CLEAN HYDROGEN MONITOR

2024

Hydrogen Europe

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Foreword

Hydrogen remains a major pillar for the European and global energy transition

Four years have passed since Europe launched its ambitious hydrogen strategy recognising hydrogen as a key decarbonisation pillar of the economy. Not only in Europe, but well across the Atlantic, in China, India, Japan, and in the Middle East investments into clean hydrogen production are rapidly growing. In Europe, only 4 percent of the announced clean hydrogen volumes are under construction, including only 3 percent of the electrolytic ones. Under the Fit for 55 package, the European Union has designed a regulatory framework which could help the emerging clean hydrogen market.

But the job is far from done. Most of this pioneering regulation still has to be transposed at national level. There, Members States, as reflected in their National Climate and Energy Plans, remain highly positive about the contribution that renewable hydrogen will make to meeting the 2030 targets. However, they still have to clarify the legal framework that can drive investments by hydrogen offtakers, producers, and infrastructure operators. Meanwhile in Brussels, policy makers are still finalising the low-carbon hydrogen framework.

Being a nascent market, regulatory clarity and certainty is critical, and so are the right investment incentives. There is a lot of positive news coming out of the sector: The Innovation Fund and Hydrogen Bank are helping with the difficult task of scaling up the clean hydrogen technology. Demand focused national funding schemes like the German Carbon Contracts for Difference are also starting to deliver positive results, supporting large deployment. The regulatory approval of the German core network is also excellent news, but partially overshadowed by numerous delays and cancellations of other key infrastructure and production projects.

With this Clean Hydrogen Monitor 2024 report, we provide Hydrogen Europe's perspective on how the market is evolving in addition to the usual analysis and market stocktake. This year, we have developed, for the first time, a 2030 market outlook. With a growing understanding of national policies, available funding, and announced projects, we have concluded that the European Union as a whole might still be able to meet the 2030 minimum obligations set out in the renewable energy directive and maritime and aviation regulations. However, some Member States will struggle with the individual targets given the lack of an interconnecting infrastructure. Imports from within and outside of Europe will have a key role to play.

It is our pleasure to bring together all key data and information on the hydrogen sector to present to you our refreshed and shorter version of the Clean Hydrogen Monitor. We hope you will find it insightful and useful as we continue striving for a decarbonised world enabled by clean hydrogen!

Sincerely,
Daniel Fraile

Executive summary

Total hydrogen demand in Europe decreased 3% year on year and while electrolysis grew to 0.4 GW_{el}, 95.5% of the 7.9 Mt consumed in 2023 was based on fossil fuels

- Hydrogen demand in Europe was 7.9 Mt in 2023, a 3% decrease compared to the 8.2 Mt reported for 2022 and close to a 15% fall since 2020.

- Ammonia and methanol production are the most affected by closings plants and competition from imports. Hydrogen consumption for ammonia production decreased by 36% in 2022 to 2 Mt due to high natural gas prices. While prices returned to around 40 EUR/MWh levels in 2023, consumption didn't recover. Some plants resumed operations while others chose to discontinue. Methanol imports continue to replace domestic production.

- Electrolytic hydrogen production capacity in Europe more than doubled in the past two years to 385 MW_{el} by September 2024 but only represents 0.4% of total hydrogen production capacity.

- Given the current conditions, the EU Hydrogen Strategy target of deploying 6 GW_{el} by 2024 will not be achieved.

FIGURE A

European hydrogen demand per sector 2019-2023

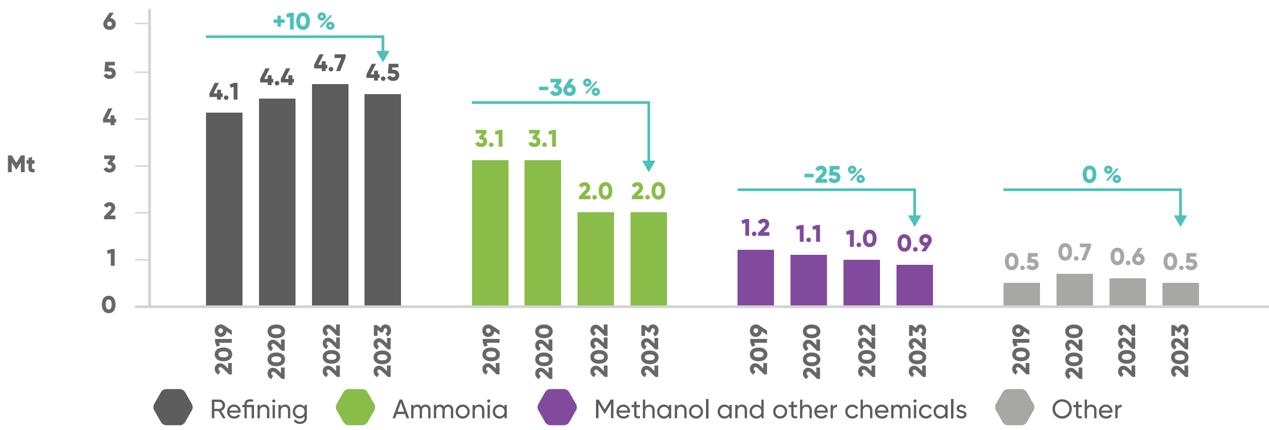
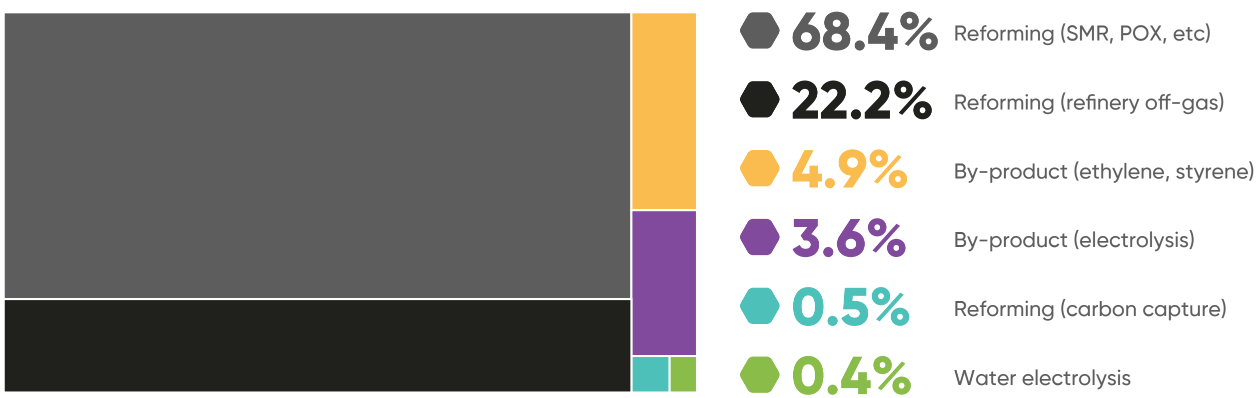


FIGURE B

Hydrogen production capacity in 2023 in Europe by production process



Note: 2021 values are not available as Hydrogen Europe did not estimate hydrogen demand for that year. Total hydrogen demand in refining includes 2.5 Mt of dedicated hydrogen production and 2.0 Mt by-product hydrogen produced during refining processes and ethylene/styrene production. "Other" as an end-use refers to hydrogen used in industrial heating, mobility and unknown applications.

4% of the project pipeline in Europe is under construction and 1/3 of the project pipeline is in an advanced stage

- The total pipeline of projects in Europe that announced to come online by 2030 is 14.4 Mt, 8% decrease compared to 2023. It consists of 844 electrolytic projects amounting to 8.9 Mt/year by 2030 and 59 clean thermochemical projects amounting to 5.5 Mt/year.

