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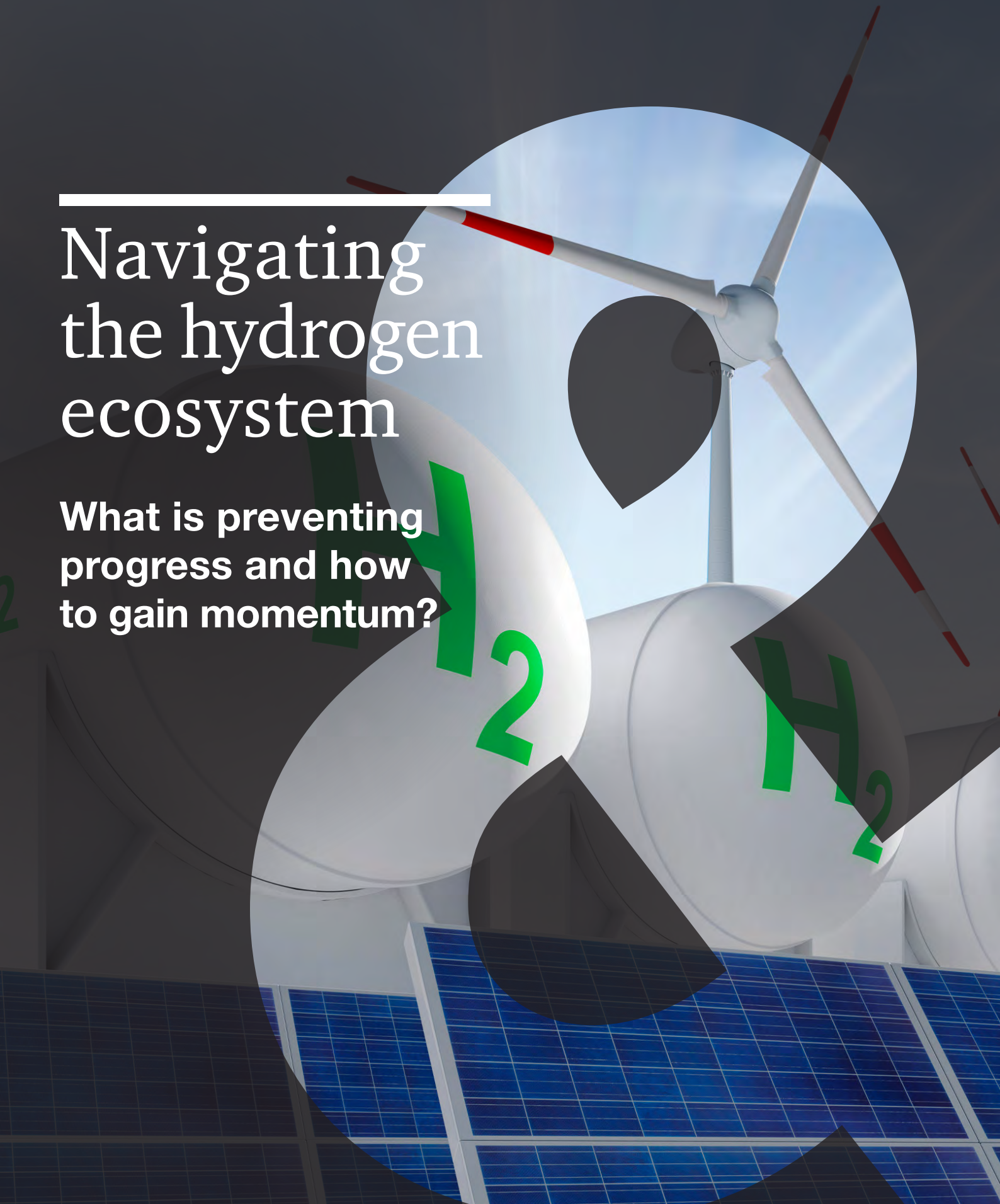
Navigating the hydrogen ecosystem

What is preventing progress and how to gain momentum?



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We would like to thank RWE and Hynamics for their guest posts detailing their view on the rampup of hydrogen.

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EXECUTIVE SUMMARY

Clean hydrogen is regarded worldwide as the solution to decarbonizing some of the most hard-to-abate sectors, including steel production, the chemical industry and long-haul truck transportation, as well as a feedstock for PtL fuels for aviation and shipping. For this reason, hydrogen has been given a significant role in national and regional strategies to limit climate change. These include the EU's target of using 20 million tons of clean hydrogen (which includes low-carbon as well as renewable hydrogen) by 2030, as part of its goal to reduce greenhouse gas emissions (GHG) by 55% by the same year.[1] The US estimates replacing fossil fuels with clean hydrogen could reduce overall emissions by 10% by 2050.[2]

840 GW

capacity of clean hydrogen projects have been announced.

Despite these ambitions, globally the market remains in its very early stages and progress has been – with a few exceptions – quite slow. This is highlighted by the significant gap between the capacity of the clean hydrogen projects that have been announced, which stands at 840 gigawatts (GW), and the capacity of projects which have reached the final investment decision (FID) or construction phase, which is just 15 GW or 1.8%.

Only 15 GW

capacity of clean hydrogen projects have reached the final investment decision (FID) or construction phase.

Looking at Europe for example, where the greatest number of hydrogen projects has been announced, our research for this report[3] shows that:

- Around 120 GW of electrolyzer capacity will be needed to reach the goal of producing 10 million tons of renewable hydrogen in the EU by 2030.[4]
- To meet that target, around 20 GW of capacity would need to be added each year for the next six years. However, for the past two years, only 1 GW per year has reached FID – which still does not mean that it has been built. The usual time to market for electrolyzers is between three and five years.
- Almost all the announced clean hydrogen projects are still in a concept or demo phase – only projects of around 3 GW of electrolyzer capacity had reached the FID or construction phase as of 2023.

Worldwide, the main obstacles are five-fold: firstly, the high cost of clean hydrogen means there are not enough offtakers, with the willingness or ability to pay. That in turn means producers cannot secure the investment they need to start production, because there is no clear, profitable business case. The second barrier is closely related – initial investment costs remain very high making it hard to build the types of large-scale projects that will bring down the cost for offtakers. Higher interest rates and inflation in building materials have increased investment costs further in recent years, making formerly profitable projects now unprofitable.[5]

Thirdly, regulators have struggled to set big enough incentives to support progress. This is also a challenge in Europe, where payouts for Important Projects of Common European Interest (IPCEIs) on hydrogen were delayed by two years or more, and contracts for difference have only recently come into play.

The fourth challenge is the lack of renewable energy supply to produce renewable hydrogen (also known as renewable hydrogen) through electrolysis. With the additional challenge of producing hydrogen not just at times when renewable electricity is produced, but as a baseload or scheduled product as required by many industrial customers.

Finally, the lack of infrastructure to store and transport clean hydrogen to offtakers is a significant barrier. Transport of large volumes depends on pipelines, ships and terminals, and scheduled delivery based on fluctuating production requires storage to level delivery.

In this report, we offer detailed analyses of the hydrogen market in seven regions: Europe, Australia, North Africa, China, the Middle East, the United States and Latin America. For each region we assess the progress made to date on clean hydrogen projects, and what needs to happen to increase the pace of development.

We then set out how each of the ecosystem players – producers, offtakers, distributors and other intermediaries, plus governments and regulators – can play their part in a consistent joint effort to build a well-functioning hydrogen market that will contribute to decarbonizing the global economy at the speed required.

120 GW of electrolyzer capacity is needed to reach the goal of producing 10 Mt of renewable hydrogen in the EU by 2030

Global hydrogen market dynamics

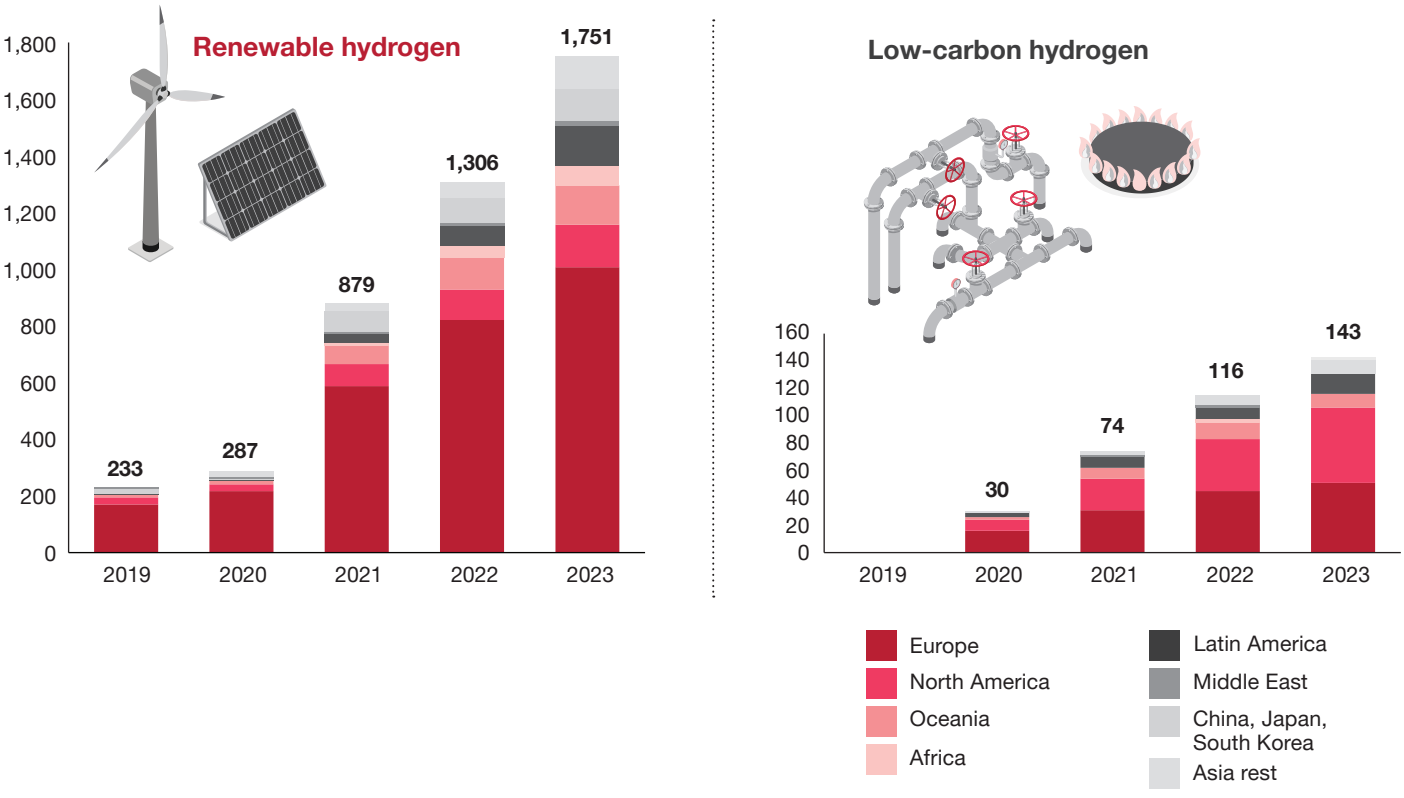
The number of low-carbon and renewable hydrogen projects announced worldwide is rising steadily, with more than 1,500 new production projects announced between 2020 and 2023.

