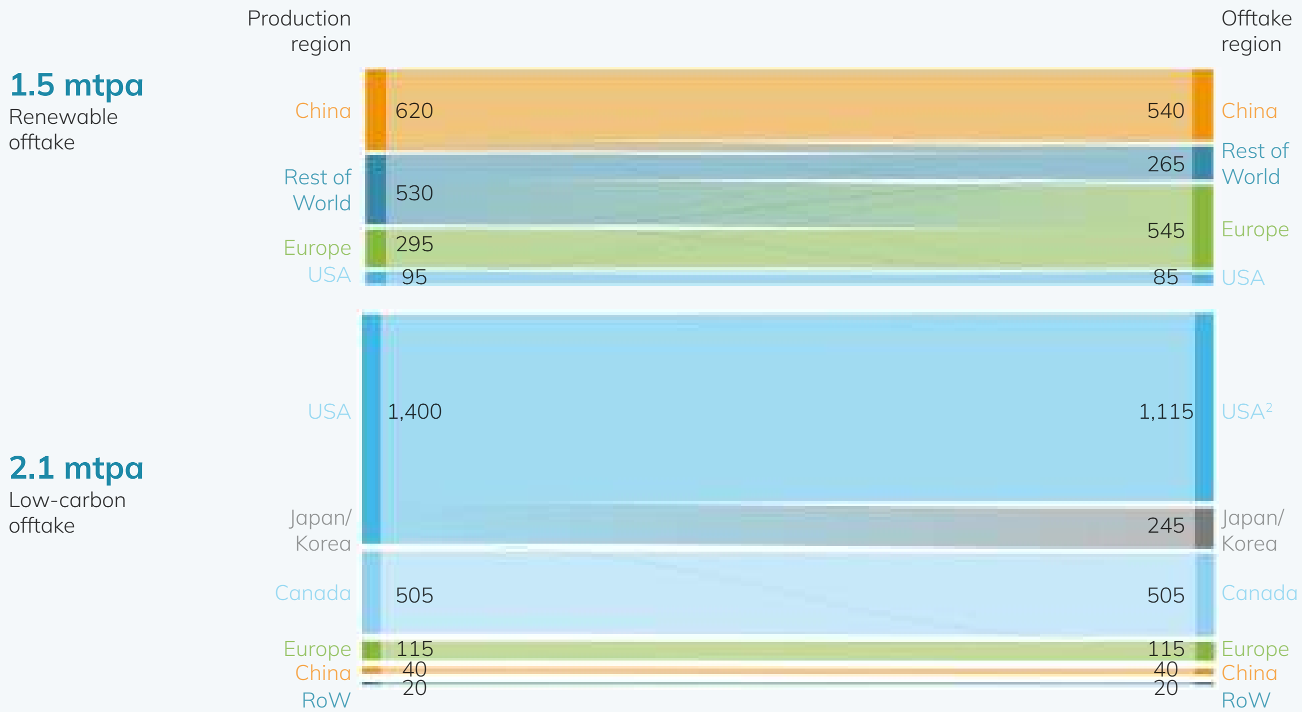
The US and Canada account for the overwhelming majority of low–carbon offtake, all of which is sourced domestically. Half of Canadian low–carbon offtake is driven by the Linde–Dow Path2Zero ethylene and derivatives plant under construction and highlighted as a case study in Chapter 3, in which Linde's on–site complex will supply clean hydrogen to support Dow's world–first net–zero emissions integrated ethylene cracker and derivatives sites.

Three–quarters of US low–carbon offtake is captive offtake associated with ammonia production facilities. Examples in the gulf coast include CF Industries' Donaldsonville Complex, which is operational, and its Yazoo City Complex, where a carbon capture and sequestration project is under construction. Around half of US low–carbon offtake (540 ktpa) is associated with legacy low–carbon projects.

While the majority of existing capacity still serves domestic markets, international trade offtake for low–carbon and renewable is expected to increase in upcoming years as policy clarity emerges and regulations fall into place in East Asia and Europe. Currently 45% of European offtake is imported and highlights the beginnings of an international market. An increasing trend in equity investment from companies based in different regions also suggests an initial shift toward a more distributed trade ecosystem. One example involves the Japanese company investment and associated offtake from the Blue Point low–carbon ammonia plant, which is highlighted as a case study in Chapter 3 and is responsible for the low–carbon import into Japan.

As countries transpose RED III, which sets targets for RFNBO uptake across transport and industry sectors, additional imports of renewable molecules could be seen in Europe. Europe could also import additional low–carbon volumes as the combination of ETS and CBAM support the business case compared to unabated molecules, particularly ammonia. However, additional import infrastructure, such as pipelines, port infrastructure, and ships, would still be required to fully unlock inter–regional trade.

Exhibit 13: Clean hydrogen offtake for committed projects by pathway and region[1], ktpa H_2e



[1] Considers only binding offtake associated with FID+ projects. There is an additional ~0.4 mtpa of non–binding offtake associated committed (FID+) projects, as well as ~1.0 mtpa of sales & purchase agreements signed with earlier stage projects; [2]540 ktpa of US low–carbon offtake is associated with the legacy projects: Valero Port Arthur Refinery, Coffeyville Gasification Plant, Great Plains synfuel, PCS Nitrogen Enid fertilizer, North West Sturgeon refinery, Nutrien Alberta Project.
Source: Hydrogen Council & McKinsey Project & Investment Tracker, as of July 2025; McKinsey Hydrogen Insights Clean Hydrogen Offtake Tracker, as of Q1 2025.

China accounts for 35% of binding renewable offtake globally; 1.6 mtpa of supply in pipeline expected to serve growing domestic demand

Chinese demand today is served entirely by domestic production. Chinese renewable offtake capacity accounts for 35% of total binding renewable offtake globally and is overwhelmingly from captive agreements at domestic plants, although there is limited transparency on the ultimate end uses for a portion of captive offtake. Major current offtake sectors are ammonia, refining, and power, which make up approximately 80% of all offtake agreements.

Energy security and diversification, alongside technology leadership in a growing market, appear to be key drivers of hydrogen deployment as China seeks to reduce dependence on imported fossil–based energy sources. China is simultaneously building out supply and demand with a growing hydrogen ecosystem including electrolyzer technology development, commercial road mobility deployment (with a parallel focus on FCEV and BEV), and industrial domestic offtake.

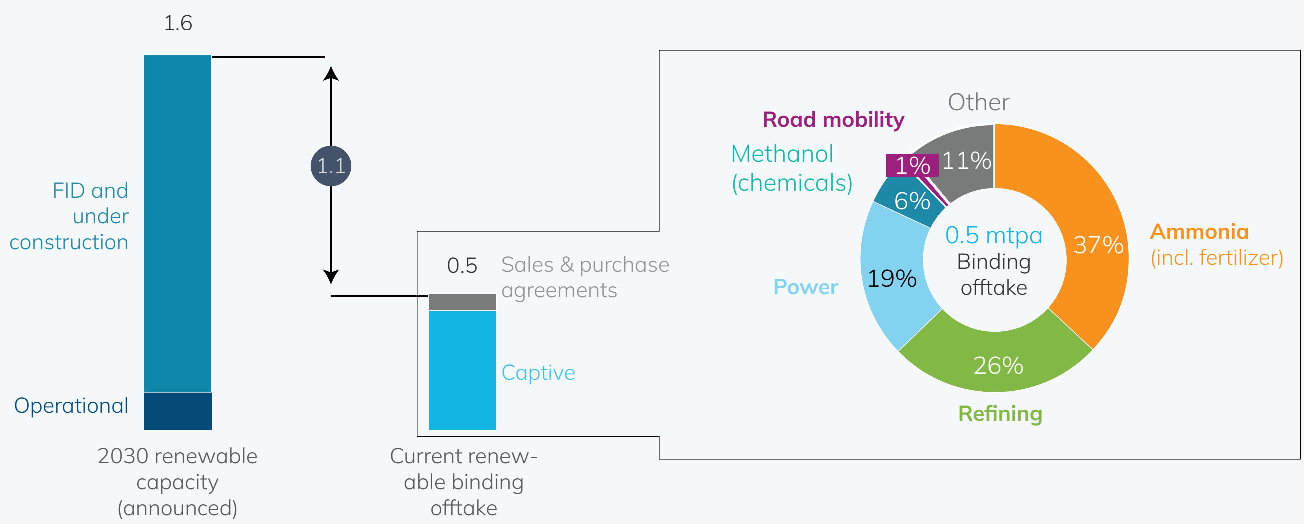
Hydrogen's strategic importance is reflected in the national and provincial policies and targets. China's Medium and Long–Term Strategy for the Development of the Hydrogen Energy Industry sets a production target of 0.1–0.2 mtpa operational renewable capacity by 2025, which China has already met, and a deployment of 50,000 hydrogen FCEVs.[1]

Certain provinces have set more aggressive targets such as Inner Mongolia's aim of approximately 0.5 mtpa hydrogen production capacity by 2025, which could be 60% fulfilled by projects currently under construction in the province, and Gansu setting a goal for 0.2 mtpa.[2] Demand is likely to scale with production as China's Medium and Long–Term Strategy plan sets out a blueprint for forming an industrial system of producing and applying hydrogen energy, including transportation and energy storage, with a specific pillar for decarbonizing road mobility.[2]

In addition, China's 14th Five Year Plan (2021–2025) lists hydrogen as one of China's six industries of the future.[3] In addition, China is beginning to expand their involvement in the hydrogen industry internationally. For example, FRV's strategic partnership with Chinese Envision Energy for a large–scale renewable ammonia project at the Port of Pecém in Brazil.

While momentum in China appears relatively intact under current conditions, China's 15th Five Year Plan is expected to be released later this year, which will likely shape whether the current rate of hydrogen build out continues and which applications it prioritizes. The direction China takes could then dictate the pace and scaling required in other regions, particularly for technology suppliers, to maintain inter–regional competitiveness and a diversified supply chain.

Exhibit 14: Committed Chinese production capacity through 2030 compared to offtake and end-use offtake sector, mtpa H_2e



[1] IEA–Hydrogen Industry Development Plan; [2]Center on Global Energy Policy at Columbia–China's Hydrogen Strategy: National vs. Regional Plans | Energy Iceberg: China's National Hydrogen Development Plan | Rystad Energy: China set to smash national hydrogen targets, solidifying lead in global electrolyzer market; [3]China Briefing – China's Hydrogen Energy Industry.
Source: McKinsey Hydrogen Insights Clean Hydrogen Offtake Tracker, as of Q1 2025.