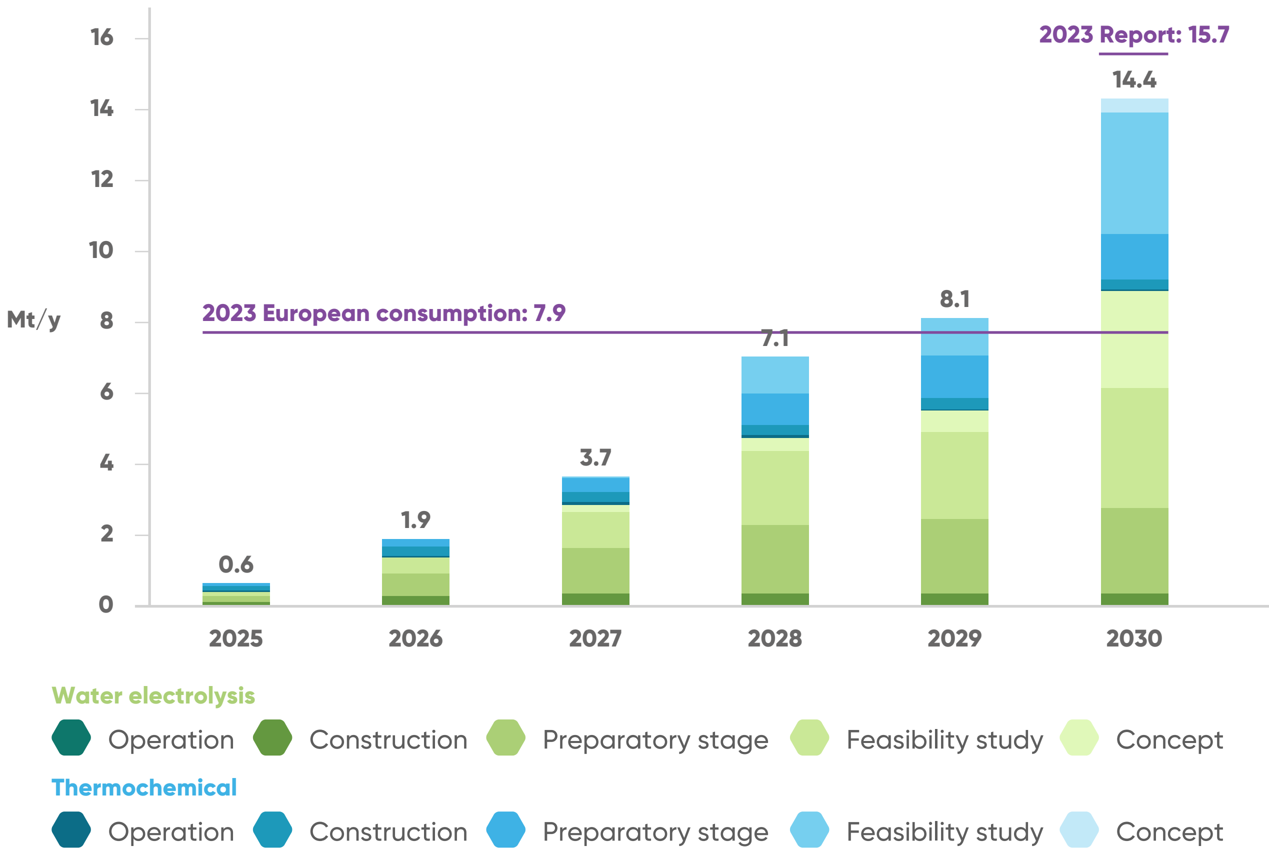
- 4% of the project pipeline is under construction compared to 2% last year. That equates to 3% or 0.3 Mt (2.6 GW_{el}) of water electrolysis and 5.3% or 0.3 Mt of clean thermochemical project pipeline being under construction.

- 34% of the project pipeline is in an advanced stage (pre-FEED, FEED, construction compared to 28% last year equating to 2.8 Mt (26 GW_{el}) of electrolytic projects and 1.5 Mt of thermochemical projects.

- The project pipeline is maturing with 66% of the total project pipeline by 2030 being now in early phases (concept or feasibility study) compared to 72% last year.

FIGURE B

Cumulative announced clean hydrogen production capacity in Europe up to 2030 by current development stage



Notes: Data does not represent a forecast but announced production project pipeline; For methodology and terminology clarifications, please consult the methodological note at the end of the chapter and the terminology section at the end of the report.

Only 3% of the electrolytic project pipeline capacity is under construction, representing 2.6 GW_{el}

- Only 3% of the 8.9 Mt electrolytic project pipeline capacity (equivalent to 86.4 GW_{el}) is currently under construction, representing just 0.3 Mt (2.6 GW_{el}) of water electrolysis.

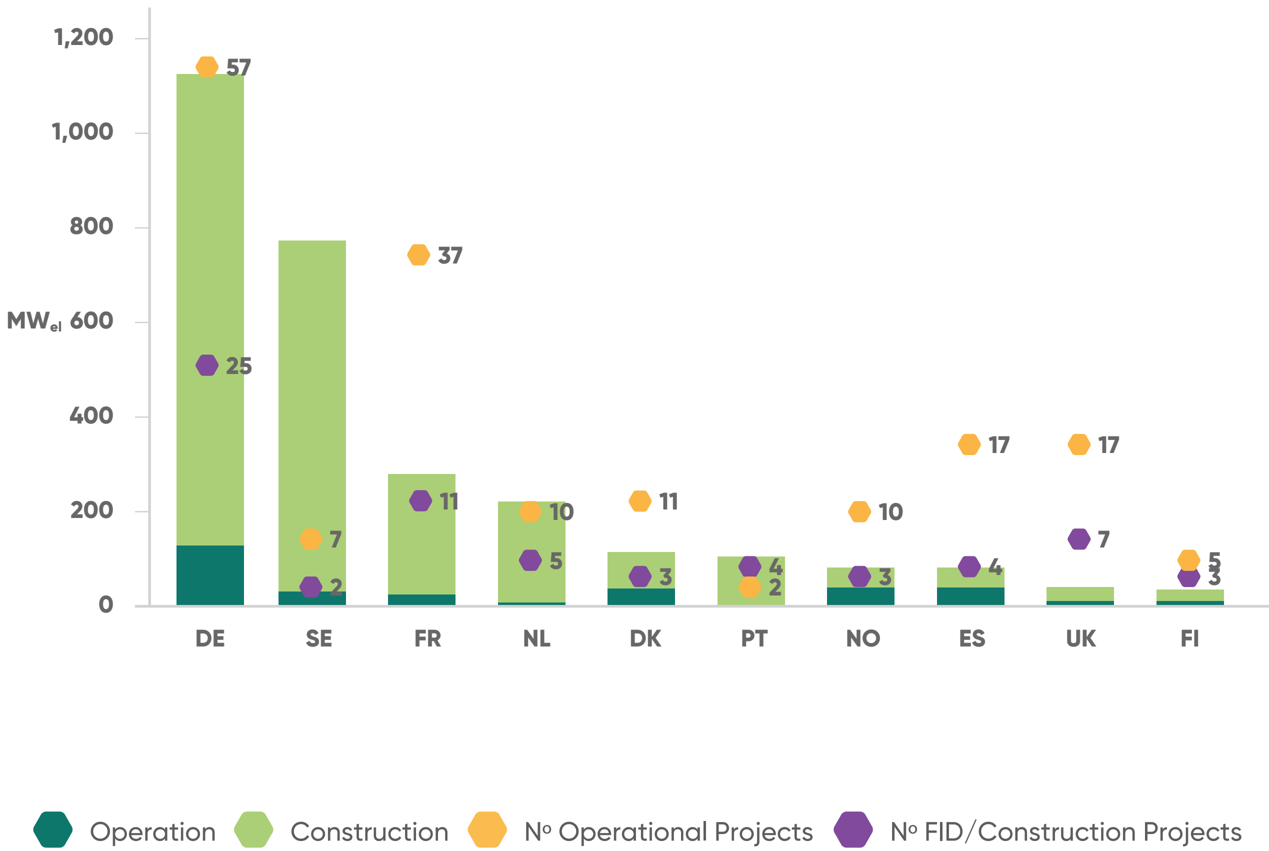
- The electrolytic projects under construction are mainly concentrated in Nordic, Iberian, and Western European countries, driven by the availability of renewable energy sources, low-cost grid electricity, government support, and willing offtakers.