When it comes to renewable hydrogen, produced using renewable electricity to split water into oxygen and hydrogen, Europe continues to dominate. More than half of the world's known renewable hydrogen projects are located there (*see Exhibit 1*).

Looking at low-carbon hydrogen – produced using methods including carbon capture and storage (CCS) technology to reduce emissions created in the process of producing hydrogen from natural gas – North America took the lead by number of projects announced in 2023 (*see Exhibit 1*).

EXHIBIT 1

Number and location of renewable and low-carbon hydrogen projects



Source: Strategy& analysis based on IEA (2023)

The number of low-carbon hydrogen projects is still far smaller than the number of renewable hydrogen announcements, but low-carbon hydrogen will play a crucial role especially in the early stages of hydrogen market development in providing a reliable baseload delivery of energy. This is particularly important during periods of high demand or when renewable energy sources are not readily available. Another important advantage of low-carbon hydrogen is that it is currently cheaper than renewable hydrogen.

Looking at renewable hydrogen capacity rather than numbers of projects alone, Europe leads with the largest announced capacity by 2023 (205 GW) followed by Africa (169 GW) and Oceania (130 GW) (*see Exhibit 2, next page*). However, it is important to note that 'announced' is not the same as built, and risks remain that these projects will never be completed.

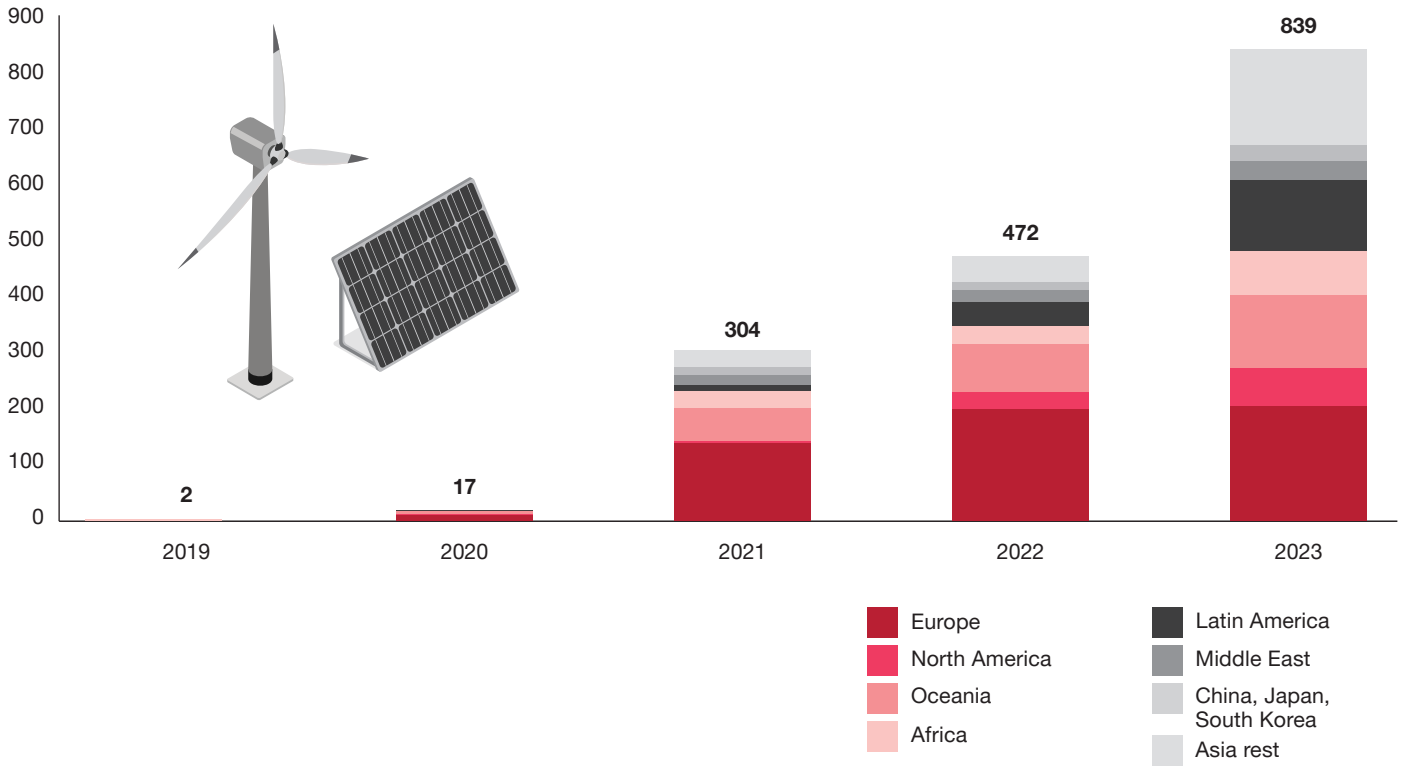
> "The rising number of announced low-carbon and renewable hydrogen projects globally highlights the potential for clean energy, but the slow progress in turning these announcements into reality emphasizes the urgent need to secure long-term offtake agreements to improve bankability of production projects."
>
> **Dirk Niemeier, PwC Strategy& Germany, Renewable Hydrogen and Alternative Fuels Leader**

In Europe, renewable hydrogen projects with 200 GW of electrolyzer capacity have been announced, and if they are built, the region would be able to produce more than the 10 Mt of clean hydrogen it aims to achieve by 2030. 200 GW of electrolyzer capacity could generate around 560 terawatt hours (TWh) of renewable hydrogen, the equivalent of 17 Mt.[6]

However, as described above, turning announced capacity into reality has been a slow process in Europe to date. Only 3 GW of electrolyzer projects had reached FID or construction phase by the end of 2023 (out of 200 GW announced in total), an increase of 2 GW since 2021. There is still some way to go to reach the 20 GW per year from projects that are up and running that will be required to reach the 2030 goal.

EXHIBIT 2

Announced capacity and location capacity and location of renewable hydrogen projects (in GW)



Source: Strategy& analysis based on IEA (2023)

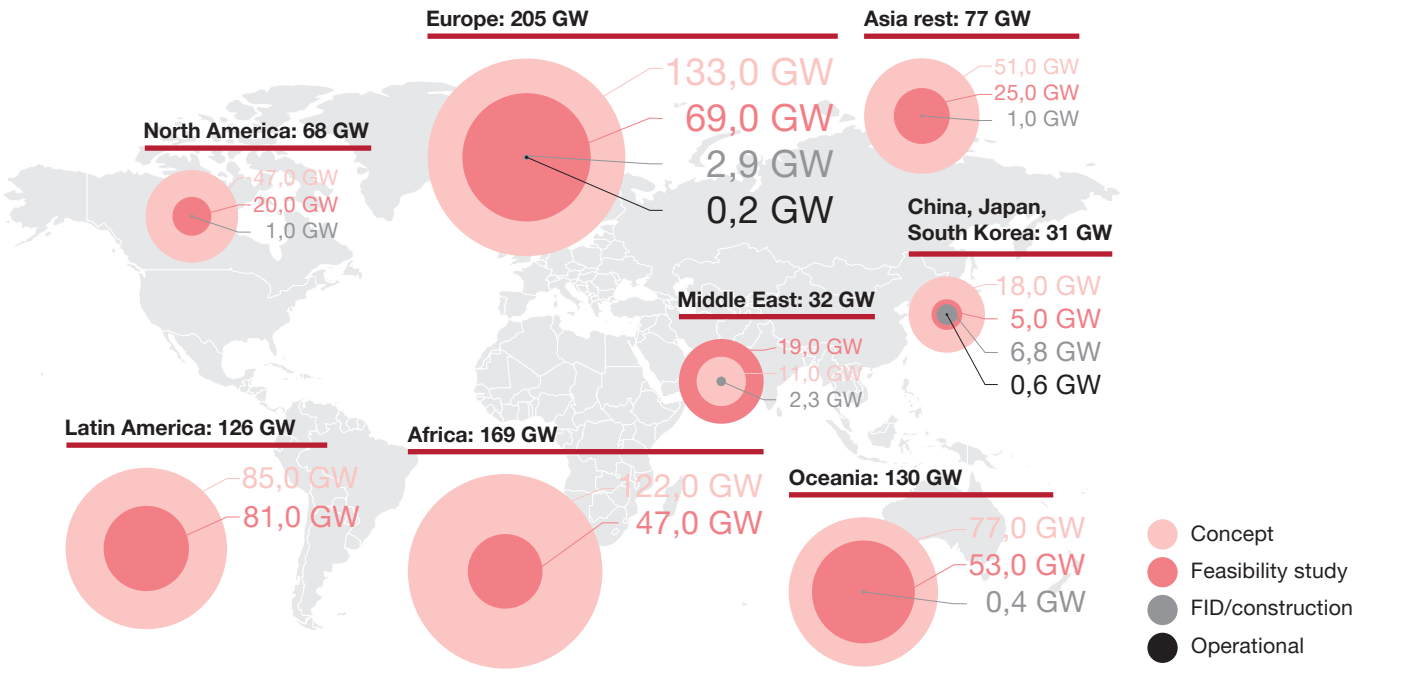
By comparison, in China, Japan and South Korea, close to 7 GW of electrolyzer capacity reached FID or construction phase by 2023 (*see Exhibit 3*).

Looking ahead, around 100 million tons of clean hydrogen will be needed globally by 2030 to meet the Paris climate targets. By 2050, the volume needed to decarbonize the global economy will be 500 million tons, which would likely still include some low-carbon hydrogen because of its role in providing a reliable baseload, as well as the lower cost.

Yet currently only around 14 GW of electrolyzer capacity is operational globally, which is enough to produce around 1 million tons of renewable hydrogen (given sufficient renewable power). To increase this by a hundred times by 2030, and 500 times by 2050, there is no time to lose in building up production capacity worldwide. In the following chapters, we will look at how this can be made possible, including through policy and funding initiatives to kickstart change, maybe in a similar way as Germany's Renewable Energy Sources Act (EEG) did for renewables in the 2000s.