Outside of China, 8 mtpa of policy–supported demand could carry a positive business case by 2030; another 13 mtpa could be unlocked

Demand–side policies and supply–side policies both affect the viability of the business case for each segment of demand. In the EU, US, Japan and Korea, the key hydrogen policies announced either raise a given end user's "value–in–use" for clean hydrogen (i.e., the cost of hydrogen at which the end–user's economics break even with a conventional alternative) or lower the cost to serve that end–use segment. When a given end–use segment's "value–in–use" is higher than the likely landed cost of hydrogen to serve that end–use, the segment carries a policy–supported positive business case.

In the EU for instance, Renewable Energy Directive (RED) III, the Emissions Trading Scheme (ETS), which is in effect, and Carbon Border Adjustment Mechanism (CBAM), which is in its transitional phase until Dec 31, 2025 when it becomes operational,[1] increase value–in–use estimates for refining, chemical and industrial sectors by 2.4–9.4 \$/kg H_2e above economic breakeven with conventional technologies.

Alternatively, supply side policies like the US 45Q carbon capture tax credit and 45V production tax credit from the Inflation Reduction Act serve to lower production costs (i.e., for renewable and low–carbon ammonia, respectively).

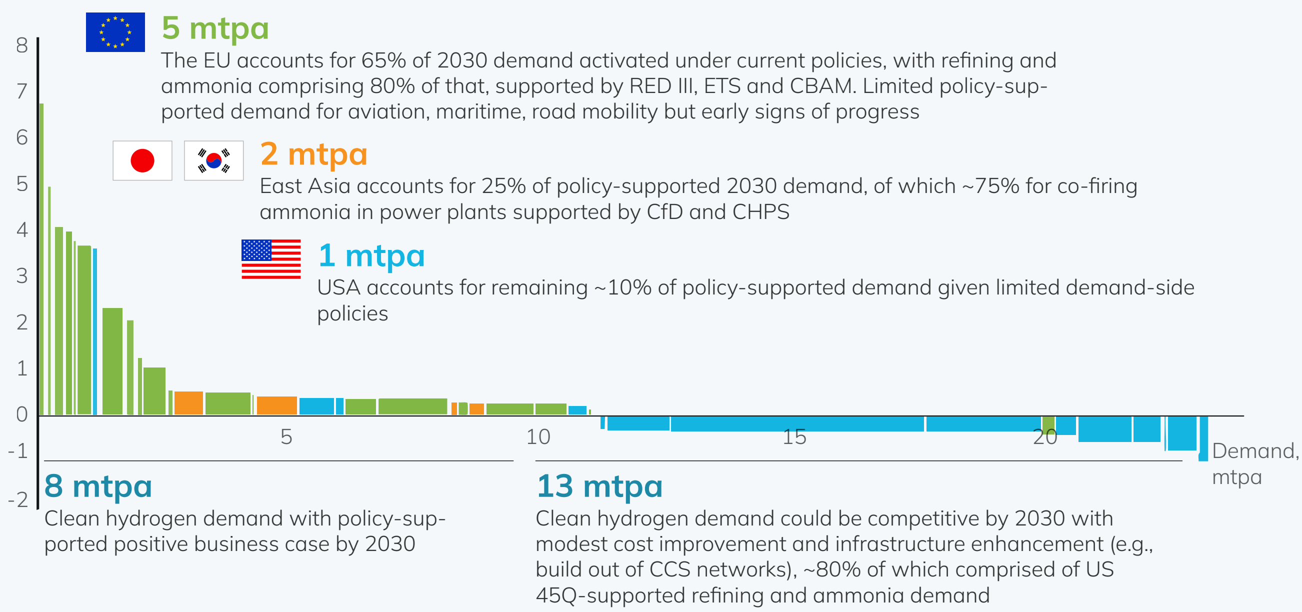
The difference between value–in–use and supply cost determines whether there could be a positive business case for that end–use segment by 2030. After subtracting each sub–segment's estimated cost–to–serve from its value–in–use, the resulting cost differentials can be used to divide demand into segments that carry a policy–supported business case, segments with a business case that nearly breaks even but requires additional cost or infrastructure support, and segments without a positive business case by 2030.

In the EU, US, Japan and Korea, approximately 8 mtpa of demand could carry a positive business case by 2030 if existing regulations are enacted as written, with another 13 mtpa feasible to unlock. RED III segments comprise the highest value–in–use segments, with the EU accounting for about 5 of the 8 mtpa with a business case by 2030.

The Japanese CfD and Korean CHPS programs support the majority of an additional 2 mtpa in East Asia. Limited demand–side support in the US leads to lower relative value–in–use for US segments. However, in segments served by 45Q–enabled low–carbon production, the supply–side tax credits help bring the business case nearly to parity with conventional alternatives.

For additional details on value–in–use calculations for each segment, please refer to our recent publication: Hydrogen: Closing the cost Gap.

Exhibit 15: Cost-competitiveness for clean hydrogen by use case by region, 2030, \$/kg H_2e difference between estimated value-in-use and supply cost



[1]European Commission – CBAM.
Source: Hydrogen Council & McKinsey: Closing the Cost Gap report, 2025.

Refining and ammonia in the EU show earliest momentum, followed by power demand in East Asia; segments like road mobility and maritime still emerging

The demand segments showing the earliest momentum include refining and ammonia in the EU and power demand in Japan and Korea. The earliest momentum across the key markets examined appears in refining and ammonia in the EU with a combination of project momentum, economics in place and early offtake contracts being signed.

RED III transport transposition is starting to fall into place, although most Member States did not finalize by the May 2025 deadline.[1] Draft guidance so far generally indicates the flexibility to leverage RFNBO to decarbonize transport fuels via co–processing in refining or via direct uptake in FCEVs,[2] although under current conditions, the co–processing route would likely be the lower–cost option to implement first.

Transposition of RED III industry targets may be partially diluted as Member State guidance falls into place (e.g., exemption of some imports, lower direct industry target if additional conditions are met) as the legal obligation is on Member States, rather than individual industrial consumers as in transport.[3] Any national quotas must consider competitiveness and provide state–aid–compliant measures, which requires time to design and implement. Nevertheless, a combination of ETS and CBAM could support the business case for imported low–carbon ammonia.

East Asian power policies appear to be first directing funding toward decarbonizing power, specifically via co–firing of ammonia in a relatively young fleet of coal power plants.

Pockets of maritime and road mobility demand appear to be gaining early traction in some markets but the future demand outlook is less certain. A constellation of regulations including the EU's FuelEU GHG reduction targets and RFNBO sub–quotas, ETS & CBAM, and the global IMO greenhouse gas reduction targets could potentially start to support transition to clean fuels as early as 2030 and increasing through the decade. However, final IMO guidance would dictate the degree to which fleet operators switch fuels as well as the selection of fuels based on availability and total cost of ownership (TCO) tradeoffs.

Initial segments of road mobility demand have materialized in South Korea, Japan and China, and to a lesser extent in the EU, but road mobility appears to be a regionally–motivated end use segment driven by geographical circumstances and government targets. Across key hubs of mobility development, companies are partnering across the value chain to advance infrastructure and unlock future demand. For example, Hynet and Kohygen consortiums development of HRS in South Korea and Kawasaki Heavy Industries and Daimler Truck's MoU to optimize liquid hydrogen supply chains particularly for road freight transport.

Other segments like aviation, steel, methanol and industrial heating have seen less overall momentum despite a few key projects in each category that have found creative ways to make the business case work.

The following select sector deep dives explore the current momentum in the three earliest demand segments for clean hydrogen and derivatives – refining, ammonia and power in East Asia – as well as two of the emerging end use sectors with either explicit regulatory support proposed (maritime) or emerging regional pockets of momentum (mobility).

Beaumont clean ammonia| Construction progress on Beaumont clean ammonia production facility in Texas, US | image sourced via public press release

[1]According to the European Commission; [2]The refining route is an acceptable use of renewable hydrogen over direct use in FCEV, such as in Spain where a 1.5% sub–mandate encourages its use according to Ministry for the Ecological Transition and the Demographic Challenge Spain, Draft transposition of RED III (2025); [3]Netherlands industrial RFNBO draft exempts ammonia production (SMR exemption) and suggests 8–24% target directly on industry according to Dutch Government. (2024): Wet jaarverplichting hernieuwbare brandstoffen van niet–biologische oorsprong in de industrie: Memorie van Toelichting. Tweede Kamer der Staten–Generaal.
Source: Hydrogen Council & McKinsey: Closing the Cost Gap report, 2025.

Sector deep dive: refining

RED III could support 1.6 mtpa of refining demand in Europe, about 40% of which is expected to be served by domestic projects in the pipeline and existing imports

Refining in Europe could be one of the earliest–moving demand sectors. The offtake focus of approximately $2 billion in committed renewable production investment in Europe is in the refining sector, which is about 25% of renewable production investment.

A substantial portion (about 40%) of large, commercial scale (50MW or more) renewable projects in the planning and committed stages in Europe intend their hydrogen production for use in refining, with Germany, Spain, and the Netherlands as especially mature regions. Holland Hydrogen in the Netherlands, which is highlighted as a case study in Chapter 3, and HyVal in Spain are notable committed project examples, as well as Shell's Refhyne project in Germany that will expand its exiting 10 MW PEM electrolyser to 100 MW.

Supported by RED III, refining is likely to maintain its position as a robust driver of demand, but currently has a supply gap with European production. In addition to industry mandates for RFNBO use, RED III also mandates that at least 1% of energy supplied to the transport sector must be from RFNBOs. Early transposition and draft transposition of RED III transport targets indicate 2030 renewable demand could potentially be higher than the currently projected 1.6 mtpa[1] (RED III drafts published in e.g., Germany and Spain, go beyond the EU minimum).

All 0.2 mtpa of binding offtake in refining is currently renewable that qualifies as RFNBO and can support RED III quotas. Additional EU capacity from existing FEED and FID+ projects intended for the refining sector could meet a portion of the 1.6 mtpa demand, however there is still a 1.0 mtpa demand gap that could spur additional domestic growth or international imports.