- The average size of projects is increasing. Operational projects typically have an average size of around 2 MW_{el}, while projects under construction already average above 50 MW_{el}. An increasing number of projects are now above the 100 MW_{el} mark.

- Upcoming investment decisions can be expected as countries continue to award national funding (e.g., IPCEIs, CCfDs), awarded projects in the Hydrogen Bank and Innovation Fund move further towards FID and RED3 targets are transposed at the national level.

FIGURE C

Top 10 countries in Europe with largest operational and under construction water electrolysis capacity and number of projects by September 2024



Notes: The values represent installations larger than 0.5 MWel. Hydrogen Europe's project tracking might omit installations smaller than 0.5 MWel and in some cases the number of these installations can be significant. Chapter 3 Methodological note further expands on the data collection process.

Europe can expect a supply of 2.5 to 4.4 Mt of clean hydrogen by 2030, driven by regulatory demand but highly dependent on regulatory constraints, access to funding, and the development of pan-European infrastructure

- The Current Trajectory scenario (CT) forecasts 1.7 Mt of electrolytic and 0.8 Mt of thermochemical hydrogen supply in Europe by 2030.

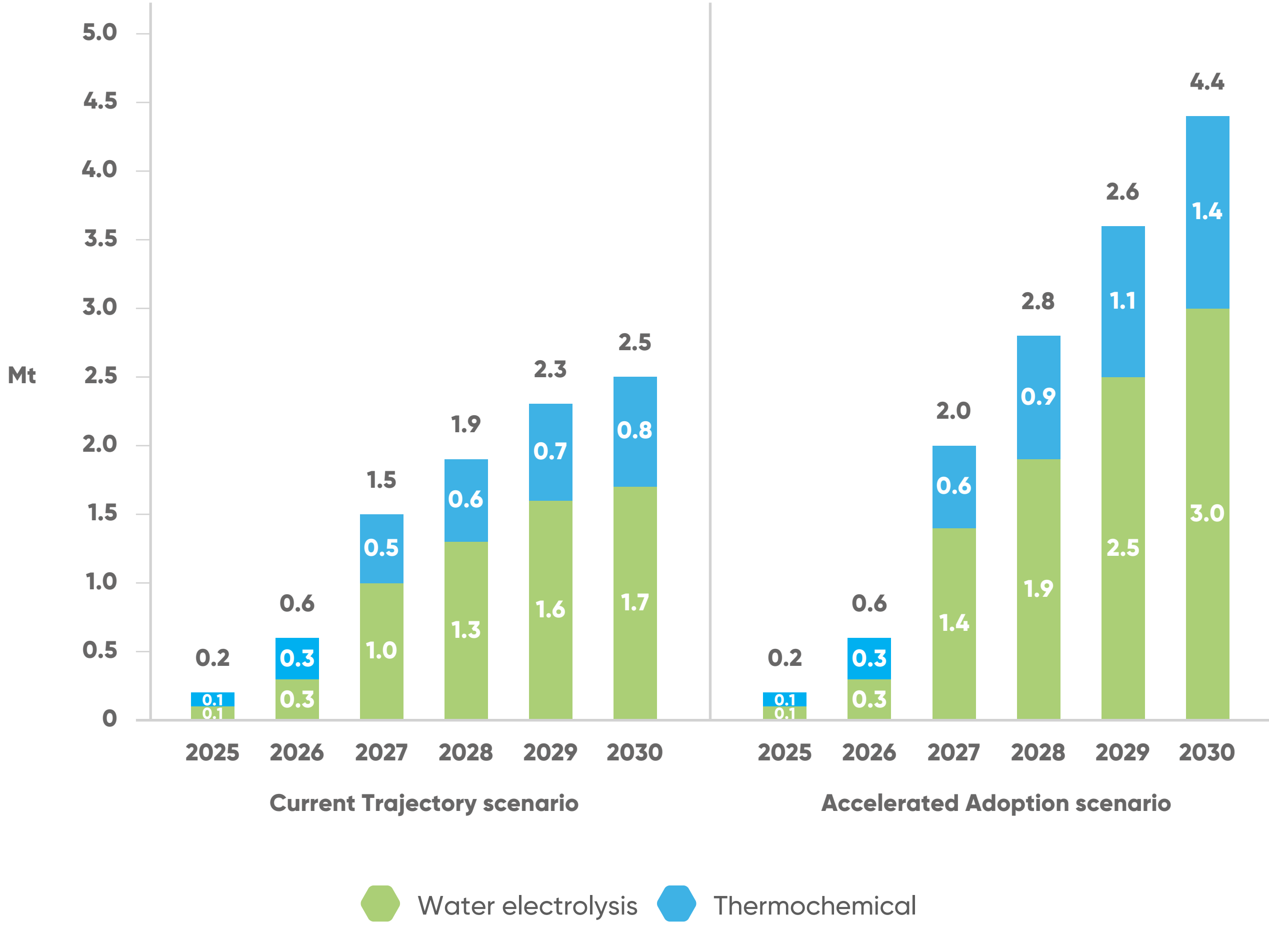
- With improved market conditions under Accelerated Adoption (AA) scenario, projects in Europe could supply 4.4 Mt with 3 Mt of electrolytic and 1.4 Mt of thermochemical hydrogen, but still missing the European Hydrogen Strategy goal of up to 10 Mt of renewable hydrogen production by 2030.

- Nordics and Iberia lead the supply of electrolytic hydrogen by 2030 in both scenarios while most thermochemical volumes are expected in BeNeLux and UK.

- The CT scenario assumes continued access to public funding and favorable regulatory policies to reach 2030 climate targets. However, growth is hindered by increasing project costs, high PPA costs to achieve decent utilisations, tedious funding processes, missing infrastructure, as well as regulatory uncertainty for low-carbon hydrogen. The AA scenario assumes improvements to the challenges above allowing the industry to scale up faster.

FIGURE D

Forecast of European clean hydrogen supply by 2030



Levers to reach the Accelerated Adoption scenario and 4.4 Mt of clean hydrogen produced in Europe by 2030