EXHIBIT 3

Project status for renewable hydrogen projects



Source: Strategy& analysis based on IEA (2023)

SECTION 2

Region-by-region analysis – Europe

EXHIBIT 4

Overview of clean hydrogen projects in Europe

Ambition

- Europe targets for 10 Mt of domestically produced and 10 Mt of imported renewable hydrogen by 2030, becoming a major import hub[1]
- The continent aims to become first climate neutral one by 2050

Conditions

- 44% share of renewables in electricity mix in 2023[2]
- Only limited natural gas deposits for low-carbon hydrogen production

Governmental support

- Both the EU and member states are providing significant funding to promote the ramp-up of the hydrogen economy. IPCEIs have already been selected for funding totalling €5.4 billion in 2021 and a further €6.9 billion in 2024 with a focus on hydrogen infrastructure[3]
- Renewable hydrogen auction caps price at €4.50/kg, subsidizing projects starting in 5 years[4]

Infrastructure

- RePowerEU plan envisages five large-scale pipeline corridors that connect local supply and demand in Europe in the mid- and long-term
- Import Terminals for Ammonia, for example, in Rotterdam and Wilhelmshaven
- Germany plans to establish a hydrogen infrastructure to connect key sites, including industrial centers, storages, power plants, and import corridors to connect producers and industrial offtakers by 2030

Project development

- Total renewable hydrogen projects: 1,007 with 205 GW capacity
- Total low-carbon hydrogen projects: 51[5]

Note: Illustration based on IEA interactive project map, showing projects with following status: concept, demonstration, feasibility study, FID/ under construction and operational (2023)
Sources: 1 European Commission "Hydrogen Systems" (2023), 2 Solarpower Europe (2023), 3 European Hydrogen Observatory (2023), 4 European Commission "Hydrogen Bank Auction" (2023), 5 IEA "data base" (2023)

Creating a hydrogen economy is a key element of the European Union's legally binding commitment to be the first climate-neutral continent by 2050. To get there, the EU has set a target of producing 10 Mt of clean hydrogen within the EU by 2030, and to import the same volume by that date.[7]

While the region leads the world by the number of hydrogen projects announced, as the figures above make clear (*see Section 1, Global hydrogen market dynamics*) there is a significant lack of progress on turning announcements into production.

So what needs to change?

More financial support to bring down costs

Developing renewable hydrogen is very expensive and relies on large-scale adoption projects, initially coming from hard-to-abate industrial sectors. To compare, the price of renewable hydrogen in the EU is between €200 – €250 per MWh and low-carbon hydrogen costs between €100 – €150 per MWh, while natural gas costs between €25 – €40 per MWh (plus €15 – €20 per MWh for the carbon emissions trading system ETS).[8]

Potential offtakers are clear, but the substantial funding required to bridge the cost gap between renewable hydrogen and fossil fuels is only slowly being ramped up. More financial support is required to reduce the risk for industrial offtakers. One current example is support for the transition to more sustainable steel production in the EU, particularly in Germany. All steelmakers received significant funding (around €10 billion in total across the sector)[9] to invest in low-carbon steel plants, and one of the companies has already started to buy clean hydrogen for their direct reduced iron (DRI) plants. Others are setting up local electrolyzer projects due to a lack of grid connection and are expected to start using clean hydrogen in the near future.

This change is happening for a number of reasons: there will be OPEX-funding for parts of the cost gap, some customers are expected to accept the higher cost of the lower-carbon steel, and the CAPEX funding the steelmakers receive requires them to gradually shift from using natural gas to hydrogen. However, the major driver is the partial funding of the cost gap, either via Germany's H2Global government-backed import auctions, direct funding or the new carbon contracts for difference (Klimaschutzverträge).

Greater acceptance of low-carbon ('blue') hydrogen over renewable ('green') hydrogen[10]

Recently declined natural gas prices make low-carbon hydrogen the more cost-effective option compared to renewable hydrogen, with a levelized cost that is around 50 to 60% lower for projects financed in 2023.

Germany's revised national hydrogen strategy also signals a softer stance on low-carbon hydrogen, shifting from its previous preference for hydrogen derived from renewable energy-powered electrolysis.

This shift creates opportunities for low-carbon hydrogen producers seeking to produce in or export to Germany, benefiting from demand-side incentives like climate protection contracts, which provide payouts to offtakers of renewable and low-carbon hydrogen based on the EU ETS price.

Building the infrastructure between project locations and potential transport corridors

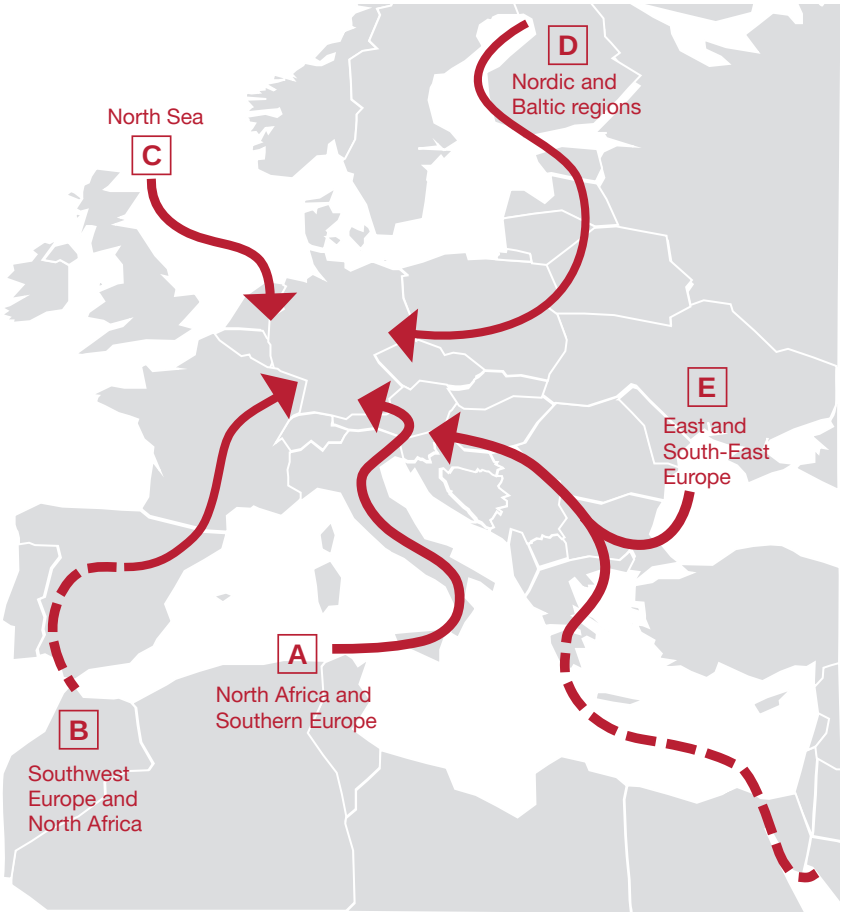
To meet EU hydrogen production and import goals, better coordination is needed over the construction of pipelines to move the fuel between the countries where clean hydrogen will be produced (for example, those with lower renewable energy costs such as Spain) and where it will be used.

The European Hydrogen Backbone (EHB) initiative is a comprehensive infrastructure pipeline plan designed to establish 5 pipeline corridors within Europe (*see Exhibit 5*), before expanding and connecting Europe with neighboring regions with export potential:

EXHIBIT 5

EHB supply corridors

There are well coordinated parts, for example from Spain or the Netherlands to central and northern Europe. However, there are currently also corridors planned where the pipeline connectivity and production project planning seem to be uncoordinated, for example from North Africa to southern and central Europe (*see North Africa analysis, page 16*). Beyond pipelines, Europe is committed to building up ammonia terminals and cracking infrastructure to enable delivery of hydrogen by sea, including from the Middle East. Currently, ammonia appears to be the most likely way for hydrogen to be transported via ships.



Source: Strategy& analysis based on European Hydrogen Backbone (2022)

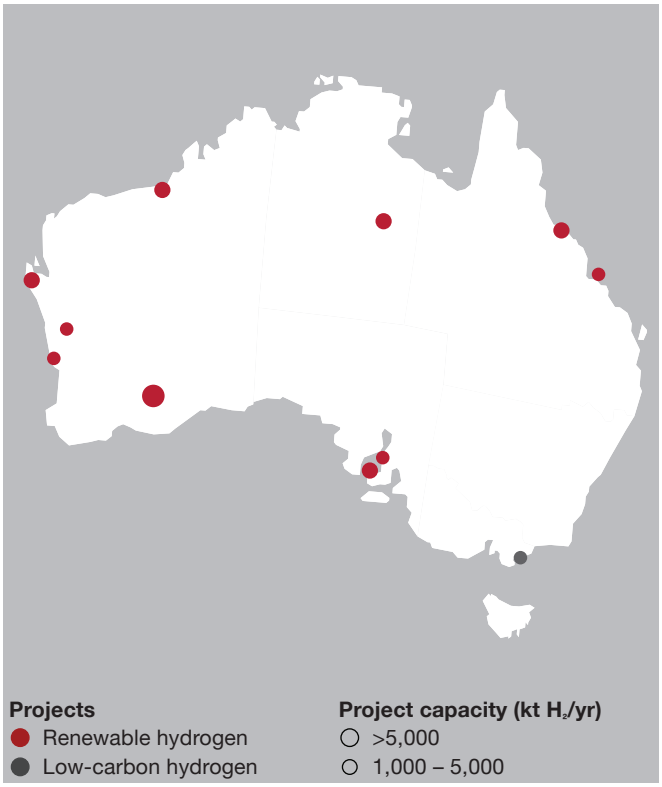
Europe in summary

The EU has pledged to transform into the world's first climate-neutral continent by 2050. To achieve this goal, the region has ambitious plans for integrating clean hydrogen into its energy transition and is already taking significant strides in the right direction. Now it is crucial to turn announced projects into reality.

Region-by-region analysis – Australia

EXHIBIT 6

Overview of clean hydrogen projects in Australia



Ambition

- Australia initially targets exports to Asia, EU and US, followed by domestic offtake
- No production targets are published yet; however the government aims to become a global player by 2030

Conditions

- 37% share of renewables in electricity mix in 2023, aiming for 82% by 2030[1]
- Ideal conditions for renewable power generation, no significant natural gas deposits for low-carbon hydrogen production

Governmental support

- AUD $2 billion (€1.2 billion) investment in the new Hydrogen Headstart Program to support large-scale renewable hydrogen projects (>50 MW, targeting 1 GW in total) by 2030[2]
- National hydrogen strategy targets "Hydrogen under 2", producing hydrogen at a cost below AUD $2/kg (€1.2/kg)[3]

Infrastructure

- Comprehensive hydrogen project infrastructure plans across coastal areas
- Focus on hydrogen production hubs, limiting the need for long distance hydrogen pipelines

Project development

- Total renewable hydrogen projects: 139 with 130 GW capacity in Oceania
- Total low-carbon hydrogen projects: 10 in Oceania[4]

Note: Illustration based on IEA interactive project map, showing projects with following status: concept, demonstration, feasibility study, FID/ under construction and operational (2023)
Sources: 1 Renew Economy (2024), 2 Australian Government (2023), 3 Australian Embassy Germany (2023), 4 IEA "data base" (2023)

In 2023, Australia updated its national hydrogen strategy, stressing the country's potential to become a leading exporter of renewable hydrogen thanks to its large solar and wind energy resources. However, progress in building production and creating the necessary infrastructure to allow exports has been very limited to date. The clean energy sector went through a "lost decade" under the previous coalition government, which prioritized the country's coal producers and aging coal-fired power stations over renewables.