Exhibit 16: European renewable projects in refining, FEED+ projects larger than 50 MWH$_2$e

Committed (FID+) refining projects
FEED refining projects
Projects < 200 MW
Projects >=200 MW

1.4 GW (180 ktpa)
Committed (FID+) renewable hydrogen capacity for refining (35% of committed renewable capacity in Europe)

2.5 GW (250 ktpa)
Additional renewable capacity for refining in FEED

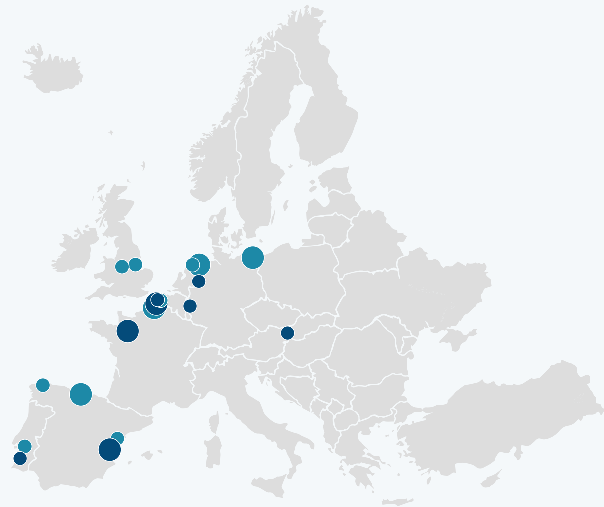
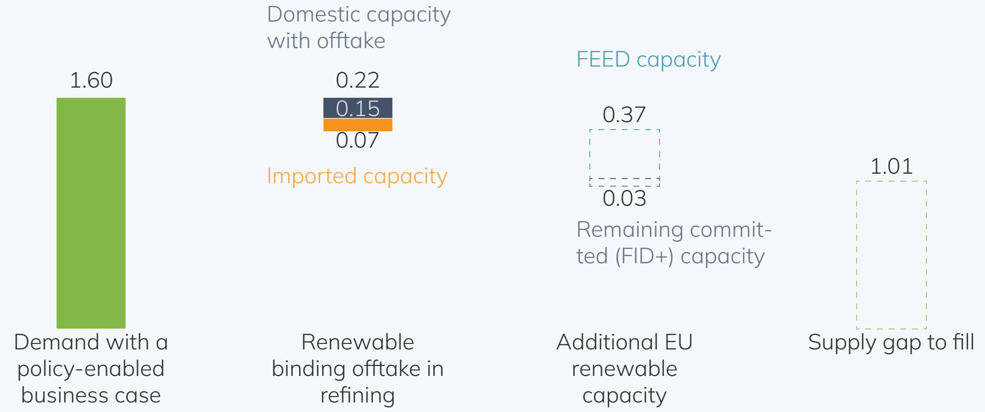


Exhibit 17: 2030 European refining demand vs. current offtake, mtpa H$_2$e

40%
Of estimated RFNBO demand in refining supplied by existing offtake agreements and additional committed and FEED capacity



[1] Hydrogen Council & McKinsey: Closing the Cost Gap report, 2025.
Source: Hydrogen Council & McKinsey Project & Investment Tracker, as of July 2025; McKinsey Hydrogen Insights Clean Hydrogen Offtake Tracker, as of Q1 2025; Hydrogen Council & McKinsey: Closing the Cost Gap report, 2025.

Sector deep dive: ammonia

Low–emission fertilizers represent an addressable and economic decarbonization lever, but uptake to date is limited

Clean ammonia demand today is driven by emerging policies. The EU's ETS and CBAM mechanisms increase CO_2 costs on domestic and imported ammonia, making low–emissions ammonia a cost–effective option, depending on sourcing. The Japanese and Korean power auctions and the Japanese Contract for Difference program also bolster ammonia adoption for co–firing in coal power plants. Several governments, including the US, China, and India, are incentivizing production although mechanisms and policy structures differ by region.

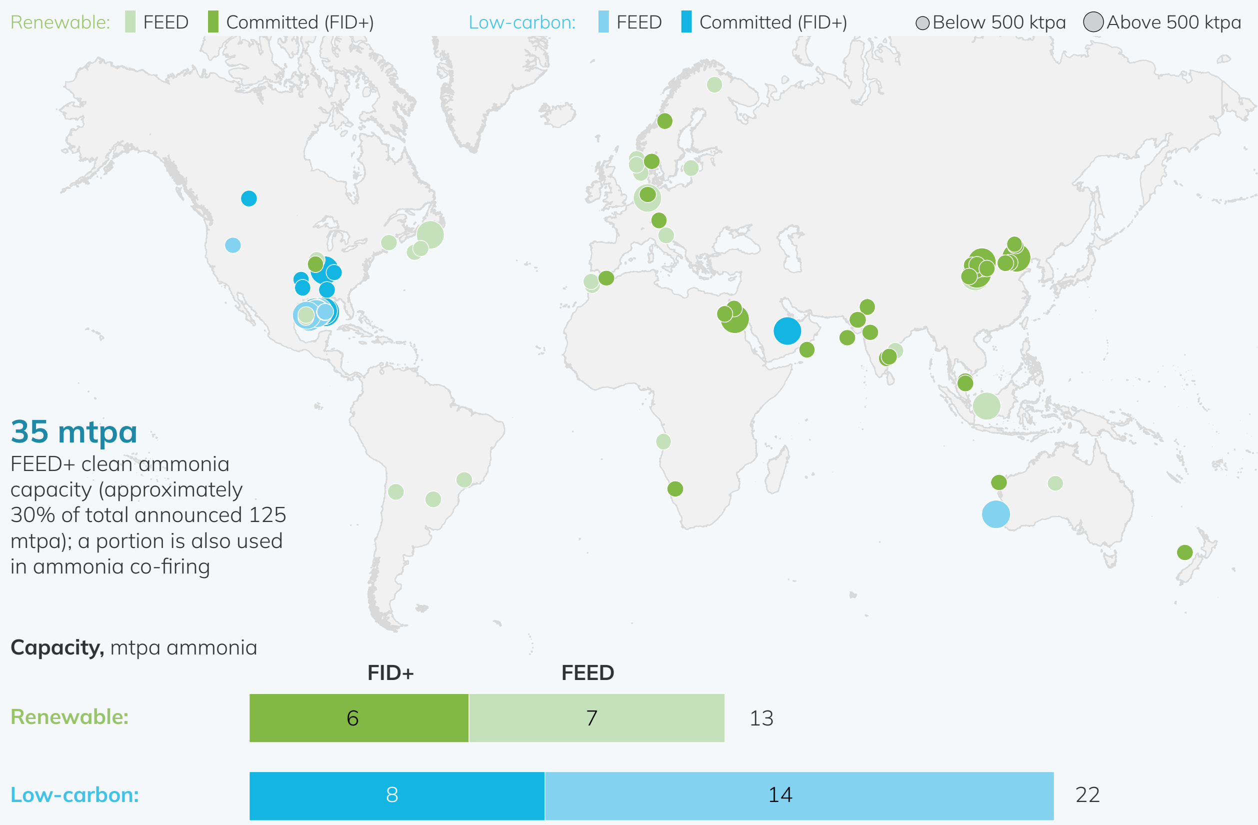
Producers are responding, with over 125 mtpa of new clean ammonia capacity announced. However, only about 30% of the announced projects are in FEED or later. Leading committed project examples are Blue Point in the US Gulf Coast, which is highlighted as a case study in Chapter 3, and Qatar Energy's Ammonia–7 project. Notable partnerships include Yara's agreement with PepsiCo to deliver up to 165,000 tons of fertilizer per year to cover around 25% of crop fertilizer needs in Europe by 2030 and the long–term partnership between the two companies in Mexico to supply of crop nutrition programs

The incremental cost of adopting low–emission ammonia in fertilizer production generally increases the cost of a basket of goods by less than 1%, while reducing emissions by up to 30% in some cases.[1] Low–emission fertilizers rank among the most cost–effective decarbonization options for most food producers, including bread, sugar, and cotton production, and range in abatement costs of $50–150/ton CO_2.[1]

Recently, India set historically low price thresholds with the announcement of ACME securing tender with India's Solar Energy Corporation at approximately $640/ton for renewable ammonia.[2] This could spur additional renewable ammonia production investment in the region.

Addressing three critical barriers could support additional clean fertilizer uptake: a lack of aggregated, at–scale demand in a highly fragmented downstream food/product market; limited globally–recognized tracking & tracing systems, which inhibits visibility and emissions reduction measurement; and a lack of financial instruments geared toward supporting first of a kind adoption.

Exhibit 18: Global clean ammonia projects in FEED+ (FEED, FID, Under construction, Operational)



[1] Based on analysis conducted with McKinsey Catalyst Zero modelling; [2]Fuel Cell Works–India's First Green Ammonia Auction Concludes with 75,000 mtpa Award at Record–Low Rate.
Source: IFA, FAOSTAT, McKinsey – Catalyst Zero (for abatement costs and consumer goods price impact), Eurostat, Consumer Price Index as of May 2025, Hydrogen Council & McKinsey Project & Investment Tracker, as of July 2025, McKinsey Hydrogen Insights Clean Hydrogen Offtake Tracker, as of Q1 2025.

A combination of power decarbonization policies in Japan and South Korea could drive 1–1.5 mtpa H_2e (5–8 mtpa NH_3) of low–carbon ammonia imports

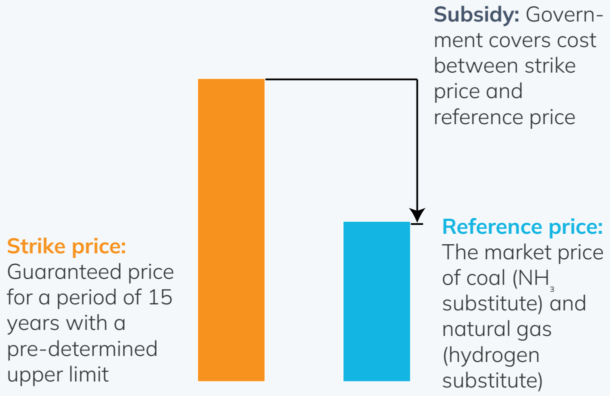
The Japanese Contract for Difference (CfD) scheme is progressing with oversubscription for the first $20 billion budget. Japan's Ministry of Economy, Trade and Industry has allocated a 3 trillion yen (approximately $20 billion) budget for a CfD program to support the decarbonization of Japanese industries, starting with the power sector, specifically in co–firing ammonia in the country's relatively young coal–fired power generation fleet. [6]

The CfD is designed to bridge the cost–price gap between a conventional fuel or feedstock (e.g., coal for power plants) and the decarbonized alternative (e.g., low–carbon ammonia). At a delivered cost of ammonia ranging from $650–750 per tonne of low–carbon ammonia and a reference price based on a coal price range of 130–400 $/t, the $20 billion CfD could potentially incentivize 0.4–0.6 mtpa of H_2e demand (2–3 mtpa NH_3).