Lever	ISSUE:	
EU regulatory framework	**COMPLICATED OR MISSING REGULATORY FRAMEWORK FOR CLEAN HYDROGEN PRODUCTION**	Developers continue to delay or cancel projects due to regulatory uncertainty or regulatory compliance costs for producing renewable or low-carbon hydrogen. **Regulatory framework** – Create an investment friendly regulatory framework for all clean hydrogen production technologies that are aligned with the 2050 Climate targets. **Renewable fuels of non-biological origin (RFNBO) DA** – Review the definition of RFNBO by 2026 latest, making it a lot more pragmatic to spur deployment and scale-up the industry. **Low-carbon hydrogen DA** – Adopt a definition of low-carbon hydrogen that encompasses and enables all production pathways as long as they meet strict emissions criteria.
National implementation	**LACKING NATIONAL REGULATORY FRAMEWORKS**	National transposition of RED3 and Hydrogen and Decarbonised Gas Markets package creates uncertainty. Developers and offtakers are unsure whether and how should the targets be met, whether there will be obligations and penalties, which incentives are available and whether a hydrogen infrastructure will be in place to help deliver clean hydrogen. **Target structure** – Provide visibility on how the industry and transport targets will be transposed. **Penalties** – The Commission to clarify what penalties for Member States for non-compliance and encourage penalty uniformity if targets are implemented at company level. **Certification** – Attain Member State acknowledgment or adoption of certification schemes endorsed by the Commission. **Book and claim** – Get clarity on transferability of RFNBO credits and creation of a book and claim system for RED3 compliance (like for ReFuelEU Aviation).
Funding	**INADEQUATE FUNDING MECHANISMS AT EU AND NATIONAL LEVEL**	EU funding is limited and complex (Innovation Fund calls, EU Hydrogen Bank) while national level funding can be dispersed and not effectively supporting market uptake. Some countries still lack a clear funding scheme for clean hydrogen deployment. **European funding** – The EU Hydrogen Bank should evolve to further support offtaker risks and to include imports. Rules on accumulation need to be addressed to facilitate the funding of projects. **National funding** – Member States should develop mechanisms to address the cost gap between clean and conventional hydrogen. Mechanism to support production can be complemented with offtaker support in the form of CCfD. It is important to continue supporting innovation and industrialisation, with a reinforced focus on deployment through OPEX base schemes.
Infrastructure	**SLOW DEVELOPMENT OF HYDROGEN TRANSPORT, STORAGE, AND IMPORT INFRASTRUCTURE PREVENTING CONNECTING CLEAN HYDROGEN SUPPLIERS AND INDUSTRIAL CONSUMERS**	**Implementation** – Rapidly implement the Hydrogen and Decarbonised Gas Markets package at national level, designating a hydrogen network operator, clarifying the framework for third party access to infrastructure, and design a funding framework for infrastructure roll out. **Planning and modelling** – Incorporate energy storage into network development and strengthen cross-sectoral system planning via better scenarios and improved modelling tools. **Strategy** – Develop a European hydrogen grid and storage strategy that forms a fundamental pillar of the EU grid action plan.

Hydrogen trade could enable achieving Europe's 2030 RED3 targets if the infrastructure is built on time to support trade flows from within and outside Europe

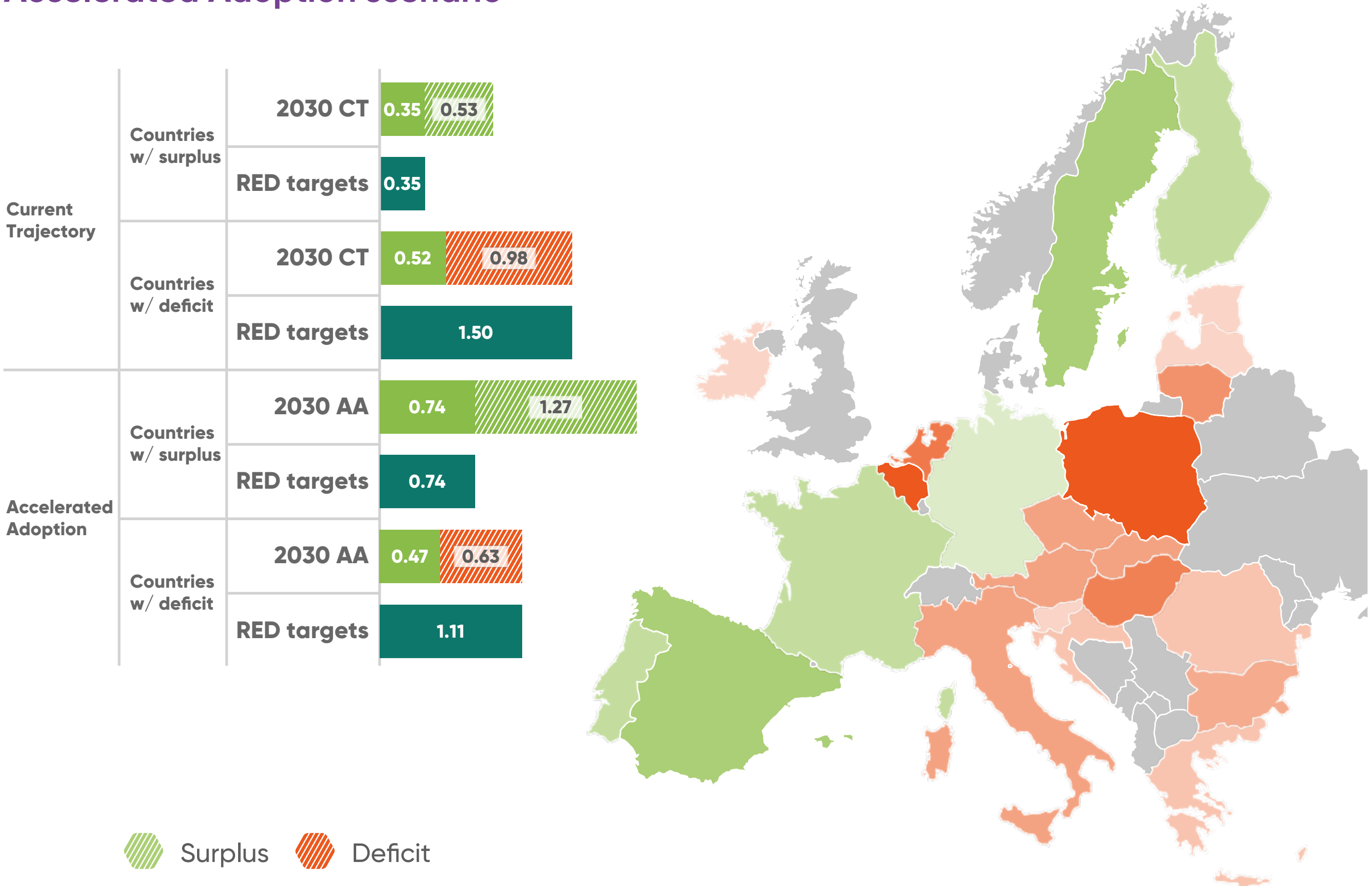
- At EU level, compliance with RED3 could require around 1.85 Mt of RFNBO by 2030. However, targets must be met at Member State level and results show varying progress across countries. Countries with high industrial demand and limited renewable capacity, like BeNeLux, Germany, and Central Europe, may face deficits, while the Nordics and Iberia are expected to have surplus supply.

- In an Accelerated Adoption scenario, intra-EU trade could cover deficits (0.63 Mt), as Iberia and the Nordics are expected to produce 1.27 Mt more than their local needs. This underscores the need for the right infrastructure to efficiently match supply and demand, ensuring decarbonization goals are met.

- However, we are likely to see imports from outside the EU to help Member States meet their targets. Imported hydrogen can represent a good competitive solution, and in derivative forms, can solve the challenges of a missing infrastructure.

FIGURE E

Hydrogen supply deficit and surplus relative to the minimum RED3 targets by country based on both scenarios for 2030. The map shows results for the Accelerated Adoption scenario



Notes: RED3 targets are calculated based on 2023 consumption and do not omit any volumes from the target due to specific exclusions. For the purposes of this calculation, electrolytic hydrogen supply from the two scenarios equals RFNBO hydrogen supply. Countries in grey on the map are not included in the analysis.

The European Union needs to increase public funding for hydrogen to keep up with other international players, such as Japan or the USA

Scaling up Europe's clean hydrogen sector requires substantial investment. The European Union has allocated EUR 125.6 billion for climate initiatives, and clean hydrogen has received EUR 5 billion since 2021, primarily from the Innovation Fund and Horizon Europe.