Australia's hydrogen strategy does not set out production targets, but the IEA estimates the country could produce 6 million tons of "low emissions" hydrogen by 2030. As part of the national hydrogen strategy, Australia has defined a set of "hydrogen hubs"[11] and corresponding renewable energy zones[12] in order to focus scale-up and limit required infrastructure. The government has set up a capacity investment scheme[13] to target 32 GW of additional renewable capacity until 2030 and also announced plans to invest AUD $2 billion (€1.2 billion) in large-scale renewable hydrogen projects under the Hydrogen Headstart program. Successful projects will be able to apply for funding credits to cover the gap between the cost of producing renewable hydrogen and the market price, with the aim of allowing producers to sell the fuel at

lower cost, the Department of Climate Change, Energy, the Environment and Water has said. Six projects with a total capacity of more than 3.5 GW have been shortlisted for funding.[14] However, such funding is not yet available for small-scale projects.

What else needs to change for Australia to meet its hydrogen market potential?

Attracting offtakers for hydrogen exports

It is particularly hard for Australian producers to compete with fossil fuels on price in their home market because of a limited carbon pricing and hydrogen offtake support scheme.[15] As a result, the hydrogen ecosystem is expected to be established by export projects supplying international offtakers with subsequent development of domestic markets on the back of this infrastructure built within the hydrogen hubs.

The government has partnerships in place with countries including Germany (e.g. €400 million H2Global subsidy auction), Japan and South Korea, and foreign investment in the renewable hydrogen market is increasing. The pipeline of announced projects increased from $230 billion (€140 billion) in 2021 to AUD $300 billion (€180 billion) in 2022, including a planned $40 billion (€24 billion) investment by South Korea's POSCO.

Building the required infrastructure

Infrastructure investment is one of the key obstacles for the clean hydrogen industry globally. In Australia, meeting the market's potential will require building large-scale electrolyzers with enough water and water pipelines to supply them, increased renewable electricity production and transmission capacity, CCS for low-carbon hydrogen, and hydrogen pipelines, storage and port facilities for exports.

These are all costly and long-term projects – the Australian Hydrogen Council estimates it could take as long as eight years to go from initial investigation to a final investment decision on very large projects, for example. Australia is also disproportionately affected by supply chain issues because of its current lack of local manufacturing capabilities for electrolyzers.

To give real impetus to the necessary level of infrastructure work, extending Australia's renewable energy targets and setting clear dates for closing coal power plants would give investors more transparency over the future energy landscape. In addition, strategic partnerships with electrolyzer manufacturers from countries such as the US and Europe will also help Australian hydrogen producers at a time when the equipment is in short supply around the world. Australian mining and green energy company Fortescue has an electrolyzer factory in Queensland but will still ship electrolyzers with 550 MW of capacity from US supplier Plug Power for a hydrogen project in that state, for example. Beyond that, emergence of new technology manufacturers like Hazer Group (low emission hydrogen and graphite production method), Hysata (Capillary-fed Electrolysis), H24U (High temperature waste gasification to hydrogen) or Energys (fuel cells for marine sector) can be observed in Australia.

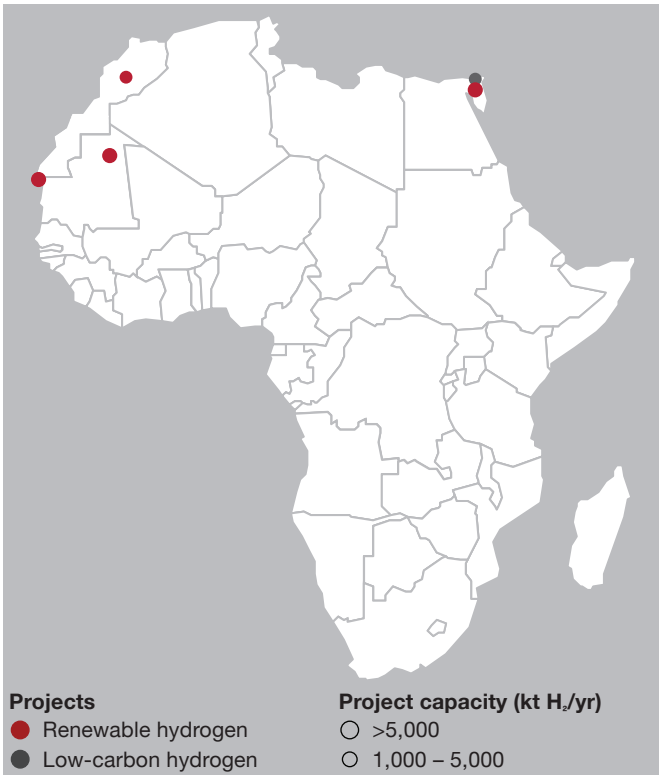
Australia in summary

To unlock its clean hydrogen potential, Australia must harness its abundant, high quality renewable energy sources by getting large export projects off the ground and establishing domestic business cases on the back of low-cost large-scale export production. Ultimate challenge will be creating industries out of its renewable energy and critical mineral prospectivity for diversifying its economy to ensure long-term success.

Region-by-region analysis – North Africa

EXHIBIT 7

Overview of clean hydrogen projects in North Africa



Ambition

- North African countries target hydrogen export, in particular, to Europe
- Hydrogen targets differ across countries, production potential could reach 20-40Mt by 2050[1]

Conditions

- Renewable energy share varies, relatively low renewable energy share, for example, Morocco 38%, Egypt 20%, Tunisia 3%[2]
- Optimal renewable resource potential, predominantly solar and wind; no significant natural gas deposits for low-carbon hydrogen production

Governmental support

- Different levels of governmental stability and incentivization in some cases limit potential to attract foreign investors
- Foreign investments and support for hydrogen projects required, for example €150 billion EU-Africa Global Gateway Investment Package for green transformation[3]

Infrastructure

- Infrastructure gaps, include insufficient pipeline networks and export terminals, impeding potential exports via Corridor A and Corridor B targeting Europe

Project development

- Total renewable hydrogen projects: 71 with 169 GW capacity in Africa
- Total low-carbon hydrogen projects: 0 in Africa[4]

Note: Illustration based on IEA interactive project map, showing projects with following status: concept, demonstration, feasibility study, FID/ under construction and operational (2023)
Sources: 1 UNFCCC (2022), 2 US Trade Government (2022), 3 European Commission (2023), 4 IEA "data base" (2023)

North Africa's climate and proximity to Europe give the region the potential to play an important role in the global hydrogen market. Reliably sunny weather means solar panels in North Africa generate up to three times more energy than those in Europe and there is also more space for them than in densely populated Europe. There is the potential to use existing ports and partly existing pipelines, as well as building new ones, to transport renewable hydrogen directly to EU countries that will rely on imports to meet the region's ambitious decarbonization goals (*See Corridor A on map in Europe analysis on page 13*). Germany and Italy, for example, have jointly committed to advancing the construction of a pipeline across the Alps, as part of the creation of a corridor to import renewable hydrogen from North Africa to Germany.

Foreign investment, supported by the EU, will be essential to build up production and supply infrastructure, and North Africa will rely on export markets because the high cost of clean hydrogen could cause difficulties in finding domestic offtakers. However, the degree of political instability in some countries puts investment in doubt. Currently, a number of companies have a position that they will not invest in hydrogen projects in North Africa without governmental guarantees to increase the security of their potential investments.

Here, we look at the market potential of four countries: Algeria and Tunisia, Morocco and Egypt.

Algeria and Tunisia

As shown in the Europe analysis above, Corridor A could transport large quantities of cost-competitive renewable hydrogen from Tunisia and Algeria through Italy to central Europe, leveraging the existing gas infrastructure of the Transmed pipeline. The corridor could be complete in the early 2030's, made up of 11,000km of large-scale hydrogen pipelines, of which around 60% would be repurposed and 40% new.[16] It would also be possible to leverage two existing Algerian liquified natural gas (LNG) export terminals: Arzew/Bethouia and Skikda.

Algeria had no hydrogen projects in operation in 2023, but German development bank KfW will finance a 50 MW renewable hydrogen pilot project, and the German and Algerian governments announced in February 2024 they would set up a joint hydrogen taskforce.[17] Tunisia also had no hydrogen projects as of last year and would be highly dependent on working in partnership with Algeria to leverage the existing gas pipeline.

But while Algeria has no renewable hydrogen strategy of its own, the country does have low-cost domestic natural gas and experience in CCS technology linked to its gas fields. That could prompt an interest in exporting low-carbon hydrogen if the business case was developed and the right infrastructure to transport it existed.

However, projects are not yet ramping up, despite strong interest from abroad. Both Algeria and Tunisia pose a risk as the starting point of the export corridor as the region is marked by conflicts. International companies operating in Algeria have also found that laws and regulations are applied inconsistently, according to the US Department of State, raising the commercial risk for foreign investors in hydrogen projects.

Morocco

Morocco has been a longstanding partner of the EU and has goals to be an exporter of renewable hydrogen to the region. Morocco's energy potential in renewable energies is remarkable and competitive, particularly wind and solar energy (more than 3,000 hours of sunshine per year and a significant offshore and onshore wind field with regions exceeding 10 meters per second of average annual wind speed),[18] which enable high-performing solar and wind power plants and offer significant potential for green electricity generation. Morocco has implemented the Green H_2 National Strategy in order to satisfy local demand and optimize the use of national potential, particularly through export and also create an economic and industrial sector around green molecules, particularly hydrogen ammonia and methanol. The strategy also included a timeline from 2020 to 2050 that gives a forecast of different renewable hydrogen usage and application.

The timeline helped identify the short, medium and long-term lines of work and priorities:

- The short-term applications (2020 – 2030) are exporting H_2 products, and local usage for national industry, especially phosphates, and the main priority is to explore natural hydrogen deposits.
- The medium-term applications and priorities (2030 – 2040) are developing hydrogen projects, using hydrogen as an energy storage vector.
- The long-term applications (2040 – 2050) are exporting more and better ammonia, hydrogen and green synthetic fuels for export and the domestic usage of renewable hydrogen for different needs.

Egypt

There were 17 hydrogen projects in Egypt in 2023, 16 of which were in renewable hydrogen.[19] Egypt is pursuing a different approach to other countries in North Africa: not just production and export of hydrogen but production of low-carbon steel and chemicals or fuels. With the Nile and the Suez Canal, the country is close to shipbuilders and the international maritime industry as offtakers for those products.

Egypt would also be unable to compete as a hydrogen exporter with other countries in the region that are connected to the EU via pipelines. There is no pipeline connection expected, and the cost of liquifying hydrogen for shipping is too high. Instead, the country has potential to become an e-fuel producer, or to export ammonia or methanol, all made using hydrogen.