First round applications for the CfD exceeded the proposed budget, indicating resilient interest in the Japanese co–firing offtake market. Japan's Ministry of Economy, Trade and Industry is set to select awardee projects starting in the second half of 2025.[7]

Exhibit 19: Illustrative Contract for Difference in Japan

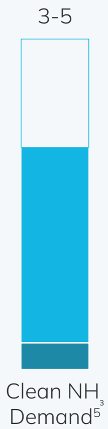
$20 billion
Contracts for Difference[1] for hydrogen or derivatives, predominately allocated toward co-firing ammonia in coal power plants



$1.3 billion	÷	365-600 $/t	=	2-3 mtpa
Annual CfD Subsidy, $20 billion over 15 years[2,3]		Range of strike price – reference price[4]		Clean ammonia demand for power **(0.4-0.6 mtpa H_2e)**

Exhibit 20: South Korea demand for clean ammonia in power (2030) based on CHPS, mtpa H_2e

6,500 GWh
Clean H2 Energy Portfolio Standard (CHPS) targets ~1% annual power generation sourced from hydrogen or derivatives by 2028, potentially rising to 9,500 GWh, although traction limited so far



~3-5 mtpa
Clean ammonia demand for power **(~0.5-1 mtpa H_2e)** based on CHPS target and co-firing efficiency of ammonia[5]

11%
Of targeted auction volume awarded in first round (about 0.3 mtpa)

Korea set a high aspiration for decarbonizing power, but limited volume was awarded in the first round of clean hydrogen power generation auctions. Korea aims to incentivize decarbonizing power through a series of auctions targeting clean hydrogen and derivatives. The initial target to procure about 6,500 GWh of power could support approximately 3 mtpa of ammonia demand (and then a potential increase in that target to 9,500 GWh by 2028 could support an estimated additional 2 mtpa).

However, only ~11% of the first round of auctioned volume was awarded to a single bidder, Korean Southern Power (KOSPO). Additional bids were potentially not selected due to a combination of costs higher than the implied price ceiling of around $540/t NH_3, inability to meet the infrastructure requirements for export and import terminals, or potential foreign exchange fluctuations impacting realized bid prices.

The second round, in which some of these hurdles like exchange rate risk have been mitigated, is currently open for applications with awardee announcements expected in second half of 2025.

[1]Applicable to both renewable and low–carbon; Both domestic and overseas manufacturing + marine transportation covered; [2]Strike price is set at project–level for a period of 15 years, with a pre–determined upper limit automatically adjusting based on fluctuations in exchange rates and raw material costs; [3]Announced budget by Japanese government is 3 trillion yen, equivalent to ~$19 billion; [4]Assuming a strike price of $750/t delivered ammonia and reference price of $150–385/t, based on assumed coal price range of ~130–400 $/t Coal with a carbon tax of 10 $/t$CO_2$ and a HHV of 20.65 GJ/kg for sub–bituminous; [5]Equivalent of 6,500 GWh, using 5.2 kWh/kg NH_3; assuming ammonia serves target; [6]Norton Rose Fulbright: Japan's hydrogen subsidies kicking–off in Summer 2024; [7]S&P Global News: Commodities 2025: Japan set to enter year of decisions over hydrogen.

Early momentum is building around clean fuels–capable vessels and bunkering, driven by maritime decarbonization policies and company targets

Decarbonization polices and company targets are driving initial momentum in the maritime sector. In addition to ETS, the EU has enacted the FuelEU Maritime scheme which sets an increasing carbon intensity reduction target tied to a non–compliance penalty of 2,400 €/t of very low sulfur fuel oil (VLSFO).[2] Within FuelEU, there is also a sub–quota for RFNBO (i.e., renewable hydrogen–based fuels like e–methanol). In addition, the International Maritime Organization (IMO) has set a globally–applicable emissions reduction scheme in which shipowners would be subject to a penalty of 100 $/t CO_2e for excess emissions between 53–65 g/MJ and 380 $/t CO_2e above 65 g/MJ.[3] Meanwhile, 90% of the largest container companies have voluntarily set 2050 net–zero emissions targets, including most with interim targets.

To date, both ports and fleet operators have begun preparing for the increasing usage of alternative fuels. The initial focus is on bio–based fuels (e.g., biogas, biodiesel[4]), but supply constraints and increasing decarbonization targets could drive the uptake of hydrogen–based fuels longer term, including methanol, ammonia, and liquid hydrogen.

Of these three, methanol bunkering appears to be the most prevalent to date with 9/10 of the largest bunkering ports representing 45% of today's bunkering volumes already demonstrating or planning to implement methanol bunkering.[5] The Ports of Singapore and Shanghai each are projecting over 1 mtpa methanol demand by 2030.

Exhibit 22: Implied abatement cost ranges per ton CO_2eq by fuel type, $/t$CO_2$e[8]

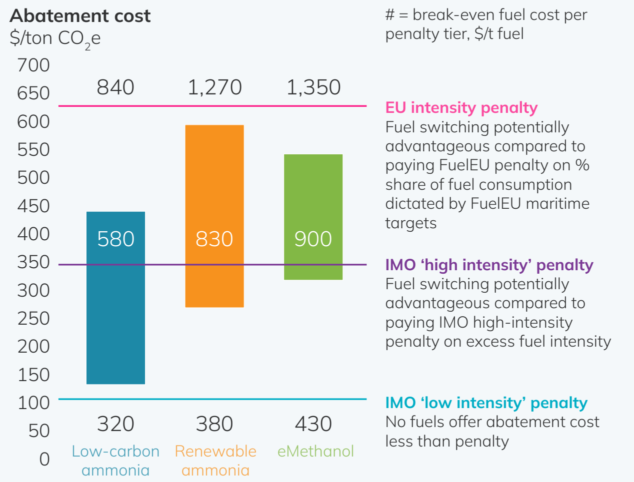
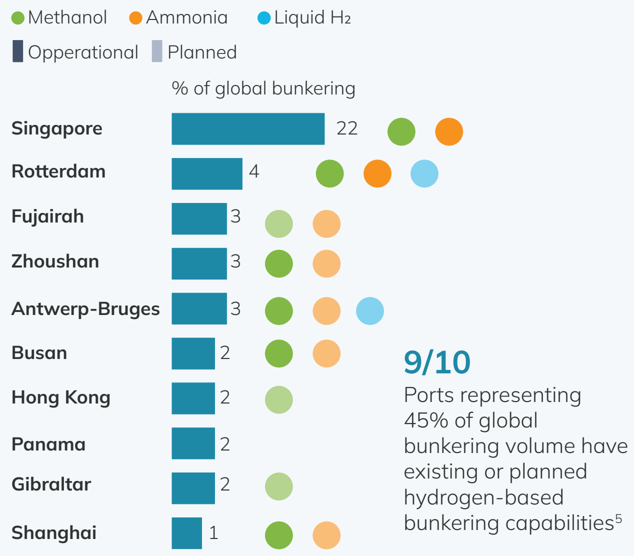


Exhibit 21: Alternative bunkering capabilities for top ten bunkering ports by share of global bunker volume[1]



In addition, over 400 hydrogen or derivative–capable ships are on order, a 14–fold increase in three years, with hydrogen or derivative–capable ships now comprising 6% of all vessel orders.[6] Methanol dual–fuel ships currently have the most traction due to a combination of relatively cost–effective retrofitting of diesel engines, planned availability of bunkering, ability for operators to continue to use existing fuels, and limited operational safety risks.

Ammonia is potentially the most cost–effective of the three hydrogen–based technologies, but safety and environmental risks need to be addressed. In addition to infrastructure challenges regarding boil–off, liquid hydrogen drivetrains may be limited to smaller/midsize vessels (e.g. ropax, ferries) due to higher refueling frequency as liquid hydrogen has the lowest volumetric energy density of the three fuels.

As companies consider fuel alternatives, there may be a phase–in period for hydrogen–based fuels based on TCO impact and fuel availability. Until 2030 it may be more cost efficient for VLSFO–operated ships to pay penalties, with the lower IMO penalty increasing TCO by less than 10% and few fuel options that can decarbonize for a under $100/t CO_2.

Starting around 2035, the impact of the IMO's high–intensity penalty could increase TCO by nearly 30%, potentially incentivizing biodiesel[4] blending as an economical option to comply with IMO guidance or low–carbon ammonia if it can be sourced for less than about $580/t NH_3, particularly if biofuel supplies are constrained. Inside the EU, the combination of ETS[7] and FuelEU, coupled with the limited supply of biodiesel, could potentially make even renewable ammonia or methanol blending attractive alternatives by the mid– to late–2030s, assuming fuels can be sourced at less than about $1,260/t NH_3 or $1,350/t MeOH respectively.

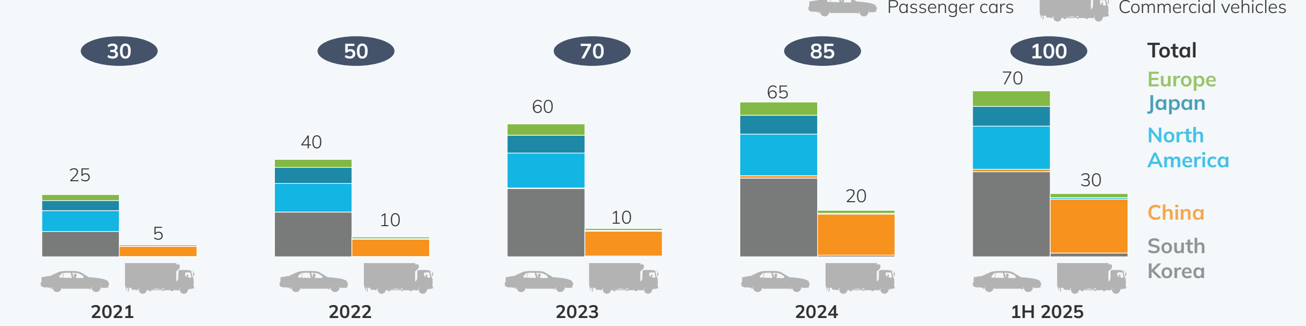
[1] Limited to ammonia, methanol, and liquid hydrogen projects in various phases of development; [2] Regulation (EU) 2023/1805 of the European Parliament and of the Council of 13 September 2023 on the use of renewable and low–carbon fuels in maritime transport, and amending Directive 2009/16/EC (Text with EEA relevance); [3] Reuters: UN shipping agency strikes deal on fuel emissions, CO_2 fees; [4] Includes FAME, UCOME, HVO – blending rates and pricing impact of limited supply could alter TCO economics; [5] Net Zero tracker, ECIU, Science Based Target initiative, Company website, Clarksons; [6] Including dual–fuel capable vessels; orderbook as of Q4 2024; [7] Assumes 60 EUR/t in 2030; [8] Fuel price ranges assumed include 350–650 $/t low–carbon ammonia, 650–1,200 $/t renewable ammonia, 800–1,200 $/t eMethanol.
Source: Clarksons, DNV GL, WPCI, IMO MEPC 83, McKinsey Energy Solutions 2025 powered by Mærsk Mc–Kinney Møller Center for Zero Carbon Shipping NavigaTE model.