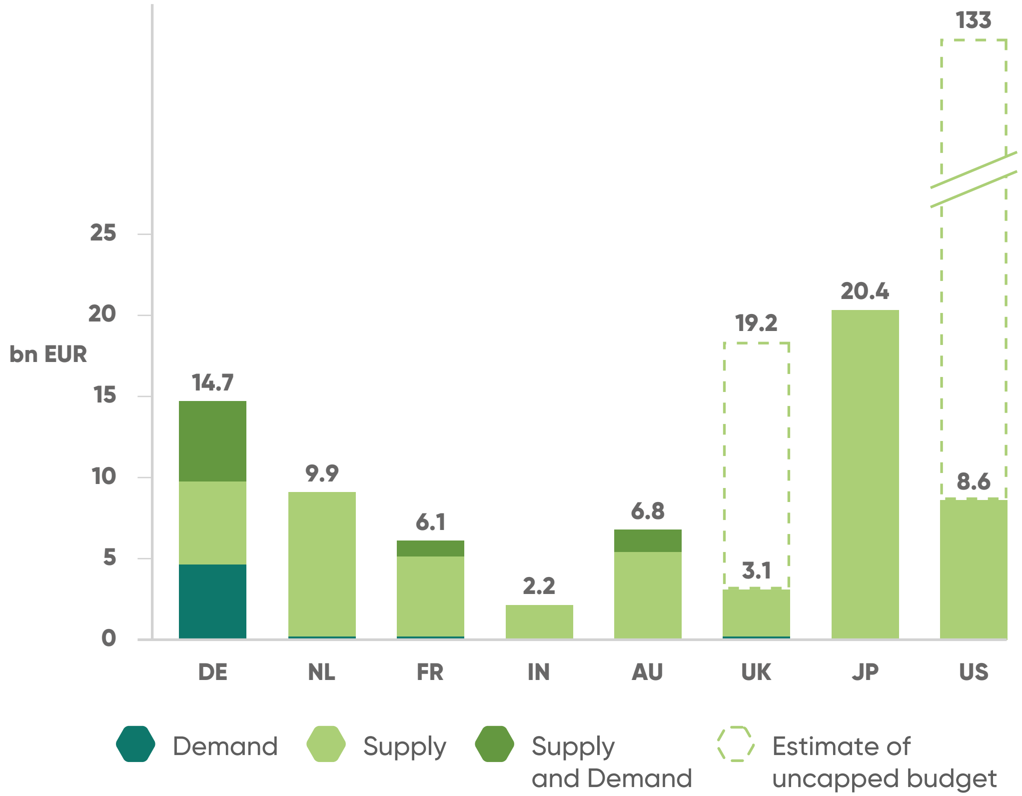
In Europe, cumulative national commitments to the sector are estimated at EUR 37 billion, with Member States pledging an additional EUR 18.9 billion through IPCEIs; however, most of this funding has not yet been granted, as projects struggle to reach final investment decision and some of these mechanisms are yet to be launched.

Meanwhile, countries like the US, Japan, and the UK are making significant commitments to clean hydrogen development. To enhance competitiveness, Europe must increase public investments and focus on demand-side support.

The Innovation Fund should continue supporting manufacturing and large-scale projects, while future EU budgets must include dedicated funding for hydrogen to ensure the sector's growth and sustainability.

FIGURE F

Estimation of announced public funding for clean hydrogen by selected countries, split between supply and demand (by September 2024)



Notes: Selected national funding schemes often target more than just hydrogen. The authors generally estimate that 20% of national public funds are allocated to hydrogen, except for schemes with specific funding targets. This estimate is based on the average 20% investment in hydrogen related projects from the EU Innovation Fund (grant, excluding IF23 results, as grants are not signed at publication of the report). A detailed list of national schemes and assumptions is provided in Annex 1 of the report. For the UK, the first round of the Hydrogen Allocation Round (HAR1) funded 125 MW_{el} of hydrogen capacity at €2.3 billion. To reach an additional 875 MW_{el} by 2025, the authors estimate that about €18.4 billion is needed at similar trike price. In the US, the IRA's uncapped hydrogen tax credits (45V and 45Q) are projected by BNEF to total public funding of up to €137 billion over the next ten years.

Ammonia, refining, and steel constitute ~45% of the declared end-uses in the two supply scenarios while ~23% of the volumes did not announce an end-use

- Industrial end-uses like refining, ammonia, steel, methanol, other industries, and heating could account for 60% of the expected clean hydrogen supply by 2030, while ~23% of supply remains unallocated.

- Under the Accelerated Adoption scenario, around 0.92 Mt of hydrogen is expected for ammonia production by 2030, with 0.6 Mt coming from electrolysis, insufficient to replace the 0.84 Mt from RED3 industry target.

- Refineries, the largest current hydrogen consumer will be key offtaker of clean hydrogen by 2030 with 0.5-0.7 Mt in the two scenarios.

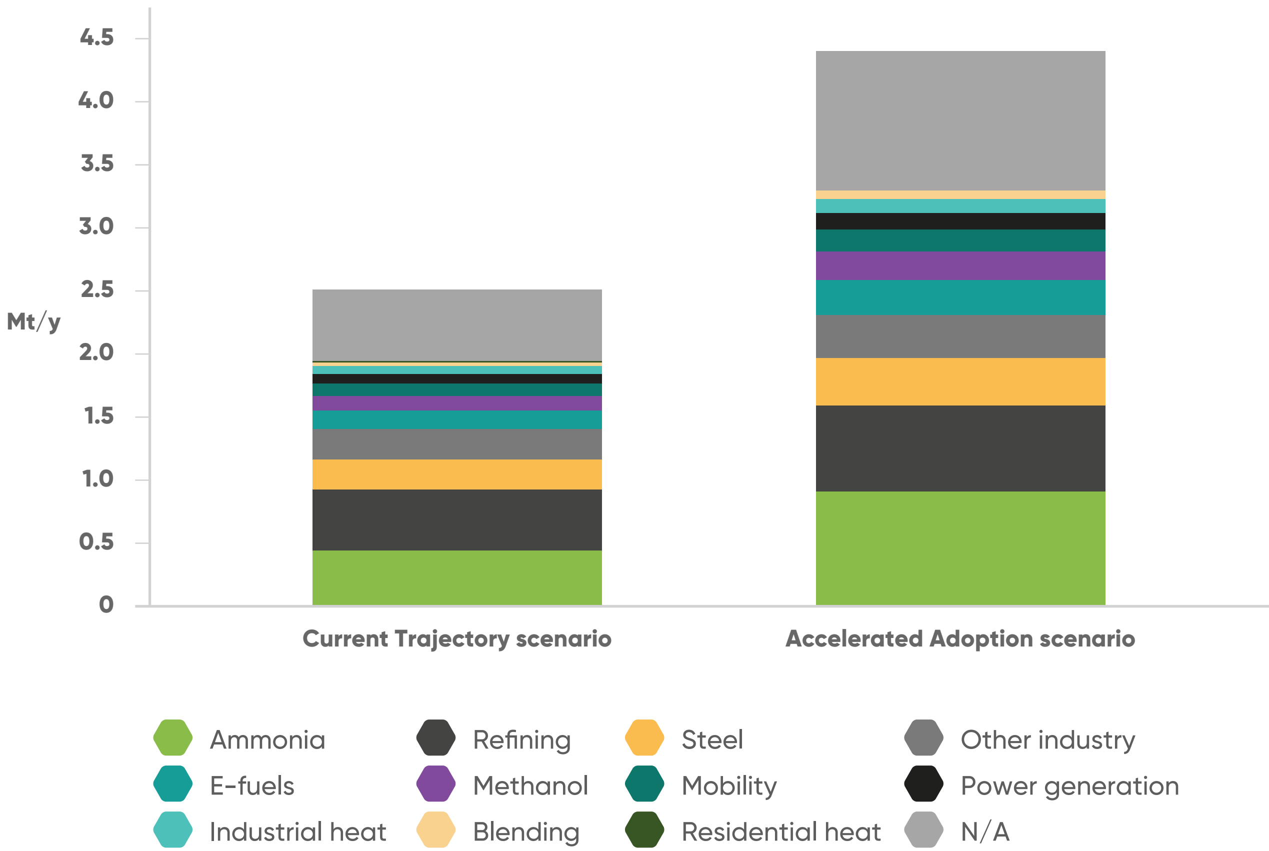
- Clean methanol demand will be driven mostly by shipping.

- Only 10% of hydrogen supply has been announced for e-fuels and mobility, with more volumes expected post-2030. However, securing long-term e-SAF offtaker agreements remains a challenge.