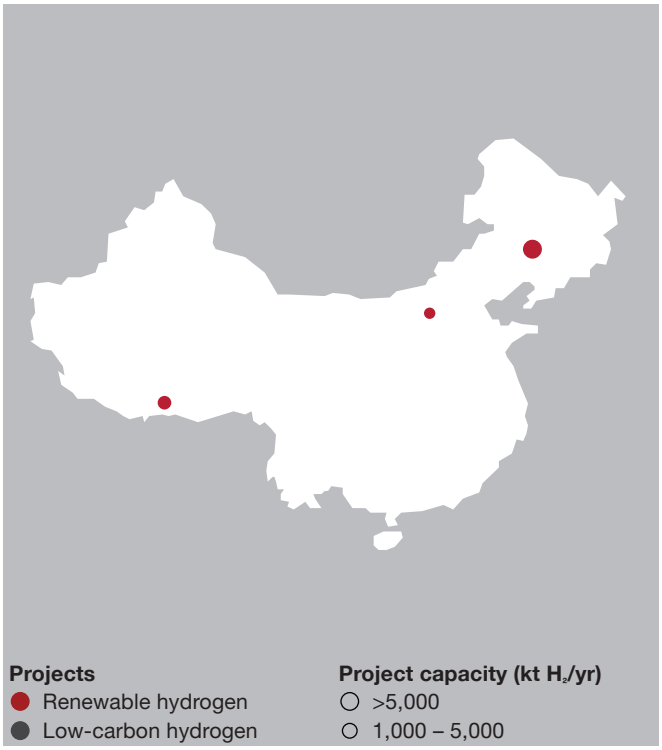
Egypt also presents a number of political, economic and environmental risks to potential hydrogen investors. These stem from its sovereign debt crisis, high inflation rates, and severe environmental degradation in places. In addition, important infrastructure is owned and operated by the military, which might be a barrier to investment for international agencies and private companies.

North Africa in summary

North Africa boasts optimal production conditions for clean hydrogen and benefits from its geographical proximity to European pipelines. Nevertheless, varying levels of governmental stability and incentives act as deterrents for companies considering investment, particularly without government-backed guarantees.

Region-by-region analysis – China

EXHIBIT 8
Overview of clean hydrogen projects in China



Ambition
- Predominantly for domestic use, aiming for self-sufficiency
- Development of hydrogen roadmap to reach 100 GW of electrolyzer capacity by 2030[1]

Conditions
- 51% share of renewables in electricity mix in 2023[2]
- Renewable hydrogen projects make up nearly 20% of the global capacity

Governmental support
- Significant governmental funding support, for example, China's State Power Investment Corp announces USD $5.85 billion (€5.5 billion) investment in northeast China to produce hydrogen fuel from wind power[3]

Infrastructure
- Significant expertise in electrolyzer engineering with intentions for export
- Developments in CCS offer the potential to retrofit existing facilities, transitioning hydrogen developed from coal operations to low-carbon hydrogen

Project development
- Total renewable hydrogen projects: 110 with 31 GW capacity in China, Japan and South Korea
- Total low-carbon hydrogen projects: 15 in China, Japan and South Korea[4]

Note: Illustration based on IEA interactive project map, showing projects with following status: concept, demonstration, feasibility study, FID/ under construction and operational (2023)
Sources: 1 World Economic Forum "China" (2023), 2 Reuters (2023), 3 Green Hydrogen News (2023), 4 IEA "data base" (2023)

China is already the world's largest hydrogen producer, using it to make ammonia, methanol and for refining. The country plans to increase its renewable hydrogen production from less than 1% of hydrogen produced to 15% by 2030, with the ambition of reaching 70% by 2050.[20] Government support for technology development and market creation is supporting the transition to renewable hydrogen on a large scale, as China seeks to bring down its emissions in line with its commitment to reach net zero by 2060.[21]

Significant investments in large-scale renewable hydrogen projects and electrolyzer technology are driving growth, with China's installed capacity expected to reach 1.2 GW[22] by the end of 2023, constituting 50% of the global capacity.[23] While the country plans to produce clean hydrogen for its domestic industries rather than for export, there will be export opportunities for its electrolyzer technology, as China works on efficiency advancements to achieve economies of scale in renewable hydrogen.

In short, China should not be underestimated as a clean hydrogen leader for the following reasons:

Government ambitions are backed up by funding

China's hydrogen plan for 2021 to 2035 recognizes the fuel as a major component of the country's future national energy supply and the transition to a net-zero economy. However, the plan only included the goal to produce 100,000 to 200,000 tons of renewable hydrogen annually by 2025 and to have about 50,000 hydrogen-fueled vehicles by the same year (a focus that is unique to China).[24] It is low-carbon hydrogen technologies, using CCS with fossil fuel-based hydrogen production, that are expected to play an important role in China's path to carbon neutrality.

In support of the country's ambitions, there has been a ramp-up in government investments. The number of renewable hydrogen projects already functioning, under construction, or pending approval for construction reached 57 in 2023. China's State Power Investment Corp (SPIC) announced a 42 billion yuan (€5.5 billion) investment plan[25] in northeast China, for example, to produce fuel derived from hydrogen produced by wind power.

Electrolyzer capacity, size and innovation is increasing

Electrolyzer project announcements are surging in China, with the country's installed capacity expected to triple to 3.3 GW this year, compared with 2023, and further rising to almost 5.4 GW in 2025. Project sizes are also rapidly increasing, with about 60% of announced projects in 2023 falling within the 100 to 500 MW capacity range. Larger-scale facilities ranging from 500 to 1,000 MW are planned for installation starting in 2025, with giga-scale (1,000 MW and greater) projects making up nearly global 20% of the capacity reaching final investment decision stage that year.[26]

Chinese companies also are making advances in electrolyzer technology: Peric Hydrogen Energy Technologies presented the largest single-unit hydrogen alkaline electrolyzer in December 2022 (around 9 MW), while Longi Hydrogen introduced a more efficient alkaline model in February 2023, consuming 4 kWh/Nm3 (equivalent to 44.5 kWh/kg hydrogen), surpassing the efficiency of most electrolyzer models on the market.[27]

Given China's vast domestic energy demand, the constraints on long-distance transport of hydrogen, and the sheer distance between the EU and China, the opportunities for establishing trade connections in hydrogen between the regions are limited. However, we believe opportunities for collaboration exist in R&D, standard-setting, trade in low-carbon hydrogen technology and equipment and joint projects in third countries, particularly in the field of exporting electrolyzers. Such projects would help accelerate the transition to renewable hydrogen in both regions.

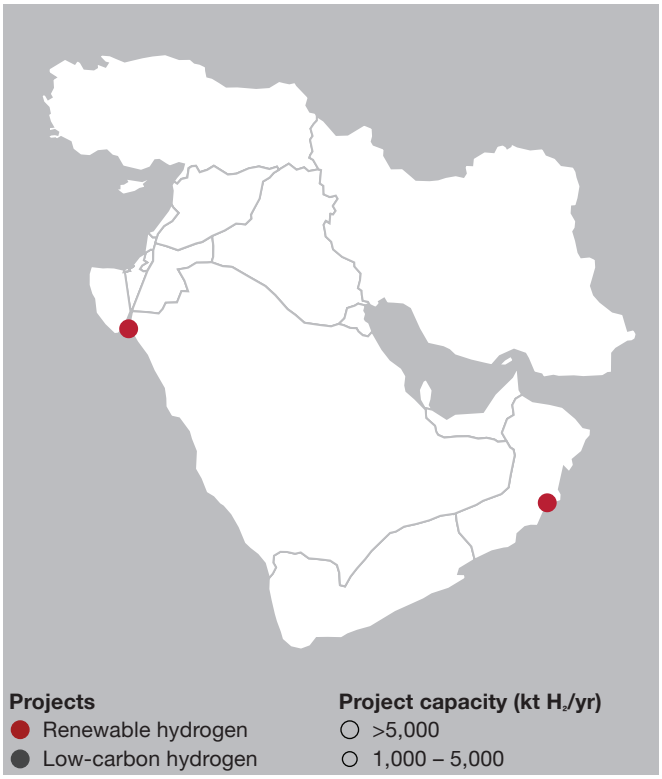
China in summary

China, positioned as a frontrunner in electrolyzer production, holds the capacity to export the renewable hydrogen technology. The nation ought to prioritize utilizing domestically produced hydrogen to tackle pollution challenges in densely populated regions.

Region-by-region analysis – Middle East

EXHIBIT 9

Overview of clean hydrogen projects in Middle East



Ambition

- Middle East targets exports to Asia, EU and the US
- Only Oman has set a target of producing 1 Mt of renewable hydrogen by 2030; Saudi Arabia, UAE, and Qatar have not disclosed any production targets yet[1]

Conditions

- 20% share of renewables in electricity mix in Middle East in 2023[2]
- Optimal renewable resource potential, predominantly solar energy; significant natural gas deposits for low-carbon hydrogen production

Governmental support

- Financial support frequently tied to public funds, for example Sovereign Wealth Funds, such as Mubadala (UAE), focusing on energy, infrastructure and aviation projects

Infrastructure

- Profound focus on shipping, lack of a pipeline system necessitates leveraging hydrogen corridors and constructing pipelines to access the EU, a pivotal market
- Currently focus on ammonia shipping, hydrogen export corridor via pipelines to Europe from Saudi Arabia and Oman currently under study (Corridor E)

Project development

- Total renewable hydrogen projects: 20 with 32 GW capacity (including NEOM, the largest renewable hydrogen plant globally)
- Total low-carbon hydrogen projects: 2[3]

Note: Illustration based on IEA interactive project map, showing projects with following status: concept, demonstration, feasibility study, FID/ under construction and operational (2023)
Sources: 1 World Economic Forum "Oman" (2023), 2 O&G Middle East (2023), 3 IEA "data base" (2023)

Oil and gas producing countries in the Middle East are putting in place national transformation initiatives such as Saudi Arabia's Vision 2030, to reduce their economic reliance on fossil fuels as worldwide demand shifts to renewable sources of energy in line with net zero commitments.[28] They have also set net zero targets for their own economies, although Saudi Arabia's is 2060, a decade later than the EU, as well as the UAE and Oman.

Saudi Arabia, the UAE and Oman have all put in place national hydrogen strategies with production goals for 2030. However currently, 20 renewable hydrogen projects with a total capacity of around 30 GW are known about, of which the majority are in the feasibility study stage.[29] Overall, renewable hydrogen production in the region is held back by a lack of offtakers, insufficient renewable energy sources and missing infrastructure for exporting the fuel.

Countries in the Middle East have the natural resources, financial strength and energy industry expertise to become leading innovators in renewable hydrogen production, with Saudi Arabia, the UAE and Oman likely closest to realizing renewable hydrogen exports.