China, South Korea account for majority of FCEVs sold, with shift towards commercial vehicles

Road mobility momentum is regionally–driven with China and South Korea leading in deployment. South Korea has been a historical leader in passenger vehicle deployment, consistently accounting for 45–50% of global sales since 2021. In the last three years, China accounted for the fastest growth in hydrogen fuel cell vehicle deployment, contributing over half of new FCEV additions in the last year, underlining a road mobility strategy where FCEVs complement (BEVs) with emerging market applications for both.

After initial momentum in passenger car deployment, the focus has shifted toward commercial vehicle classes (trucks, vans, buses), given more favorable total cost of ownership (TCO) profiles compared to battery electric vehicles (BEVs) for larger, highly utilized platforms. So far, in 2025, commercial vehicles have made up two–thirds of new sales, increasing their share from about one–quarter in 2022. This trend appears to be predominantly driven by China, which accounts for approximately 75% of these sales.

Exhibit 35: Cumulative fuel cell EV sales by region, '000 FCEV vehicles[1]



Commercialization challenged in other regions, but TCO possible to address

Other regions have thus far deployed fewer FCEVs, with several challenges hindering commercialization. Achieving at–scale road mobility deployment requires advancements across all components of an end user's TCO. In addition to bringing up–front vehicle capex and operating costs in line with alternative drivetrains, the mobility ecosystem has to be designed to support at–pump prices consistently low enough to motivate at–scale deployment of those vehicles.

On the vehicle side of the equation, standardization of platforms and simplified, functional designs can help reduce operating costs, but all–in capex cost–out relies on at–scale manufacturing in the tens of thousands of vehicles per year.

Achieving at–pump prices that enable wider–scale adoption relies on ecosystem design along three primary factors: First, HRS sizing and loading must be optimized in key demand hubs, potentially via highly utilized closed–loop ecosystems. Second, those systems need access to a consistent supply of low–cost hydrogen to reduce overall TCO while optimizing for the lowest emission blend possible as new renewable and low–carbon production comes online in parallel to vehicle deployment. Third, distribution network efficiency can be improved through denser HRS networks focused on selected areas, pooling of demand to create at–scale offtake and siting ecosystems in proximity to production or distribution hubs.

Viability of the road mobility business case will vary by region, with tipping points for each factor dictated both by policy design and conditions unique to each region (e.g., vehicle use profiles, existing infrastructure, domestic hydrogen supply).

Exhibit 36: Primary drivers of fuel cell vehicle commercialization (based on core commercial vehicle TCO components)

Vehicle capex & maintenance costs
Standardize and simplify commercial vehicle platform designs and produce at scale needed to minimize both up-front capex and lifetime maintenance costs compared to diesel ICE, BEV

+

Fuel costs
Optimize hydrogen production, distribution and refueling to reduce hydrogen price-at-pump, targeting overall TCO parity with alternative drivetrains (both diesel ICE and BEV). Full commercial benefit potentially requires some form of offtake guarantee

HRS sizing and loading
Deploy large-scale, standardized refueling stations in highly-utilized closed-loop ecosystems to optimize unit economics; scale HRS network size in line with vehicle deployment to mitigate under-utilization or insufficient station availability

Hydrogen cost and sourcing
Source lowest-cost hydrogen with flexibility to leverage renewable, low-carbon or unabated molecules, simultaneously optimizing for TCO reduction to support vehicle adoption and emissions reduction as decarbonized hydrogen production scales

Distribution network
Bundle hydrogen demand via clustering demand centers in proximity to molecule production or distribution infrastructure and pooling demand with other hydrogen end users to enhance local distribution efficiency and provide at-scale offtake for producers

[1] Commercial vehicles includes trucks, light–duty vehicles, vans, buses; passenger includes passenger cars and 2–3 wheelers.
Source: McKinsey Hydrogen Insights Equipment values pool model, h2stations.org; iphe.net, EU Guidance on REDIII implementation in the transport sector, IEA global EV sales outlook, EV Volumes market statistics.

A look ahead: themes to watch across the project pipeline, supply and demand

The first wave of hydrogen projects was forged in a difficult environment with policy uncertainty, inflation, and increased cost of capital. Looking ahead, three key themes could shape the emergence of the next hydrogen wave as developers look to leverage winning strategies and apply lessons learned from the first wave:

Continued pipeline maturation, including both advancing projects and anticipated cancellations

Project pipeline maturation has led to a growing foundation of capacity with a compelling business case while natural attrition has begun to streamline the earlier–stage funnel.

Further maturation of the pipeline is anticipated: about 7 mtpa of capacity is currently in FEED with 16 mtpa more in feasibility, of which approximately 3–8 mtpa could still move forward by 2030 if it secures offtake. Additional attrition is expected, particularly in cases where projects were announced before 2022 when the industry was operating under different cost expectations and global decarbonization ambitions, and in instances where limited policy clarity emerges.

In addition to ongoing pipeline cleanup, the composition of new announcements may continue to shift toward more infrastructure projects and end use segments as early trade routes materialize.

Committed clean supply from first–wave projects coming online despite challenges

For the approximately 6 mtpa of committed capacity, most projects are slated to start operation in the next two to three years, bringing five times more capacity online relative to today.

For renewable hydrogen projects, compounding cost factors have forced operators to rapidly streamline designs, put a renewed focus on addressing costs outside of electrolyzer systems, and find creative operating models that maximize resource use and revenue streams.

For low–carbon projects, finding the right combination of low–cost natural gas, existing CCS networks, access to trade infrastructure and supportive policy landscape has helped regions like the US Gulf Coast emerge as hotbeds of development.

Looking ahead, Chinese electrolysis deployment is expected to continue at pace, with the majority of mature supply supporting domestic demand. Although inter–regional technology transfer could create downward cost pressure elsewhere, the degree to which other regions adopt elements of the Chinese deployment model will depend on local conditions.

The US and Canada appear likely to remain positioned as the low–carbon leaders in the near term. Low–cost renewable ammonia exports may emerge from India, the Middle East and other regions with abundant renewable resources.

Demand materializing in first–mover segments on the back of additional regulatory stability

Offtake into stable demand segments remains the critical determining factor for the pace and extent of the industry's deployment and for individual projects to move forward. Emerging policies have created initial demand signals (e.g., RED III, ETS, Japan's CfD, Korea's CHPS) with offtake momentum already anticipating enactment of these policies, but the overall business case for clean hydrogen continues to hinge on the stability and implementation of these policies.

Commercialization of hydrogen end uses would likely be sequenced going forward, starting with decarbonization of existing end uses (which comprises the majority of emerging demand so far). New end uses could gain more traction as the industry scales, benefitting from anticipated cost–down and the emergence of additional connective infrastructure.

Regulatory clarity is anticipated to give developers and end–users more confidence in signing contracts, but it is still worth watching how the emerging policies are implemented. For example, the specific transposition of RED III could dictate volumes of clean hydrogen uptake in refineries versus FCEVs directly and the implementation of CBAM may impact the degree of imported versus domestic supply of clean ammonia in Europe.

Other questions to shape future uptake of clean hydrogen include whether demand generated through implementation of current regulation is sufficient to catalyze sustained industry growth beyond decarbonization of existing end uses, how downstream end–user and customer activation will influence upstream competitiveness across new sectors, and how emerging demand will be most economically served, potentially on the back of new infrastructure.

The following chapter explores the specific criteria that have enabled project advancement in the first wave despite a challenging environment and examines a series of case studies that highlight these criteria.

Chapter 03

Lessons learned from the first wave of mature clean hydrogen projects

Across pathways and regions, projects that have progressed exhibit a combination of optimized project design, bankable offtake in concrete demand segments, and tight–knit value chain collaboration that shares risk among project partners. In most cases, projects are also supported by emerging hydrogen–relevant policies.

6 project enabling factors

across project ecosystem, design, and execution have been identified as critical to first wave project progress.

12 case studies

are spotlighted as representative example projects or ecosystems that showcase emerging critical factors: 2 low–carbon, 6 renewable, and 4 end–use/ecosystem.

Normand'Hy | Aerial view of Normand'Hy plant under construction | image provided by Air Liquide

Projects that have progressed in the first wave reveal 6 enabling factors required to move forward

As the first wave of clean hydrogen projects has progressed, there are 6 factors that emerge as critical for project development across project ecosystem, design, and execution. While successful projects may not have to excel across every single dimension, projects that don't exhibit a majority of the below factors are unlikely to move forward.

Although each project exhibits a distinct combination of project enabling factors, the nuances of any given project's circumstances dictate variations in prioritization of these factors. For example, a combination of a) project design optimized for both input resource maximization and market access, b) securing of bankable offtake in a concrete, policy–supported demand segment, and c) tight–knit value chain collaboration to minimize project complexity and share risk among core project participants, appear to be consistently critical.

Elements of these 6 enabling factors are applicable across industries, and equally critical for delivering other types of projects; for instance the need to optimize overall project cost structure, secure firm offtake to underpin the project's business case, and continue to execute effectively over time to manage OPEX. However, location selection, strategic relationships with value chain partners, and an effective policy landscape management strategy are uniquely important in hydrogen today given how and where hydrogen can be produced and consumed, the nascency of connective infrastructure, and the reliance of the business case on regulatory support.

Exhibit 37: Project enabling factors

Project design: Designing and engineering optimal projects

Strategic location selection
Project economics depend on siting projects in proximity to optimal feedstock resources (e.g., renewable power, natural gas), high value offtake (e.g., emerging hydrogen hubs, existing end-users like refineries), and existing infrastructure (e.g., transport pipelines, CCUS); limited optimal locations exist that combine top-tier feedstock, infrastructure, as well as direct access to demand, therefore projects must weight the economics of selecting locations without market access or infrastructure.

CAPEX and technology optimization
Projects across pathways typically need to realize all-in production costs on the lowest 10% of the cost curve to achieve commercial viability. Streamlined system design to minimize up-front CAPEX and maintenance costs, a phased project expansion strategy, and effective technology management optimized for project location (e.g., solar or wind capacity build out relative to electrolyzer size and resource profile with adequate firming mechanisms), can minimize up-front capital expenditure and lower LCOH.

Project execution: Delivering at cost & on time

Cost and schedule optimization
Successful project delivery demands strict adherence to project deadlines to prevent cost overruns, coupled with well-structured commercial contracts to effectively manage OPEX; development timelines can range from three to over six years depending on delays with best-in-class developers potentially able to reduce LCOH by 10-25% by radically challenging base assumptions in design, installation, and scale-up.