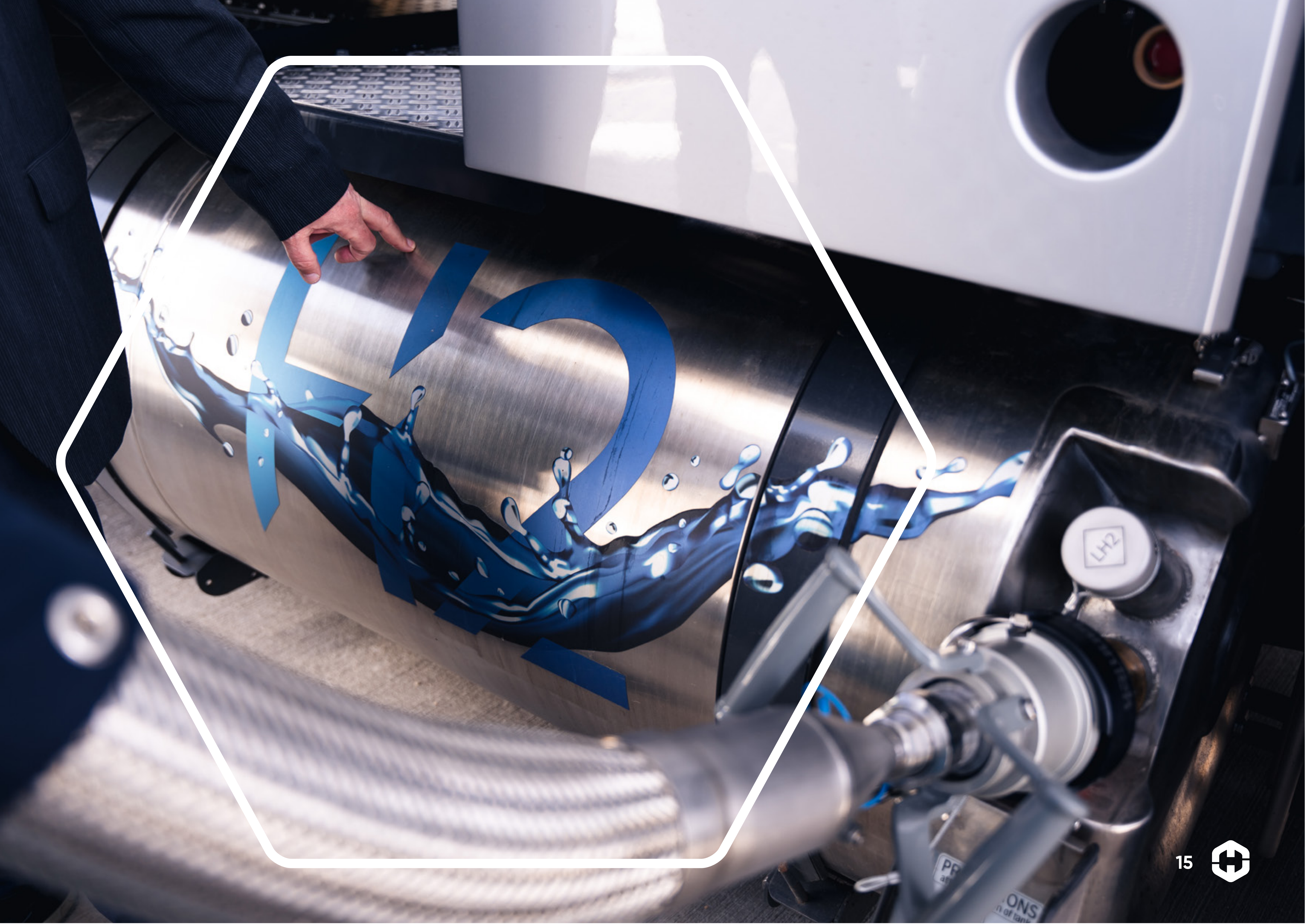
- Steel could decarbonize around 6% of the sector with the 0.4 Mt/year of hydrogen in the AA scenario.

FIGURE G

Intended end-uses of the two clean hydrogen supply scenarios by 2030



Notes: No assumptions regarding how much hydrogen supply will be assigned to a specific end-use were made by Hydrogen Europe. End-uses for the Current Trajectory and Accelerated Adoption scenarios are based on the announced projects' end-uses. See methodological notes for more details.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Current market review

Conventional fossil fuel-based production methods account for over 95% of existing hydrogen production capacity. While clean hydrogen production methods are being deployed around Europe, they need to scale in size to abate the 7.9 Mt of hydrogen produced and consumed in Europe.

- Hydrogen consumption in Europe remained relatively stable compared to 2022 at 7.9 Mt but has seen an 11% decrease since 2019. Refining is the largest consuming sector, responsible for 58% of hydrogen demand. Ammonia and methanol production has remained at similarly low levels as in 2022, being replaced with imports in some cases.

- Hydrogen production capacity amounted to 10.8 Mt in 2023, with emerging clean technologies such as reforming with carbon capture and water electrolysis accounting for only 0.9% of the total.

- Installed water electrolysis capacity more than doubled since 2022 in Europe, reaching almost 400 MW_{el} in September 2024. The largest operational water electrolyser in Europe by September 2024 has a 24 MW_{el} capacity and is located in Norway.

95.5% of European hydrogen production capacity was based on fossil fuels in 2023, water electrolysis representing 0.4% of total

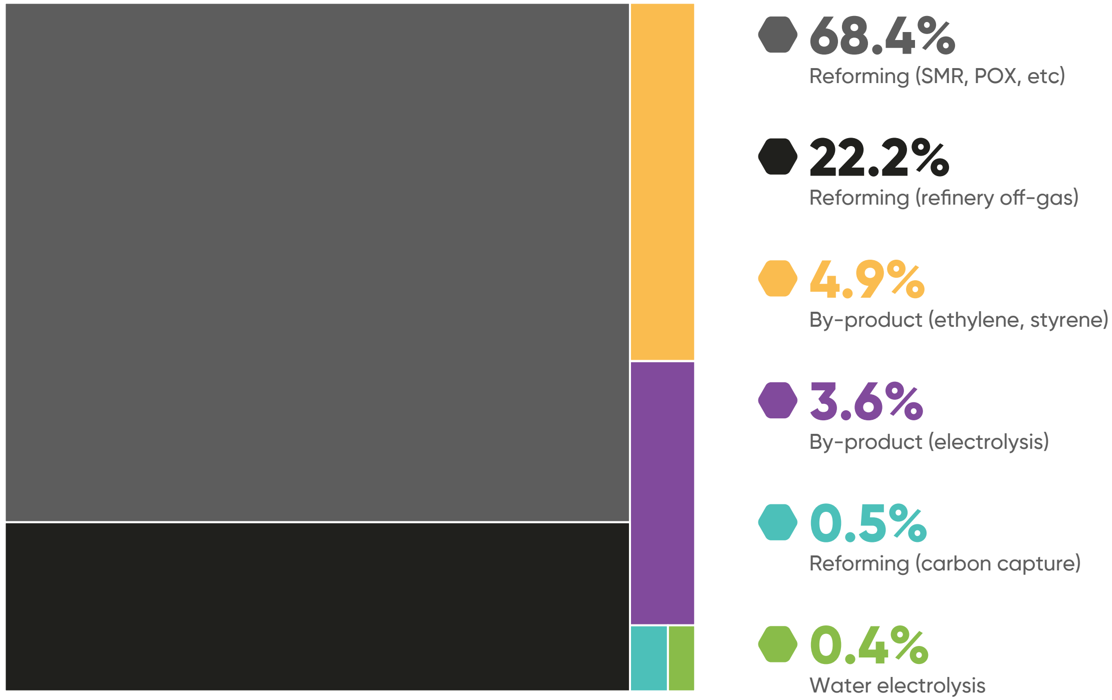
Hydrogen production capacity in Europe amounted to **10.8 Mt per year** at the end of 2023, split among 555 installations. This represents a 5% decrease compared to 2022's 11.4 Mt.