Resources

The Middle East has a natural advantage in renewable energy, with abundant solar and wind energy available due to its desert climate. It stands to benefit from the falling cost of producing energy through these two sources. Countries in the Middle East increased renewable energy capacity by 57% to 19 GW between 2022 and 2023, according to Global Energy Monitor research, led by the UAE, with another 50% increase expected this year.[30] Saudi Arabia, for example, has set a target to generate half its electricity from renewables by 2030. In addition, countries in the Middle East have the required expertise as well as financial and organizational strength to build up large scale renewable energy projects.

Financial power

Thanks to their oil and gas wealth, fossil fuel-producing countries in the Middle East have the financial resources to develop large-scale hydrogen projects. Saudi Arabia has said it plans to invest about USD $266 billion (€248 billion) in clean energy[31] production, including the transport lines and distribution networks needed to produce and export low-carbon and renewable hydrogen. The USD $8.4 billion (€ 7.8 billion)[32] renewable hydrogen project, an ammonia production facility in the brand-new city of NEOM being built Saudi Arabia, could be a model for securing further project financing.

Energy industry expertise

NEOM's renewable hydrogen project, due to be completed in 2026,[33] is the world's largest hydrogen facility (4 GW) powered entirely by renewable energy. The project's leaders have been able to draw on Saudi Arabia's decades of expertise in large energy developments, and the network of partners operating in the country.

Leading oil companies in Saudi Arabia are also driving innovation in the field of ammonia cracking, a process for separating ammonia back into hydrogen and nitrogen at scale. The purpose is to overcome the difficulties of transporting hydrogen over long-distances, because ammonia can be transported cost-efficiently by ship and then used directly, for example as a green fertilizer or be cracked into hydrogen again close to the offtaker location or pipeline.

In the longer term, a pipeline network connection to the Middle East is possible as an extension to the south-eastern corridor of the EHB backbone plan, however in the shorter and medium-term, the fuel would need to be exported via ships.

Middle East in summary

The Middle East possesses significant financial and organizational resources to embark on large-scale clean hydrogen projects, enabling them to embrace the transition toward renewable energy and maintain their position as long-term energy exporters. However, to export hydrogen, they may need to rely on ammonia production and cracking processes, due to the absence of pipelines.

Region-by-region analysis – Latin America

EXHIBIT 10
Overview of clean hydrogen projects in Latin America

Ambition
- Latin America targets exports, particularly to the US, followed by EU
- Production targets are published in only a few countries, with total capacity of 80 GW by 2030[1]

Conditions
- 60% share of renewables in electricity mix in 2023, several countries above 90% (EU threshold)[2]
- Optimal renewable resource potential, predominantly hydropower

Governmental support
- Governments lack incentives for internal investors, only Brazil is considering introducing tax credits to incentivize renewable hydrogen production domestically
- Countries rely on external investors for funding, for example, renewable energy tenders
- Financing for clean energy projects needs to double by 2030 to USD $150 billion and rise fivefold by 2050 to fulfil pledges[3]

Infrastructure
- Infrastructure scarcity for distribution and production for large-scale projects
- Projects are planned predominantly in coastal areas including Chile, Brazil and Argentina with export terminals

Project development
- Total renewable hydrogen projects: 138 with 126 GW capacity
- Total low-carbon hydrogen projects: 0[4]

Note: Illustration based on IEA interactive project map, showing projects with following status: concept, demonstration, feasibility study, FID/ under construction and operational (2023)
Sources: 1 IEA "data base" (2023), 2 IEA Report "Latin America" (2023), 3 IEA Report "Latin America" (2023), 4 IEA "data base" (2023)

Latin American countries have abundant potential renewable energy resources and with 60% the region has the highest share of renewables in the world (60%, World Economic Forum figures show).[34] Multiple countries have hydrogen strategies or roadmaps including Argentina, Brazil, Chile, Colombia, Costa Rica, Ecuador, Panama, and Uruguay.

However, the region's clean hydrogen market has yet to take off. Leading countries including Brazil and Chile have published project announcements, but the right regulatory frameworks, investments, and subsidies are missing to push them into the final investment and operating stage, often requiring external support from international investors. There is a further probability in Latin America that the region will back its already-large biomass energy industry to reduce emissions, rather than clean hydrogen.

So what needs to change in the region?

Regulation and coordination to attract investors

Catapulting Latin America to become a world leader in clean hydrogen production would require supportive policies and regulations in the various countries, as well as investment, national and international support, and skills development, to create a coordinated effort to simultaneously boost hydrogen supply and demand.

Brazil offers a good example – the country has 19 clean hydrogen projects (six feasibility studies, seven under concept, one at FID and five at the operating stage).[35] There is no legislation in place yet to regulate and define what qualifies as renewable hydrogen, which has created uncertainty for investors. However, Brazilian politicians approved bills to regulate the offshore wind and renewable hydrogen markets at the end of 2023, to be reviewed by the Senate.[36]

In addition to greater certainty, strategic partnerships are also being used to attract international investors. These collaborations go beyond financial support, bringing in specialized knowledge, technological advancements, and market development opportunities. Creating more partnerships would significantly impact Latin America's clean hydrogen landscape, as demonstrated by successful collaborations in countries including Chile and Uruguay.

In Chile, the Team Europe Initiative on Renewable hydrogen[37] (TEI GH2) aims to foster cooperation with the EU in a number of areas, including strengthening the enabling environment for renewable hydrogen (through measures such as a certification scheme for the origin of renewable hydrogen), supporting technological development, and promoting market growth.

Similarly in Uruguay, announced tender rounds from the country's state-owned energy company Ancap for renewable hydrogen and offshore wind projects have already attracted significant interest from international companies including Shell and APA Corp. Total investments are estimated to reach USD $3 billion (€2.8 billion).[38] Furthermore, the Uruguayan government has entered into a memorandum of understanding with HIF company to construct a renewable hydrogen plant in the province of Paysandú, with an anticipated investment of $6 billion (€5.6 billion).[39]

Latin American countries are rich in biogenic resources

One unique feature of Latin America's energy sector is the notable progress on using bioenergy, capitalizing on resources from the region's large agricultural sector and favorable climate. For example, IEA figures from 2020 show biomass accounted for around 15% of total primary energy supply in the region, while wind and solar were only 1%.[40]

Brazil is a key player in this area, harnessing its extensive sugarcane cultivation for ethanol production, and generating around 27 billion liters annually.[41] The high share of bioenergy resources is influenced by factors such as the ease of transporting liquid biofuel, and in Brazil, more than 80%[42] of new vehicles are capable of running on high-ethanol gasoline blends, exceeding current mandates of 20% to 27%.[43] Similarly, Argentina, Colombia, Peru, and Uruguay have implemented biofuel blending targets, bolstering the prominence of these fuels in their energy portfolios.

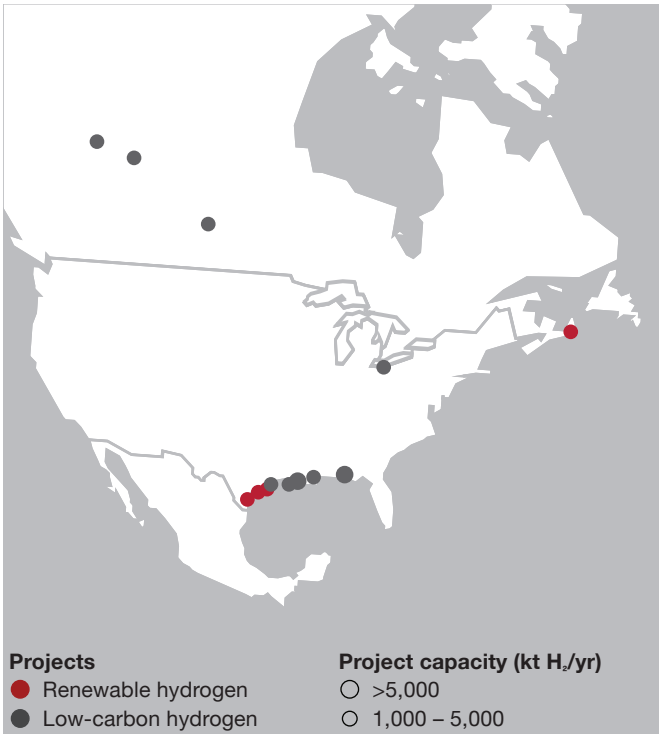
Latin America in summary

The prioritization between bioenergy and renewable hydrogen in Latin America remains uncertain, given the region's favorable conditions for both options. Should clean hydrogen production take precedence, North America is poised to become its primary export market, underscoring the significance of foreign investments in its development.

Region-by-region analysis – United States

EXHIBIT 11

Overview of clean hydrogen projects in North America



Ambition
- Predominantly for domestic use, aiming for self-sufficiency
- US targets 10 Mt (2030) and 50 Mt (2050) of clean hydrogen[1]

Conditions
- 23% share of renewables in electricity mix in the US 2023[2]
- Significant natural gas deposits for low-carbon hydrogen production

Governmental support
- Clean hydrogen production tax credits offer up to USD $3/kg (€2.8/kg) of hydrogen to low greenhouse gas emission projects[3]
- "Clean hydrogen Hubs Program" with a total volume of USD $7 billion (€6.5 billion) to catalyze nearly USD $50 billion (€47 billion) investments across 10 hubs in the US[4]

Infrastructure
- Focus on hydrogen production hubs, avoiding the need for long distance hydrogen transport
- Infrastructure scarcity for renewable hydrogen contrasts with the ease of repurposing natural gas infrastructure for low-carbon hydrogen

Project development
- Total renewable hydrogen projects: 110 with 68 GW capacity in North America
- Total low-carbon hydrogen projects: 55 in North America[5]

Note: Illustration based on IEA interactive project map, showing projects with following status: concept, demonstration, feasibility study, FID/ under construction and operational (2023)
Sources: 1 US Government (2023), 2 EIA (2023), 3 US Gov. Department of Treasury (2023), 4 US Gov. Energy Department (2024), 5 IEA "data base" (2023)

The approach being taken by the US to develop its hydrogen market is different to Europe: Firstly, the US is concentrating on building up hydrogen production hubs which do not require transport of hydrogen whereas Europe aims to build a pipeline-backed distribution network to deliver hydrogen from the best-located production areas to the offtaker. Secondly, the current tax credit for clean hydrogen under the 2022 Inflation Reduction Act also provides a significant advantage for low-carbon hydrogen production, both domestically and through imports, in contrast to the EU's focus on renewable hydrogen.

Here, we will consider how both approaches contribute to the development of the clean hydrogen ecosystem.

Network of hydrogen hubs

In Europe, the planned infrastructure needed for the hydrogen transition will be constructed to reach the companies who will use the fuel, whereas in the US, companies will access individual hydrogen hubs that accommodate both low-carbon and renewable hydrogen. Substantial investments are being made, with a particular focus on establishing large-scale network systems near coastlines for potential exports to Europe and Japan.

The Regional Clean Hydrogen Hubs (H_2-Hubs), funded by the Bipartisan Infrastructure Law (BIL), aim to accelerate the large-scale implementation of clean hydrogen by facilitating production, storage, delivery, and use of the fuel.