Project ecosystem: Engagement with external environment

Offtake and commercial strategy
Establishing offtake wither through captive use-cases or binding contracts in policy-backed demand segments is essential to de-risk investment in clean hydrogen projects. Commercial strategy execution depends on a combination of insights into the pace and firmness of downstream demand, alongside distinctive contracting strategies that optimize for both value and risk management. On average, 60% of committed capacity is coupled with binding offtake.

Policy landscape navigation
Optimizing for and effectively capturing supply-side and/or demand-side policy support is critical for nearly all projects (e.g., US IRA tax credits, EU RED III-driven demand, Japan's CfD, etc.) 97% of FID+ projects have either production or offtake located in regions with explicit hydrogen policies.

Value chain collaboration
Selection of value chain partners with proven track record of delivering industrial-scale projects is essential. Majority of FID+ projects involve best-in-class partnerships spanning the full value chain to minimize complexity (e.g., project equity stakes spread across producers and off-takers).

Source: Hydrogen Council & McKinsey Project & Investment Tracker, as of July 2025; project details confirmed in direct collaboration with Hydrogen Council member companies involved.

A representative sample of projects across pathways, regions and value chain steps, were selected that highlight the implementation of these project enabling factors as well as nuances specific to each project's circumstances. Each case study features a project description, key metrics, and real project images, together with an analysis of the enabling factor that drove its development.

Industry leaders involved in these projects aided in refining the list of representative projects and distilling what core differentiating factors have led these projects to mature and move forward. The case studies highlighted are not exhaustive, as numerous additional projects continue to advance meaningfully through the development stages.

The following select project case studies highlight the specific project enabling factor that contributed to its advance through the development pipeline.

Exhibit 38: Project case studies

Roadrunner | Assembled HYPRPlant skids for Roadrunner awaiting shipment to project site| image provided by Electric Hydrogen

Source: Hydrogen Council & McKinsey Project & Investment Tracker, as of July 2025; project details confirmed in direct collaboration with Hydrogen Council member companies involved.

Blue Point

Companies involved	CF Industries	Jera	Mitsui	Linde	
Location	**Capacity**	**Status**	**COD**	**Pathway**	**Offtake**
Louisiana,United States	**1.4 mtpa** ammonia | 246 ktpa H_2e	FID (taken in Q2 2025)	2029	Low–carbon	JV partners to offtake according to ownership share (CF 40%, JERA 35%, Mitsui 25%)

Project description

Blue Point will produce approximately 1.4 million metric tons of low–carbon ammonia per year in the U.S. Gulf Coast and is projected to start operations in 2029. The project will leverage (CCUS) processes to permanently sequester approximately 2.3 million metric tons of CO_2 per year, reducing CO_2 emissions by more than 95% compared to conventional ammonia production methods.

Project enabling factor

Project ecosystem: ⬢ **Value chain collaboration**

CF Industries, the world's largest producer of ammonia and a global leader in the production of low–carbon ammonia, JERA, Japan's largest power generation company, and Mitsui, one of the country's leading trading companies with 50 years of ammonia trading experience and the top market share in Japan, are jointly developing one of the largest low–carbon ammonia production projects in the world.

The project will have deep–water access along the U.S. Gulf Coast and CF Industries will bring critical project development and operational expertise. The project is leveraging industry–leading firms for engineering, procurement, industrial gas supply, CO_2 transport & sequestration to reduce project execution risk.

Blue Point| Aerial project rendering of completed Blue Point production facility | image provided by CF Industries

Source: Hydrogen Council & McKinsey Project & Investment Tracker, as of July 2025; project details confirmed in direct collaboration with Hydrogen Council member companies involved.

Boden renewable steel plant

Companies involved	Stegra	Siemens Energy	thyssenkrupp nucera	Hy24	SMS Group
Location	**Capacity**	**Status**	**COD**	**Pathway**	**Offtake**
Boden, Sweden	**2.5 mtpa** steel | 136 ktpa H_2e | 740 MW	Under con–struction	2026	Renewable	60%–Over 60% of production capacity has been pre–sold through a mix of binding and non–binding 5–7 year offtake agreements[1]

Project description

The fully integrated renewable hydrogen–to–steel plant in Boden, Sweden will feature a 740 MW electrolyzer, direct reduced iron process, and electric arc furnaces to produce up to 2.5 mtpa of renewable steel by 2026. The plant achieves ~95% CO_2 emission reduction compared to traditional blast furnace methods and has plans to scale to ~5 mtpa by 2030. Stegra partners with leading technology partners such as SMS Group, Siemens, and thyssenkrupp Nucera to supply key plant components.

Project enabling factor

Project ecosystem: **Offtake and commercial strategy**

Stegra has structured offtake agreements not only to purchase renewable steel, but also to integrate a circular supply of steel scrap back into their process in a pioneering method to create strategic feedstock security and reduce the need for virgin iron ore. Multi–year binding offtake agreements with major companies like Kirchoff Automotive include provisions that scrap is returned to the Boden plant for recycling, which supports both resource efficiency and reduces overall lifecycle emissions.

Boden renewable steel | Onsite production complex| image provided by thyssenkrupp nucera

[1]Off–takers include Bilstein Group, Cargill Metals, Mercedes–Benz, Marcegaglia, and Lindab.
Source: Hydrogen Council & McKinsey Project & Investment Tracker, as of July 2025; project details confirmed in direct collaboration with Hydrogen Council member companies involved.

Brunsbüttel ammonia import terminal

Companies involved	Yara Clean Ammonia			
Location	**Capacity**	**Status**	**Pathway**	**Offtake**
Brunsbüttel, Germany	**3 mtpa** ammonia import capacity	Operational	Renewable, Low–carbon	Yara Clean Ammonia is working to build an end to end supply chain for both renewable and low–carbon ammonia sold as hydrogen or ammonia together with partners

Project description

Yara's ammonia import terminal in Brunsbüttel began commercial operations on October 2, 2024. It is capable of handling up to 3 mtpa of clean ammonia—equivalent to about 530 ktpa of hydrogen and roughly 5% of Europe's hydrogen target for 2030. The terminal is situated on the North Sea and Kiel Canal, a growing central hub for Germany's hydrogen industry.

Project enabling factor

Project intrinsics: Strategic location selection

The Yara ammonia import terminal in Brunsbüttel is strategically located at the entrance to the Kiel Canal and on the North Sea, providing direct maritime access to global shipping routes and inland waterways. Its proximity to Yara's existing fertilizer and ammonia manufacturing plant at ChemCoast Park in Brunsbüttel supports streamlined operations and logistics. The ammonia can be used as feedstock for fertilizer production or delivered directly from the terminal to the point of use, where it could be cracked to low–emission hydrogen. The terminal enables both the German and broader European hydrogen market and sustainable industrial decarbonization.


Brunsbüttel ammonia import terminal | Aerial view of the Brunsbüttel plant and Yara Sela ship at the import terminal | images sourced via public press releases.

Source: Hydrogen Council & McKinsey Project & Investment Tracker, as of July 2025; project details confirmed in direct collaboration with Hydrogen Council member companies involved.

Holland Hydrogen 1

Companies involved	Shell	Worley	thyssenkrupp nucera		
Location	**Capacity**	**Status**	**COD**	**Pathway**	**Offtake**
Port of Rotterdam, Netherlands	**20 ktpa** H_2e | 200 MW	Under con–struction	2027	Renewable	100%–Captive offtake to Shell's Energy and Chemicals Park

Project description

The Holland Hydrogen project is a major renewable hydrogen initiative led by Shell, located in the Port of Rotterdam. Set to become Europe's largest renewable hydrogen plant, it will produce 60 ton/day using a 200 MW electrolyzer powered by offshore wind. Engineering and construction are being executed by Worley and thyssenkrupp nucera. The hydrogen will be used for decarbonizing Shell's refinery and regional industry.

Project enabling factor

Project intrinsics: ⬢ **Strategic location selection**

Holland Hydrogen is strategically situated along the Dutch North Sea coast to leverage access to rapidly expanding offshore wind capacity. The electrolyzer will be powered primarily by nearby Hollandse Kust Noord offshore wind farm, in which Shell holds a stake.

Hydrogen will be conveyed via the newly developed HyTransPort pipeline directly to the Shell Energy & Chemicals Park Pernis refinery in Rotterdam to replace the unabated hydrogen currently used. The existing pipeline infrastructure enables seamless integration of renewable hydrogen into existing industrial processes and streamlines the project's logistics.

Holland Hydrogen | Aerial view of construction progress and completed project rendering| image provided by thyssenkrupp nucera

Source: Hydrogen Council & McKinsey Project & Investment Tracker, as of July 2025; project details confirmed in direct collaboration with Hydrogen Council member companies involved.

Kassø E–Methanol

Companies involved	European Energy	Mitsui	Siemens Energy	Clariant	BASF

Location	Capacity	Status	Pathway	Offtake
Kassø, Denmark	**42 ktpa** e–methanol | 8 ktpa H_2e	Operational (since May 2025)	Renewable	100%–binding offtake through 3 partners (A.P. Møller–Maersk, Lego, Novo Nordisk)

Project description

The operational Kassø e–methanol plant is the world's first large–scale e–methanol plant operated by European Energy. It produces up to 42 kt annually, powered by 52 MW of electrolyzers using renewable electricity from the co–located 304 MWp Kassø Solar Park and the public grid. It utilizes 60,000 t/year of biogenic CO_2 from nearby Tønder Biogas and operates with Clariant's MegaMax 900 catalysts.

Project enabling factor

Project intrinsics: ⬢ **CAPEX and technology optimization**

Both the location and technological design of the plant were optimized for whole system efficiency on both inputs and outputs.

A co–located 304 MW solar park by European Energy supplies about half the plant's electricity, complemented by wind power. A power balancing trading partnership with Danish Commodities optimizes the cost efficiency of the plant through real–time electricity market optimization of both the solar park and e–methanol production facility and ensures stable, continuous production. The plant also utilizes 60 kt/year of biogenic CO_2 from nearby Tønder Biogas plant, significantly cutting its carbon intensity compared to fossil methanol.

On the plant outputs, the exothermic methanol synthesis generates excess heat, which is used to supply district heating and boosting project economics through an additional revenue stream.

Kassø e–methanol | Aerial view of Kassø e–methanol plant in operations | images provided by Clariant

Source: Hydrogen Council & McKinsey Project & Investment Tracker, as of July 2025; project details confirmed in direct collaboration with Hydrogen Council member companies involved.