The conventional production methods of reforming, partial oxidation, gasification, by-product production from refining operations, and by-product production from ethylene and styrene represent 95.5% of total capacity. By-product hydrogen production via electrolysis of brine accounts for 3.6%. Reforming with carbon capture accounts for 0.5%. These percentages and absolute values have remained stable along the years, but the overall capacity decrease in Europe was caused by the recently announced shutdowns, mostly in ammonia and methanol sectors. While in 2022 these shutdowns were caused by exceptionally high natural gas prices, many plants did not resume operation once prices stabilised in 2023 and some have been mothballed since. **European made ammonia and methanol are increasingly replaced by imports due to other geographies' lower gas prices and less strict environmental measures.**

Clean hydrogen represents 0.9% of the European production capacity, with water electrolysis being only 0.4%. While water electrolysis deployment is increasing every year, the size of these projects is too small to be significant in the overall hydrogen capacity. At the end of 2023, water electrolysis production capacity reached 44,000 tonnes a year.

FIGURE 1.1

Hydrogen production capacity in 2023 in Europe by production process



Notes: In this report, Europe refers to the EU, EFTA and UK regions.

Today, hydrogen is mostly produced at consumption sites and therefore centralised across industrial clusters and ports

Dedicated reforming plants benefit from economies of scale and are therefore larger in capacity. The average size of reforming plants is 42,413 tonnes/year while installations in which hydrogen is produced as by-product of ethylene and styrene production have an average capacity of 10,620 t/y. Water electrolysis plants, in contrast, have today an average capacity of only 211 t/y in Europe, with the largest one at around 4,000 t/y. Their average size is growing with additional installations every year.

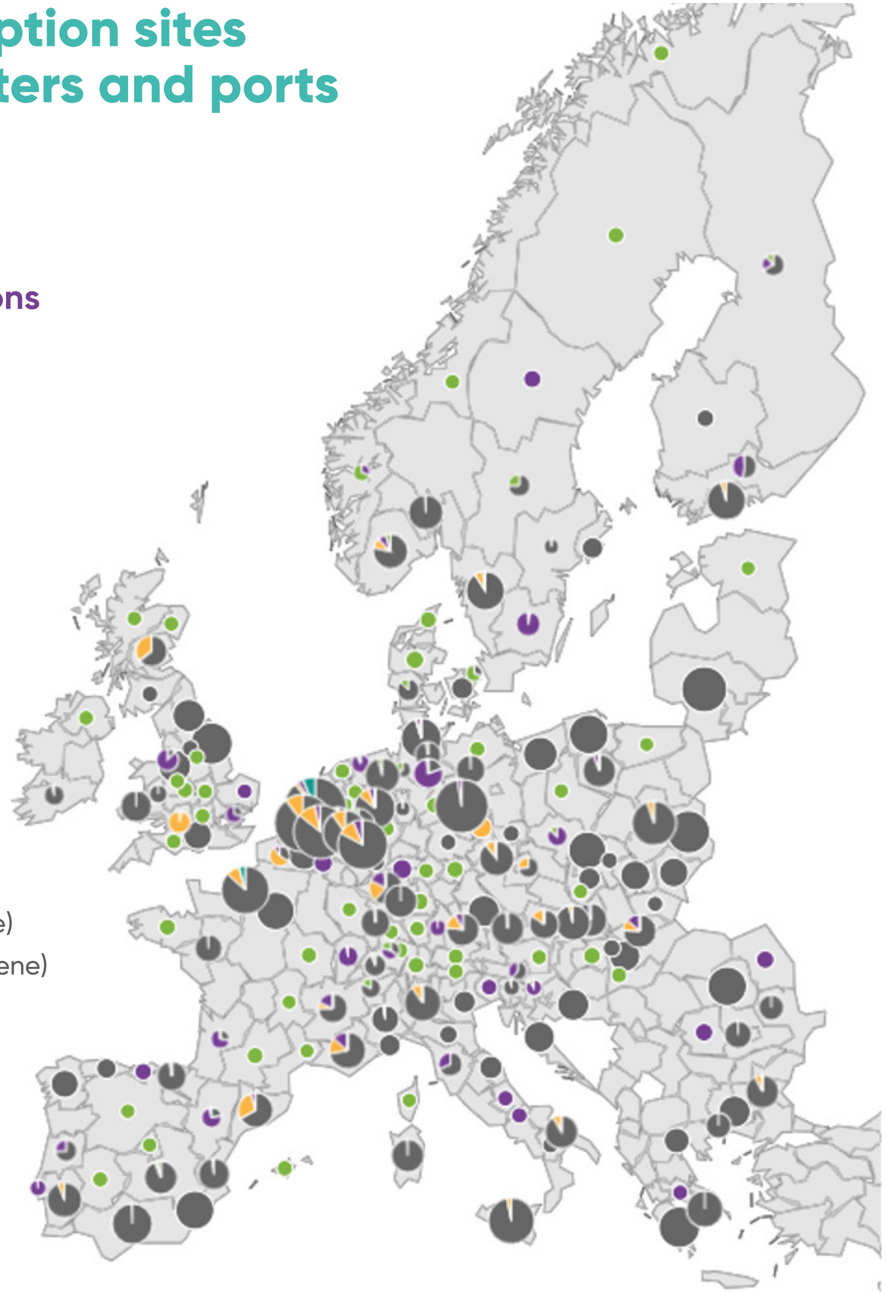
Large-scale hydrogen production is mostly centralised in industrial areas near refineries, ammonia producers, and chemical plants. Hydrogen is not yet a global commodity and is not transported over long distances for supply to meet demand as **most of the production takes places at the point of consumption.** Many of these industrial clusters are located close to ports which would facilitate future trade of hydrogen and its derivatives.

Large water electrolysis projects will be deployed in different geographies, following mostly the locations where renewable energy resources are optimal, increasing utilisation, and reducing costs associated to the power grid. **Meanwhile, until hydrogen infrastructure is rolled out, we will continue to see co-located projects helping to decarbonise energy intensive customers and refineries.**

FIGURE 1.2

Hydrogen production capacity by NUTS2 regions and production process

- Reforming
- Reforming (carbon capture)
- By-product (ethylene, styrene)
- By-product (electrolysis)
- Water electrolysis



Notes: "Reforming" includes dedicated reforming (SMR, POX, etc) and hydrogen produced as a by-product from refinery processes.

Electrolytic hydrogen production capacity in Europe more than doubled in the past two years to 385 MW_{el} by September 2024