One example is the planned California Hydrogen Hub, led by the Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES) LLC. It aims to leverage California's solar energy potential to produce hydrogen exclusively from renewable energy and biomass. Spanning the state, the project targets decarbonizing public transportation, heavy-duty trucking, and port operations, to reduce carbon emissions by 2 Mt annually. The federal government will share up to USD $1.2 billion (€1.1 billion) of the cost to create the hub.

Low-carbon hydrogen to lead the way

Despite the announcement of more renewable hydrogen projects compared to low-carbon ones in the US to date (82 compared with 26, respectively[44]), the announced capacity volumes favor low-carbon hydrogen. Estimates[45] indicate 2.8 Mt of clean hydrogen will be produced per year in the US by 2025, of which 2 Mt will be low-carbon hydrogen, and 9.3 Mt a year by 2030, of which 7 Mt will be low-carbon hydrogen.

The reason for this is that, while renewable hydrogen subsidies were only signed into law in November 2022, low-carbon projects were already able to access the 45Q tax credit for CCS, which has been in place since 2008. The IRA has also expanded the subsidy to USD $85 (€80) per ton of CO_2 that is permanently stored, and to USD $60 (€56) per ton if the greenhouse gas is used for enhanced oil recovery or in other industrial processes. The $60 (€56) band also applies to carbon dioxide that is used in making other chemicals, such as e-fuels or methanol — which are both made by combining hydrogen with CO_2.[46]

Producing low-carbon hydrogen is also perceived as easier than renewable, and buyers typically require large, uninterrupted volumes which are currently harder to produce using renewable energy because it relies on variable renewable electricity input. That necessitates energy storage, grid backup, or large-scale hydrogen storage. These factors add to the overall production costs.

While focusing on bringing down production costs at home, the US also has an opportunity to export renewable hydrogen to Europe. Using abundant Texas solar and wind power resources and leveraging the new IRA renewable hydrogen incentives, green hydrogen-derived fuels could be shipped from Gulf Coast ports to Europe, for example.

US in summary

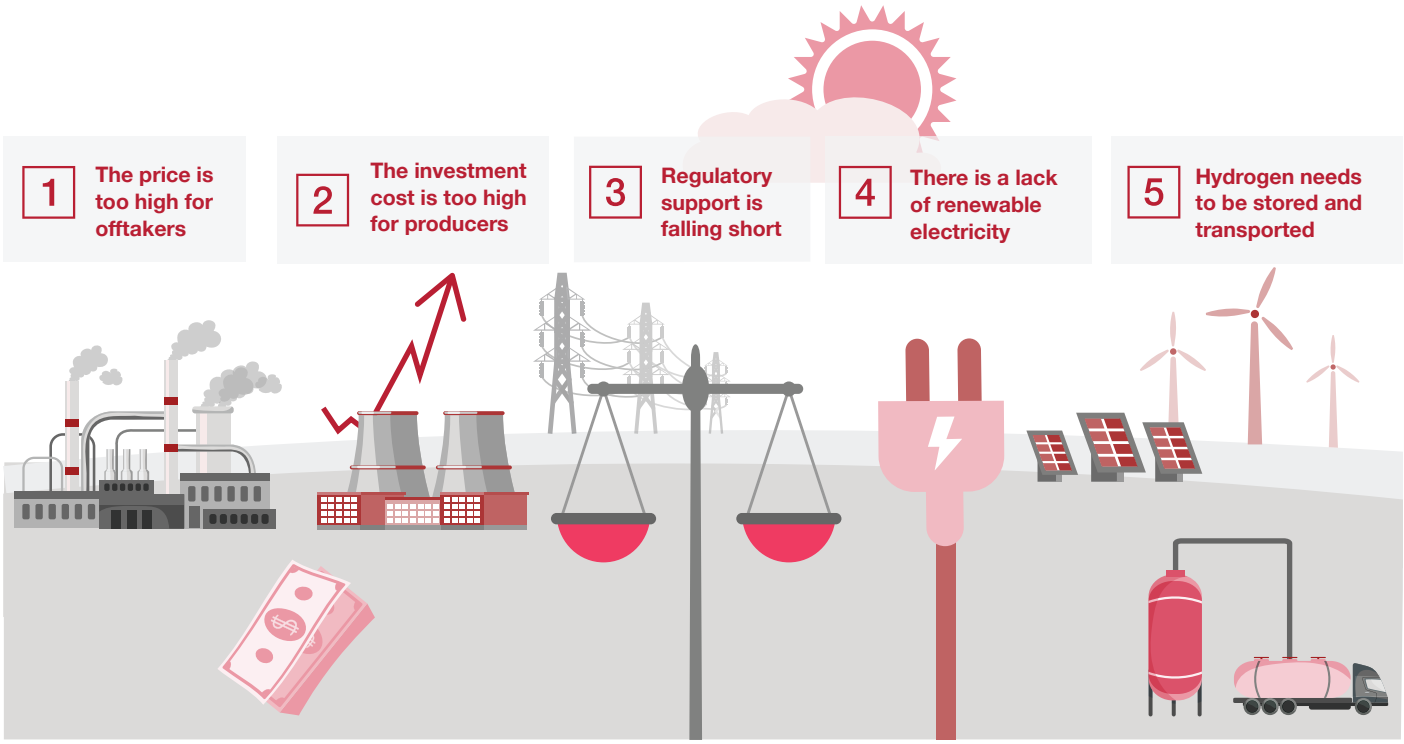
The US is strategically targeting increased production of low-carbon hydrogen to integrate the fossil natural gas industry into the future hydrogen ecosystem. The focus is on replacing current hydrogen usage in a first stage exploring new applications and using disconnected hydrogen hubs for production and use alignment.

SECTION 3

Challenges

EXHIBIT 12

Globally, the barriers to progress in building up clean hydrogen production capacity to the level required fall into five categories



Source: Strategy& analysis

As identified in the regional analyses above, the barriers to progress in building up clean hydrogen production capacity to the level required fall into five categories (*see Exhibit 12*):

The price is too high for offtakers

Potential hydrogen producers cannot raise the financing they need to reach the FID and construction phase because they don't have binding offtake agreements in place. Offtakers on the other hand can't enter the required binding agreements as the price for clean hydrogen is typically significantly higher (if not a multiple of) the fossil equivalent: renewable hydrogen in the EU might cost around €200 – €250 per megawatt hour (MWh) while low-carbon hydrogen might cost around €100 per MWh, and natural gas costs are currently between €30 and €50 per MWh (+€15 – 20 per MWh ETS),[47] for example. These gaps can only be bridged with funding, contracts for difference, or in cases where the impact of

hydrogen cost on the final product is low or a higher cost for a low-carbon product will be accepted by customers. Clean hydrogen's affordability will also improve as the cost of carbon increases, and in industries with quotas for low-carbon products.

The investment cost is too high for producers

Producers find themselves between a rock and a hard place. On the one hand, as described above they can't secure contracts and therefore financing because of the high price of clean hydrogen. On the other hand, their own investments to build production facilities are very high because scale effects are still missing due to low realization rates. These costs are actually even increasing due to inflation in building materials and higher interest rates, which have eaten up any slow improvements due to scale. Current prices for an electrolyzer system, for example, are estimated to be around €2,000 to €3,000 per kW on average.

Regulatory support is falling short

Regulation in the hydrogen market remains challenging, especially in Europe. High requirements and sustainability standards such as additionality and time/ local correlation of renewable electricity generation and hydrogen production are in place to govern the way renewable electricity for hydrogen generation is produced, creating a barrier to increasing production. Other regions of the world generally have less strict regulations, but in many cases are not setting the right incentives either (*see regional analyses on previous page*).

When it comes to governmental support for funding, the experience in Europe so far seems to be that enabling CAPEX funding is a necessary but not sufficient mechanism; the significant OPEX cost gap between clean hydrogen and its fossil alternatives also needs to be bridged initially – just as it was in the early years of the wind and solar power market in Europe. It seems likely that governments and regulators will have to accept the gap for 10 to 20 years, as they did for renewable energy, to enable the market to establish itself and grow, and to realize the effects of scale.

There is a lack of renewable electricity

Sufficient availability of renewable electricity is a prerequisite for the production of renewable hydrogen. Around 500 TWh electricity would be needed to produce 10 million tons of renewable hydrogen, so based on one wind turbine producing 20 GWh of electricity per year, 25,000 new turbines would be needed to cover the electricity requirements for electrolyzers alone. Net electricity consumption was 491 TWh in Germany in 2022[48] which is similar to the amount needed to produce 10 Mt of renewable hydrogen in the EU. At the same time, other sectors across the economy will be electrifying, and will also need additional renewable energy generation plants, increasing competition for resources. For the electrification of European road transport (passenger cars and trucks) 130 TWh electricity would be required by 2030 and 350 TWh by 2040.[49] This is another reason why, initially, low carbon hydrogen may be required to bridge the gap.

Hydrogen needs to be stored and transported

The lowest-cost hydrogen production areas are in many cases far away from where hydrogen is consumed – and in this situation, the lack of a comprehensive hydrogen infrastructure is a significant barrier. Building a network of hydrogen production, storage and distribution facilities requires substantial investment and coordination among many stakeholders. Although progress has recently been made in the EU, with an agreement to create a core network in Germany or an independent network planning body for hydrogen,[50] there is still a lack of international coordination. For example, there are no known hydrogen projects in Tunisia yet, from where an existing gas pipeline across the Mediterranean could be used to transport renewable hydrogen to meet European demand.

Guest post RWE

Green hydrogen is a fundamental component of RWE's investment strategy, with plans to invest 55 billion in expanding green generation capacity to 50 gigawatts globally by 2030. This includes plans to build two gigawatts of electrolysis capacity by 2030 in RWE's core markets. The group is involved in all stages of the hydrogen value chain. Where regulation, support schemes, and sales potential are appropriate, the company develops, constructs, and operates electrolyzers and enters import partnerships. Alongside its partners, RWE is driving over 30 hydrogen projects worldwide, primarily focusing on north-western Europe and North America. The company's production emphasis lies solely on green hydrogen, leveraging its renewable energy capabilities. Furthermore, to facilitate Germany's coal phase-out, RWE plans to also build 3 gigawatts of hydrogen-capable gas-fired power plants by 2030 – provided that the German federal government creates a suitable framework for this.

We are in an exciting phase in the ramp-up of the hydrogen economy. Slowly but surely, PowerPoint visions turn into concrete assets, not least because the regulatory framework for hydrogen is taking shape. Recent developments such as the RED II Delegated Act and RED III have provided much-needed clarity on green electricity criteria and mandated a significant portion of industry hydrogen to be green, fostering market growth. The EU's Gas Directive aims to establish an efficient European hydrogen infrastructure, while Germany's plans for an H_2 core grid further support hydrogen expansion. Meanwhile, the EU set itself ambitious build-out targets for renewables and permitting and approval procedures are being accelerated. Also, novel funding instruments are gaining traction. Just shortly, the EU approved funding support for around 60 projects in the HyInfra wave as part of an Important Project of Common European Interest (IPCEI).