NEOM Green Hydrogen Company (NGHC)

Companies involved	ACWA Power	NEOM	Air Products	thyssenkrupp nucera	
Location	**Capacity**	**Status**	**COD**	**Pathway**	**Offtake**
NEOM,Saudi Arabia	**1.2 mtpa** ammonia | 237 ktpa H_2e | 2.2 GW	Under con–struction	2026	Renewable	100%–binding offtake with Air Products

Project description

NGHC is a renewable hydrogen project in Saudi Arabia, located in Oxagon in NEOM. It is a $8.4 billion joint venture between Air Products, ACWA Power, and NEOM. The project aims to produce 600 MT/day of renewable hydrogen by 2027 using 4 GW of renewable solar and wind power. The hydrogen will be converted into ammonia for global export, especially to Europe and Asia. This project is one of the largest renewable hydrogen projects globally and central to Saudi Arabia's Vision 2030. In the beginning of June, NGHC announced it reached 80% construction completion at the start of Q1 2025 across all project sites — the renewable hydrogen facility, wind garden, solar farm, and transmission grid.[1]

Project enabling factor

Project ecosystem: ⬢ **Offtake and commercial strategy**

This project represents a breakthrough in sustainable energy finance at a total investment value of $8.4 billion. The project utilizes an innovative non–recourse financing framework pooling funding from 23 lenders, which has been certified by S&P Global as adhering to green loan principles and is one of the largest project financings under the green loan framework. Additional equity financing is provided by NEOM, ACWA Power, and Air Products JV NEOM Green Hydrogen Company. The large investment is anchored by Air Products 30–year exclusive offtake agreement to provide revenue certainty and align interests, as Air Products is also the main EPC contractor. Air Products is planning to sell the majority of the ammonia to other parties for its ultimate end–use.

NEOM Green Hydrogen Company (NGHC) | Aerial view of renewable hydrogen production facility| image provided by thyssenkrupp nucera

[1]NEOM Green Hydrogen Company News & Insights: World's Largest Green Hydrogen Plant Reaches 80% Construction Completion Across All Sites.
Source: Hydrogen Council & McKinsey Project & Investment Tracker, as of July 2025; project details confirmed in direct collaboration with Hydrogen Council member companies involved.

Normand'Hy

Companies involved	Air Liquide	Siemens Energy	TotalEnergies	HysetCo

Location	Capacity	Status	COD	Pathway	Offtake
Normandy, France	**28 ktpa** H_2e | 200 MW	Under construction (began in 2022)	2026	Renewable	Over 50% binding offtake agreements backed up by TotalEnergies

Project description

In partnership with Siemens Energy, Air Liquide is developing one of the world's largest PEM electrolyzer to produce 200 MW of renewable hydrogen (~28,000t/yr) with a COD estimated in 2026. The aim of the project is to advance decarbonization of the Port-Jérôme industrial basin through its partnership with TotalEnergies and contribute to the development of low–carbon road mobility with HysetCo.

Project enabling factor

Project ecosystem: ⬢ **Value chain collaboration**

The Air Liquide Normand'Hy project showcases a holistic and collaborative model for developing large–scale renewable hydrogen ecosystems in Europe, leveraging Europe's Renewable Energy Directive and funding under Europe's IPCEI programme. The 200MW electrolyser technology features state–of–the–art electrolyzer stacks from Air Liquide's 25:75 gigafactory joint venture with Siemens Energy.

The project's viability is anchored by structured, long–term offtake contracts with key partners:

- In Normandy itself, Air Liquide has signed a large–scale agreement to supply RFNBO hydrogen to TotalEnergies' Gonfreville refinery, as it prepares to meet its RED III obligations. Within the Normandy basin, Air Liquide can leverage its wide decarbonization strategy on its regional hydrogen pipeline network, and the creation of a CO_2 management infrastructure for its own and customer assets.
- Air Liquide can leverage the scale provided by its industrial customers to supply the downstream direct hydrogen road mobility market, particularly HysetCo, in which Air Liquide is a shareholder (alongside TotalEnergies, Toyota, Hy24). This agreement marks a key step in the decarbonization of transport in the Île–de–France region as part of the transition to low–carbon road mobility.


Normand'Hy | Aerial view of Normand'Hy plant and 300bar hydrogen trailers | images provided by Air Liquide

Source: Hydrogen Council & McKinsey Project & Investment Tracker, as of July 2025; project details confirmed in direct collaboration with Hydrogen Council member companies involved.

Path2Zero ethyleneand derivatives

Companies involved	Linde	Dow			
Location	**Capacity**	**Status**	**COD**	**Pathway**	**Offtake**
Alberta,Canada	**3.2 mtpa** of ethylene & polyethylene	Under construction (2024)	2027	Low–carbon	100%–Binding offtake with Dow ethylene cracker

Project description

Dow's Path2Zero project retrofits and expands its existing site in Fort Saskatchewan to become the world's first net–zero Scope 1&2 emissions site, which upon full completion of all phases is expected to supply approximately 3.2 mtpa of certified low–carbon emissions polyethylene and ethylene derivatives. Under a binding long–term supply agreement, Linde will deliver the necessary low–carbon gases as part of the initial phase of the project, including the recovery of hydrogen from Dow's cracker off–gas.

Project enabling factor

Project intrinsics: ⬢ **Strategic location selection**

Among other retrofits to the Dow facility, Linde will integrate a large–scale air separation and autothermal reformer complex into existing site operations in order to convert cracker off–gas into hydrogen as a clean fuel used in the ethylene production process. The project leverages existing CO_2 transportation infrastructure in the region via third–party partners for transport to long–term sequestration.

As the first net–zero ethylene cracker in the world, the project is a transformative effort in the chemical industry that sets a blueprint for similar future industrial projects.

Path2Zero ethylene and derivatives| View of Linde autothermal reforming complex | image provided by Linde

Source: Hydrogen Council & McKinsey Project & Investment Tracker, as of July 2025; project details confirmed in direct collaboration with Hydrogen Council member companies involved.

Roadrunner

Companies involved	Infinium	Electric Hydrogen

Location	Capacity	Status	COD	Pathway	Offtake
Texas,United States	**23 ktpa** eSAF | 8 ktpa H_2e | 100 MW	Under construction (as of May 2025)	2027	Low–carbon	50% American Airlines take–or–pay contract, IAG binding contract for 1/3 of production, and Citi emissions reduction credit purchase

Project description

Roadrunner will be the largest North American Power–to–Liquids facility. The project is in construction today, and will be the first installation of HYPRPlant, Electric Hydrogen's American–made standardized 100MW PEM electrolysis plant. HYPRPlant reduces total installed project costs of the hydrogen electrolysis plant by up to 60% compared to commercially–available alternatives. The Roadrunner project will use waste CO_2 and low–cost renewable hydrogen to create approximately 23,000 metric tonnes per year of eSAF, plus eDiesel and eNaphtha.

Project enabling factor

Project ecosystem: ⬢ **Offtake and commercial strategy**

IAG (parent company of British Airways) signed a 10–year offtake agreement with Infinium for 1/3 of the project's annual capacity in order to comply with the UK SAF mandate (requiring 10% sourcing of sustainable feedstocks by 2030). American Airlines has signed a separate long–term offtake agreement and will transfer the associated emission reductions credits to Citi to reduce Citi's Scope 3 emissions associated with employee travel. The novel offtake commitments demonstrate a substantive collaboration that supports project financing by providing revenue certainty for the project.

Brookfield Asset Management, a leading global infrastructure investment firm, has provided equity investment to the Roadrunner project alongside Breakthrough Energy Catalyst. HSBC, one of the world's largest banking and financial services organizations, is providing debt financing for the project.

Roadrunner | Electric Hydrogen leadership team on construction site and modular HYPRPlant skids for Roadrunner| images provided by Electric Hydrogen

Source: Hydrogen Council & McKinsey Project & Investment Tracker, as of July 2025; project details confirmed in direct collaboration with Hydrogen Council member companies involved.

South Korean road mobility

Companies involved

Hyundai Motor | Air Liquide | LOTTE Chemical | Nel Hydrogen | Kolon Industries | SK

Location

South Korea

Project description

In Korea, a number of players throughout the supply chain have aligned in response to a very effective public support system put in place to drive the country's 2030 Nationally Determined Contribution target for transport, which aims for a cumulative deployment of 4.5 million zero–emission vehicles. Hyundai Motor is deploying passenger cars, buses and trucks, with around 40,000 on Korea's roads as of June 2025. The bus market in particular is accelerating. In reaction to Seoul's "No Diesel" ban, Hyundai Motor has partnered with Seoul city and the Ministry of the Environment to replace ~1,300 buses within the city by 2026, and aims to deploy ~2000 new hydrogen buses across the country each year.

On hydrogen refueling station (HRS) infrastructure, there are a total of 242 HRS built by 2024 with plans to expand to 269 HRS by 2025. In support, Air Liquide & Lotte's JV is currently commissioning the largest 400 bar hydrogen filling center, alongside HRS investments by two of the largest hydrogen retail networks – Hynet and Kohygen – in which Hyundai Motor, Air Liquide and Lotte are shareholders.

Project enabling factor

Project ecosystem: ⬢ **Policy landscape navigation**

Fuel cell electric vehicles (FCEVs) are increasingly recognized in Korea as a strategic clean transportation solution, supported by strong public–private collaboration. This collaboration creates a positive feedback loop where government policies and industry growth reinforce each other.

The key to this loop's success has been the simultaneous expansion of both demand and infrastructure. Deployment of hydrogen passenger cars is enhancing public awareness and expanding the overall scale of hydrogen road mobility while at the same time, leveraging fixed–route hydrogen buses as a stable and predictable source of demand, HRS can achieve a certain level of economic and operational stability. As infrastructure expands — with 242 HRS nationwide — demand is increasing in parallel, driving tangible growth across the hydrogen ecosystem, including the operation of over 2,000 hydrogen buses (up from ~100 in 2020) and ~37,000 passenger vehicles (up from ~11,000 in 2020) nationwide.

Ultimately, well-designed policies — such as subsidies for the purchase of hydrogen vehicles, tax benefits, and reduced tolls — help lower the total cost of ownership (TCO) for hydrogen vehicles, making hydrogen vehicles more competitive in the early stages. Additionally, fuel subsidies for hydrogen buses and trucks enhance the competitiveness of hydrogen road mobility by improving their operational economics. Continued policy support is essential from a long-term perspective, as growing adoption stimulates hydrogen demand and drives investment in clean hydrogen production and infrastructure, which in turn enhances self-sustaining TCO competitiveness over time.

South Korean mobility| Hydrogen refueling station in South Korea serving passenger cars and Hyundai Hydrogen bus in use | images provided by Hyundai

Source: Hydrogen Council & McKinsey Project & Investment Tracker, as of July 2025; project details confirmed in direct collaboration with Hydrogen Council member companies involved.

Villeta renewable ammonia and fertilizer

Companies involved	Atome	ANDE	Yara Clean Ammonia	Hy24	Casale
Location	**Capacity**	**Status**	**COD**	**Pathway**	**Offtake**
Villeta, Paraguay	**260 ktpa** CAN fertilizer[1] | 46 ktpa H_2e | 145 MW	FEED (approaching FID)	2028	Renewable	100%–Yara International signed non–binding Heads of Terms for 100% offtake of CAN fertilizer[1]

Project description

Located in Paraguay, the project is a 145 MW electrolyzer–powered fertilizer plant that will be sourcing 100% of its electricity needs from renewable sources (the majority of which is hydro) and that is expected to achieve COD in 2028. ATOME has strategically partnered with ANDE, the Paraguayan national utility, to supply power, Casale, to provide technology and EPC, and Yara International, for offtake.

Project enabling factor

Project intrinsics: **Strategic location selection**

Paraguay owns 50% of Itaipu, the world's third largest hydroelectric dam (14 GW), which provides Paraguay with over 90% of its energy needs. Paraguay only uses 30% of its 50% share of Itaipu's power generation resulting in an excess of renewable energy available for consumption. The ATOME project capitalized on this excess by securing a 145MW 24/7 baseload PPA from the Itaipu dam at the lowest industrial tariff in Paraguay.

The project is also located near brownfield infrastructure, such as ports and transmission and distribution equipment, as well as the Paraguay River, which provides direct access to water.

Villeta renewable ammonia and fertilizer | Ammonia and fertilizer plant renderings and Itaipu dam, which provides hydro power to the plant | images provided by Hy24

[1] Calcium Ammonium Nitrate (CAN) fertilizer.
Source: Hydrogen Council & McKinsey Project & Investment Tracker, as of July 2025; project details confirmed in direct collaboration with Hydrogen Council member companies involved.

[1] Calcium Ammonium Nitrate (CAN) fertilizer.

Xinjiang Kuqa Green Hydrogen Pilot Project

Companies involved	Sinopec			
Location	**Capacity**	**Status**	**Pathway**	**Offtake**
Xinjiang, China	**20 ktpa** H_2e | 260 MW	Operational	Renewable	100%–captive offtake to Sinopec Tahe Refining & Chemical plant

Project description

The Sinopec Kuqa Green Hydrogen project features a 300 MW solar PV array to directly power the electrolysis plant capable of producing ~20 ktpa of renewable hydrogen. It is the world's largest PV–powered renewable hydrogen site with on–site hydrogen storage and pipeline connection to Sinopec's downstream Tahe Refining & Chemical plant.

Project enabling factor

Project execution: ⬢ **Offtake and commercial strategy**

Construction of the accompanying 300MW solar array and 20ktpa electrolyzer plant (including supporting power transmission and transformation facilities) was coordinated in a unified project timeline to ensure infrastructure sharing and expedite development. The project was prioritized under China's "dual–carbon" policy and secured rapid permitting.

In addition, all PV modules, electrolyzers, storage tanks, and pipeline components were domestically manufactured which eliminated the need for complex international logistics and import lead times.

In addition, Sinopec leverages a full integration of the value chain to offtake 100% of capacity to downstream Sinopec owned Tahe Refining & Chemical plant to replace the existing natural gas and coking gas used. Onsite 270,000Nm³ hydrogen storage tank and transmission pipeline to Tahe Refining & Chemical with 28,000Nm³/per hour capacity enables seamless transport.

Xinjiang Kuqa Green Hydrogen Pilot Project | Hydrogen storage tanks at Sinopec's Kuqa green hydrogen project| image sourced via public press releases

Source: Hydrogen Council & McKinsey Project & Investment Tracker, as of July 2025; project details confirmed in direct collaboration with Hydrogen Council member companies involved.

Appendix

Air Liquide and Siemens Energy gigawatt scale electrolyzer factory in Berlin | images provided by Siemens Energy

Exhibit contents

Glossary of key terms (1/2)

Term	Definition
Captive offtake	Hydrogen is used for an existing purpose (e.g., existing refinery) or it is inferred that there is a captive offtake from the same parent company (e.g., a company is building refueling stations as a part of the project).
CfD	Contract for Difference scheme in Japan that compensates the difference between the reference and replacement energy cost.
CHPS	Clean Hydrogen Portfolio Standard in South Korea that calls for clean hydrogen or ammonia–based power procurement.
Clean hydrogen	Combined term referring collectively to hydrogen derived from either renewable or low–carbon pathways.
Distribution/ infrastructure investment	Distribution/infrastructure relates to storage and transport activities, including certain derivative production (e.g., ammonification)–in cases where a single project produces hydrogen that is then converted into a derivative, the investment for hydrogen production (e.g., electrolysis, methane reformation) is allocated to "production" and the investment for derivative production is allocated to "distribution/infrastructure".
End–use investment	End–use corresponds to the ultimate application of hydrogen, for example, the manufacturing of fuel cell electric vehicles (FCEV) or the construction of HRS.
ETS/CBAM	Emissions Trading Scheme/Carbon Border Adjustment Mechanism in the EU market that aims to place a price on the value of carbon within a product (i.e., ammonia takes into account the emissions from the production whether it is imported or produced domestically.
IRA	Inflation Reduction Act in the USA that created the 45V clean hydrogen production tax credit along with the expanded 45Q credit for carbon sequestration.
Low–carbon hydrogen	Hydrogen produced with low–emissions technologies with significantly lower greenhouse gas emissions impact than conventional production pathways, based on robust life–cycle analysis–based methodologies for greenhouse gas (GHG) emissions assessment, including i) hydrogen produced using natural gas feedstock with steam methane reforming (SMR) or autothermal reforming (ATR) coupled with carbon capture and storage (CCS); ii) hydrogen produced through pyrolysis of natural gas into hydrogen and solid carbon; iii) hydrogen produced through. gasification of coal with CCS; iv) hydrogen produced through electrolysis using electricity of non–renewable origin as feedstock.
Production investment	Production corresponds to the production of hydrogen, such as electrolysis or autothermal reforming (ATR).
Project	A hydrogen project is a defined initiative to plan, finance, build, and operate infrastructure or facilities for the production, distribution, storage, or use of hydrogen. A project represents the physical deployment of assets and activities. Announcements of a government or industry alliance to develop an aggregation of projects is tracked based on the individual projects while the overarching initiative is considered a deployment and not analyzed in this report.

Glossary of key terms (2/2)

Term	Definition
REDIII	Renewable Energy Directive III is the third piece of legislation aimed at promoting renewables within the EU. Among other factors, its sets volume targets for RFNBO based hydrogen and hydrogen derivatives (42.5% by 2030, 60% by 2035).
Renewable hydrogen	Electrolytic–derived clean hydrogen produced from renewable energy.
RFNBO	Renewable Fuel of Non–Biological Origin is the definition for renewable hydrogen or hydrogen derivative in the EU market. Traditional low–carbon hydrogen does not count as RNFBO.
Sales & purchase agreement	A new binding offtake agreement for hydrogen (or the hydrogen derivative produced by the plant) has been signed between two separate companies (i.e., not a subsidiary).
Unabated hydrogen	Hydrogen produced from unabated fossil fuels.

Select methodology details

Hydrogen Council & McKinsey Project & Investment Tracker	The underlying database provides an overview of all large–scale hydrogen projects (excluding renewable hydrogen projects below 1 MW) that have been announced globally. It covers projects along the entire value chain, including: Hydrogen production, transport, distribution and retail, and end–use projects. Manufacturing projects are not included. The dataset only contains public information that was enriched by internal estimations where public data was not available and has been reviewed by Hydrogen Council members. Cancellation announcements and reasons are tracked via public press releases.
McKinsey Hydrogen Insights Clean Hydrogen Offtake Tracker	The underlying database captures information on confirmed or indicated offtake for hydrogen projects that have been announced globally. It covers the type and structure of offtake agreements, the companies involved and geographic regions, share of offtake, and distribution of volumes across end–use sectors. The dataset only contains public information that was enriched by internal estimations where public data was not available and has been reviewed by Hydrogen Council members.
Feasible capacity estimation	To quantify feasible 2030 capacity, a two step methodology is applied considering both (1) project timelines and (2) anticipated attrition rates. (1) For projects with CODs that may now be unrealistic based on typical project development timelines, a combination of announced COD, project status, pathway, and size were analyzed to determine a feasible COD for each project. A base delay is added to projects in all stages. Pre–FID projects receive 1–year base delay if they are low–carbon projects, and a 2–year base delay if they are renewable. Committed (FID+) projects receive a 1–year delay for all pathways. Then an additional delay associated with the scale of the project size is added to pre–FID projects with simple rounding applied to map the output in hydrogen equivalence to years (e.g., a project of ~200 ktpa will receive an additional 2–year scale delay). Finally, minimum thresholds are set as well so that projects still in the announced or feasibility stage, but with a COD prior to 2025, have a minimum adjusted COD of 2029 for announced projects and 2027 for feasibility projects. (2) Estimated success rates were then applied to the total delay–adjusted 2030 capacity to account for potential attrition by project stage: Announced 0–10%, Feasibility 10–40%, FEED 40–70%, FID 95–100%, Under construction 99–100%.
Difference between estimated value–in–use and supply cost	Value–in–use and landed supply cost were calculated for each sub–segment of potential hydrogen demand. Values for each segment account for imported vs. domestic production dynamics, the likely pathway (renewable, low–carbon), the molecule of use (e.g., hydrogen in refining vs. synthetic kerosene in aviation), and firmness requirements, as well as segment–specific policy impact. The difference between value–in–use and supply cost determines whether there could be a positive business case for that end–use segment by 2030. After subtracting supply costs from value–in–use for each segment, three segments of demand emerge, defined by their relative cost competitiveness. The first segment, ~8 Mt p.a. of demand, appears to carry a positive business case. About 13 Mt p.a. of demand make up the next segment where the cost gap comes within ~0.5 $/kg H_2e of breaking even for clean hydrogen vs. conventional alternatives. The third segment retains a cost gap of between 0.5–5.1 $/kg H_2e, even after accounting for the impact of existing supply–side and demand–side policy measures. A positive business case (i.e., a value above the x–axis) does not denote supplier or consumer margin per se but instead is an indication that switching to clean hydrogen could be economically viable by 2030, assuming an unconstrained clean supply market from known production centers.
Project case study selection	Potential case studies were identified either through nominations directly from Hydrogen Council members or via interview discussions with leaders across the value chain. From this pool, a representative sample of the most mature projects were selected to showcase regions across the globe, diverse production pathways and hydrogen derivatives, a range of end–offtake sectors, as well as both infrastructure and ecosystem projects.

Hydrogen Council

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