Despite these advancements, some challenges persist. The rapid build-up of renewable assets remains crucial for sufficient and cost-competitive green hydrogen production, necessitating even more pragmatic permitting. Simultaneously, regulatory uncertainty persists in several key areas. The storage and import strategy is still pending. And as there has been no support on the demand side to date, companies are shying away from long-term purchase commitments. It is also still unclear how the implementation of the use quotas from RED III for green hydrogen is to be enforced in the industry and how the mutual recognition of quota fulfilment is to be established on the market.

Furthermore, the hydrogen economy is impacted by challenges faced by all asset-heavy industries at the moment: financing constraints amid higher interest rates and supply chain worries, as well as policy uncertainty in light of many upcoming elections increase the stress.

But these challenges can and will be overcome. Pragmatic, fit-for-purpose projects among partners will dominate the next years. We are convinced that hydrogen value chains will predominantly develop in integrated, regional "H_2 valleys", close to industrial offtake and with infrastructure available. A good example of this is the project "GET H2 Nukleus", which RWE is developing in Lingen, Germany. It includes the construction of an electrolysis plant with a capacity of 300 megawatts. Soon the site will have access to industrial offtakers in the Rhine-Ruhr area and the Netherlands, as infrastructure operators are preparing to convert natural gas pipelines nearby to hydrogen transport – and RWE is also adding underground hydrogen storage to the setup, one of the most crucial, yet too-often overlooked elements of each hydrogen value chain.

No matter how fast Europe's hydrogen production scales up – we believe that imports will continue to play a big role in securing supply in Europe. Mainly in the form of green ammonia, green methanol, and e-fuels as drop-in replacements for fossil-based fuels. But while many regions outside of Europe offer better conditions for wind power and photovoltaics, political stability and regulatory clarity remain essential for investment decisions.

While securing offtake and creating infrastructure in Europe is a tough nut to crack, it will be even more difficult and take even longer on an international scale. Firstly, because capital cost and risk considerations play a huge role in the large investments required in the early hydrogen world. And secondly because the cost advantages of producing hydrogen in e.g. Chile, the USA or Australia will quickly be eroded if imports must be shipped to and cracked in the countries of destination.

That is why we believe it is best to develop hydrogen valleys first in stable and mature Western markets.

Guest post Hynamics

As a subsidiary of the EDF Group, Hynamics´ mission is to help decarbonising the economy by providing low carbon and green hydrogen and derivatives. Established in France, Germany and the UK, Hynamics develops, invests, implements and operates electrolysis-based hydrogen solutions. Our targeted markets are the industry, e-fuels and heavy-duty mobility.

Many challenges have delayed European hydrogen production capacities

Back in 2022, about 6 GW of electrolysis projects were announced for 2024 in the EU. This outlook has shrunk back to 2.4 GW in 2023 (Clean Hydrogen Monitor 2023), mainly because of regulatory uncertainties, difficult subsidy access as well as an energy and technology cost surge. All in all, the cost estimates of renewable hydrogen production in Germany have increased by more than 50% since 2019.

In addition, high complexity results from the need to couple markets of different sectors and balance their risks. Hydrogen projects involve the electricity market, suppliers for e.g. the electrolysis plants, an adequate hydrogen infrastructure, offtakers and the customers´ willingness to pay a green premium for decarbonised products. All these actors are driven by different rules and incentives coming from a legislation which is still in construction.

As an example, the delay of adoption of the RED II Delegated Acts has hindered investment decisions for more than one year. The implementation in Germany still contains many uncertainties for hydrogen producers. The necessary role of PPA aggregators is still not clarified, nor is the situation of redispatch or the challenges associated with time correlation, leading to unavoidable oversupply of electricity to ensure a viable use of the electrolysis assets.

On the offtaker side, incentives are missing. Substituting fossil hydrogen in e.g. refineries is technically one of the quickest and easiest applications. However, due to a market-failure, the price of GHG-Quotas drastically fell last year in Germany, making the decarbonization of refinery-processes through green hydrogen unattractive. For other industrial sectors, the transposition of REDIII´s H_2 consumption target is eagerly awaited.

The ramping-up of H_2 is slower than expected but seems now on the start!

The sustainable hydrogen market and the required technologies are new and immature: difficulties and delays had to be expected. Despite the above-mentioned challenges, things are evolving positively. Subsidies are now on the table (H_2 Bank, Contracts for Difference, etc.), definitions and legislative framework are being finalised, with the official plan for an H_2 pipeline network in Germany being up for validation soon. In addition, the willingness to decarbonise is enshrined in national strategies as well as in industrial climate neutrality plans.

Strongly committed to carbon neutrality, Hynamics stands ready to deliver! Thanks to the expertise of the EDF Group in electricity and Hynamics positioning, we are able to provide efficient and integrated solutions to customers: we already developed and are now operating several electrolysis-based assets and are actively developing full-scale industry and e-fuels projects across several EU Member States, as well as outside Europe.

How to finally deliver?

1. No project without support. Sufficient subsidies must be guaranteed for the hard-to-abate sectors (industry, aviation and maritime): the possibility to combine CAPEX and OPEX subsidies will be key. Also, specific subsidy schemes for decentralized hydrogen production should be developed.

2. More incentives downstream will be necessary to drive the demand for green products. This will happen through a fast implementation of RED III in complement with labels and quotas for decarbonized products.

3. A high and stable CO_2 price (GHG-Quota and EU-ETS) is paramount to improve the attractiveness of green hydrogen and its derivatives against conventional production process.

4. Establishing a robust hydrogen transport infrastructure is crucial to ensuring security of supply by linking production, storage, and demand locations. The hydrogen core network, along with distribution networks, must be rapidly developed.

SECTION 4

Required actions

As the regional analyses and guest posts from companies operating in the market show, different barriers of cost, regulation, renewable energy supply, and storage and transportation are holding back the creation of a successful international hydrogen market and making it even more difficult for regions and nations to meet their climate commitments. The scale of these challenges can only be overcome by joint industry efforts and all ecosystem players pulling in the same direction. We have identified the following actions for each group:

Regulators and governments

To provide a stable foundation for the high levels of investment needed in hydrogen production, regulators around the world must establish clear and supportive regulatory frameworks. That will include setting clear targets and standards, and not holding back production with sometimes overly detailed with sometimes overly detailed regulation (e.g. requirements for additionality, timely and local correlation for power for renewable hydrogen versus no restrictions for power for battery-electric mobility).

Fostering international collaboration and harmonization of standards, regulations, and certification processes for hydrogen technologies is also essential, as it will facilitate cross-border trade and investment, enabling the global expansion of the hydrogen economy.

Of equal importance is for governments, investors (institutional and wealthy individuals) and companies to increase funding and financial support. Incentives must be sufficient to support research, development and commercialization of hydrogen technologies. These can include grants, subsidies, tax incentives and low-interest loans to attract private investment and accelerate the growth of the hydrogen economy. Germany, for example, announced last year that it would offer carbon contracts for difference to heavy industrial companies switching to low-carbon technologies such as clean hydrogen, to offset the higher cost compared with continuing to use fossil fuels.[51] We expect contracts for difference to be the major financial support mechanism for developing the hydrogen market.

Regulators and policymakers must also streamline permitting and approval processes, in order to expedite the approval of clean hydrogen projects as well as the required installation of renewable electricity production plants and reduce administrative burdens and delays.

Producers

With the support of clear regulation and sufficient financial incentives, improving cost competitiveness is the main priority for future hydrogen producers. To narrow the gap with fossil fuels, producers must focus their efforts on technological advancements, economies of scale, and optimizing production processes.

Entering into consortia with offtakers will help producers secure buyers for large enough volumes to create a sound business case and spread the project risk among more players.

Producers, especially of renewable hydrogen, should also work on building resilient supply chains to ensure reliable and uninterrupted production of hydrogen. This includes diversifying renewable electricity sources, establishing strategic storage facilities, and developing contingency plans for potential disruptions.

Offtakers

To meet their emissions reduction obligations, offtakers in hard-to-abate sectors will need to commit to incorporating hydrogen into their energy mix and set clear timelines for hydrogen utilization. The knock-on benefit is that by creating a stable level of demand for hydrogen, producers and distributors will invest in the required infrastructure. Producers can then start building up volumes to the point where they can capture economies of scale, lowering the cost for offtakers.

Successful collaboration with producers and distributors can involve long-term supply agreements, joint infrastructure development, and knowledge sharing to optimize hydrogen utilization. Offtakers can also advocate for supportive policies and regulations to incentivize the adoption of hydrogen. This can involve engaging with regulators, industry associations, and policymakers to raise awareness about the benefits of hydrogen and push for favorable market conditions.

Offtakers also have investments to make, in hydrogen-ready infrastructure such as fuel cell vehicles, hydrogen storage systems, and hydrogen-based industrial processes.

Distributors, traders and intermediaries

A successful global hydrogen market relies on distributors and traders investing in expanding the necessary infrastructure, including pipelines, storage facilities, and refueling stations, in order to enable the efficient distribution and transportation of hydrogen to end-users. Transport corridors would ideally be aligned with planned hydrogen projects in their country or region, to connect producers with offtakers.

Developing a safe, reliable hydrogen supply chain is also essential, and distributors and traders should establish standardized protocols and safety guidelines for handling, storing, and transporting the fuel.

Aggregators

Aggregators like H2Global are important for scaling up the hydrogen economy. They aggregate demand, enabling larger projects to be built and transforming long-term contracts required for producers into short-term contracts required for offtakers. With governmental or private funding, aggregators bridge price gaps, reduce market inefficiencies, and integrate game-theory approaches to optimize the economics of procurement. Their role is crucial in creating a robust and sustainable hydrogen market.

SECTION 5

Conclusion

The global hydrogen market holds immense potential for decarbonizing hard-to-abate sectors and reducing greenhouse gas emissions. However, significant challenges remain, including high costs, regulatory barriers, limited renewable energy supply, and a lack of infrastructure. Our analyses show that each region faces its own version of these constraints, whether that is overly complex regulation in Europe, or a lack of national targets and too little clarity for investors in North Africa or Latin America. To overcome the challenges and unlock the full potential of the hydrogen market, all ecosystem players must work together in a coordinated and collaborative manner. This includes governments, regulators, producers, offtakers, distributors, intermediaries, research institutions, and investors.

By addressing the barriers and taking collective action, the hydrogen market can grow rapidly, enabling the transition to a low-carbon economy and helping to achieve climate targets. The time for action is now, and the potential benefits are immense.

> It is imperative for all stakeholders in the hydrogen ecosystem, including regulators, governments, producers, offtakers, and distributors, to collaborate and take coordinated actions to overcome barriers and create a successful international hydrogen market that can effectively contribute to meeting climate commitments and drive the transition to a sustainable future.“

Dr. Daniel Haag, ESG Lead for Industrial Production

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