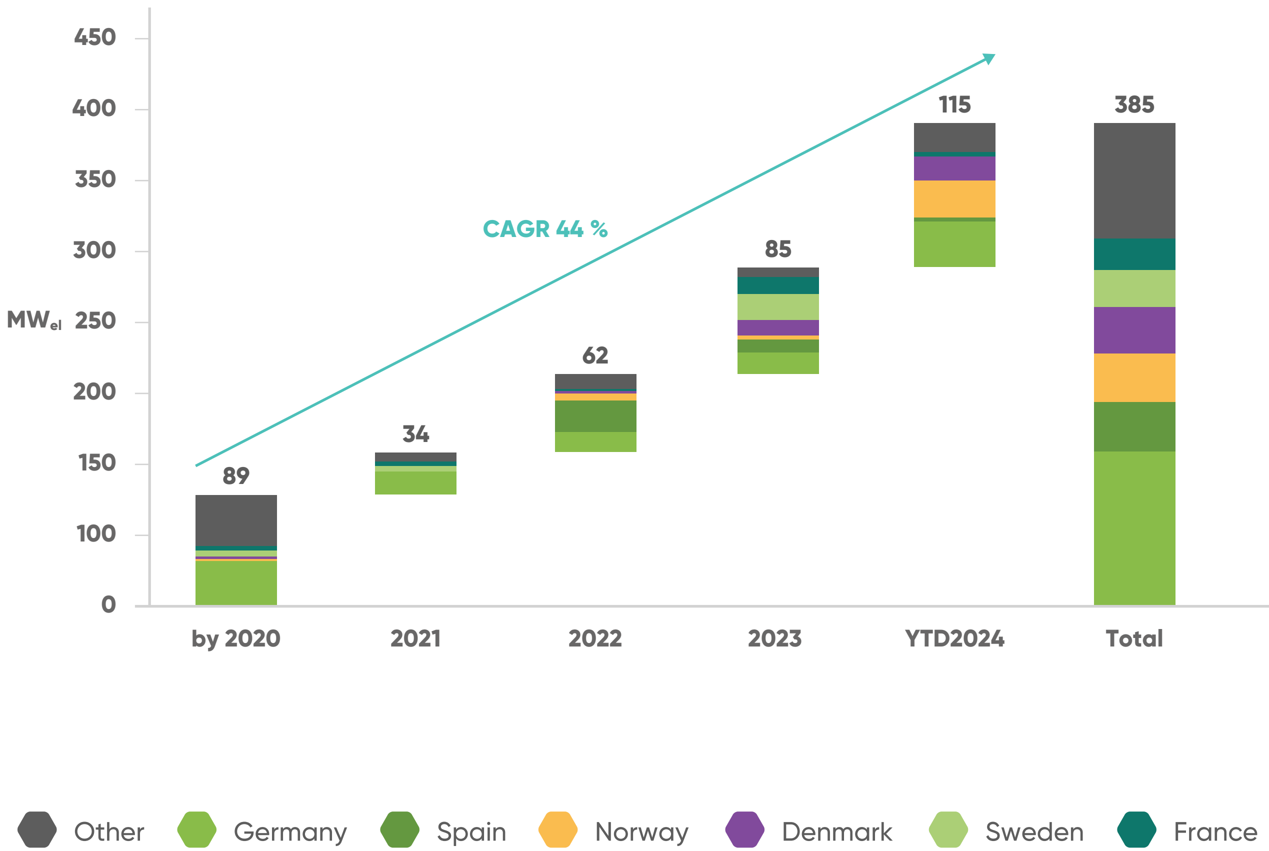
By September 2024, installed water electrolysis capacity in Europe reached at least 385 MW_{el}, or around 64,000 tonnes of hydrogen per year, from 214 identified plants. **Around 213 MW_{el} of capacity were installed between January 2023 and September 2024, doubling the electrolytic capacity available in 2022.**

While the size of commissioned water electrolysis projects in Europe remains relatively small compared to 100+ MW_{el} systems being installed in China, there is a **trend in increasing stack and installation size.** The average installation size was 0.93 MW_{el} in 2020 and 1.8 MW_{el} in September 2024 as more 10-20 MW_{el} electrolysers are being deployed at various industrial sites, the **largest being a 24 MW_{el} system** installed at Yara's site in Norway.

Given current conditions, the EU Hydrogen Strategy target of deploying 6 GW_{el} by 2024 will not be achieved. Achieving the REPowerEU target of 10 Mt domestic production by 2030 would require around 100 GW_{el} of electrolysis, which would only be possible if capacity grew at a compounded annual rate of 153%. This would mean more than doubling water electrolysis capacity every year until 2030, while CAGR since 2020 has been 44%.

FIGURE 1.3

Installed and operational water electrolysis capacity in Europe by September 2024 and since 2020 by year



Notes: Actual capacity is slightly higher due to untracked small-scale electrolysers of less than 0.3 MW.

Larger projects are being deployed in the first mover countries with either large existing demand or ambitious plans for future deployment

The deployment of ever larger water electrolytic projects is driven either by already existing high hydrogen demand and decarbonisation needs, coupled with a positive regulatory framework and available funding, as is the case for Germany, or large potential and ambitious plans, like the Nordics and Iberia.

Germany, the largest hydrogen consumer in Europe, has the largest installed water electrolysis capacity in Europe with over 122 MW_{el} in operation, its biggest electrolyser being Trailblazer's 20 MW_{el} system commissioned in 2024.

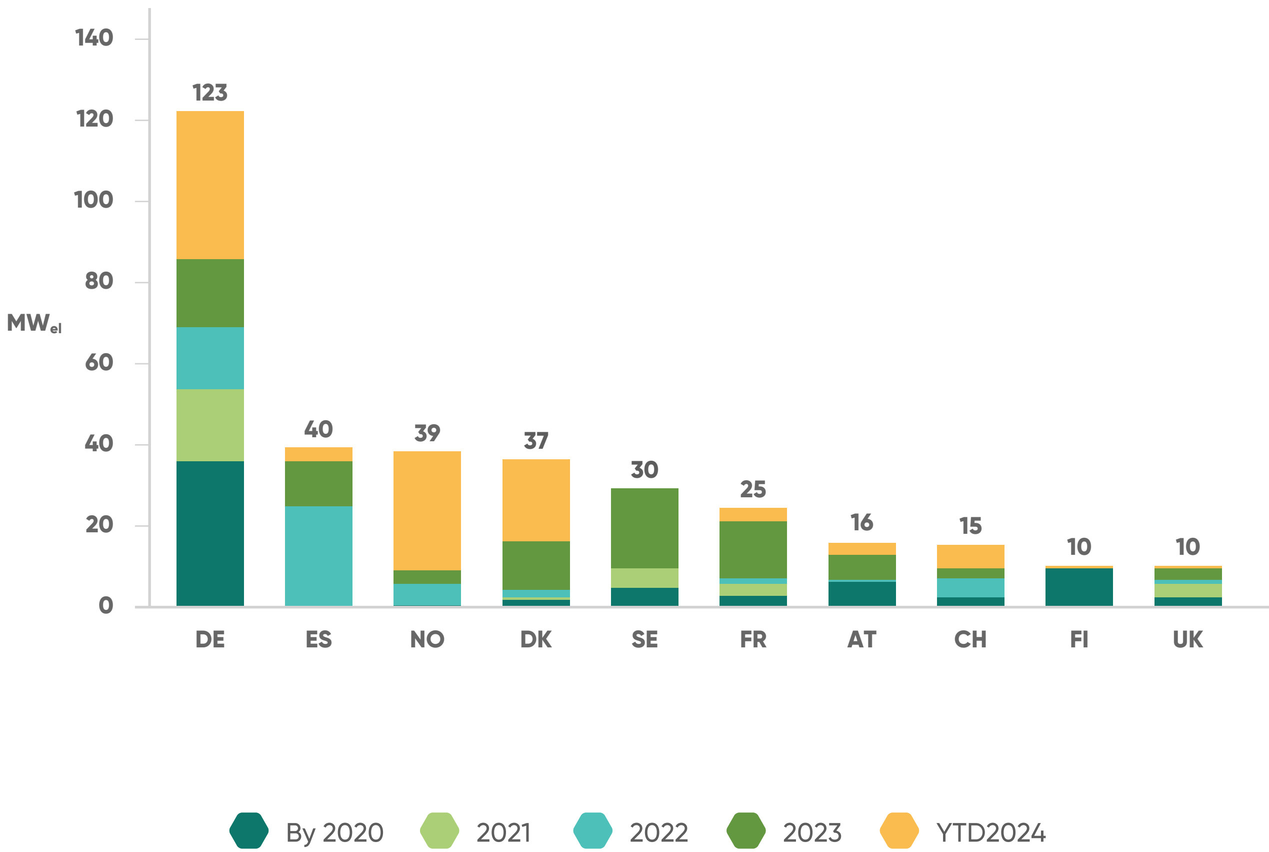
Other countries are starting to scale up, but their **overall capacity depends on flagship projects.** In 2024, Norway deployed the biggest project in Europe, a 24 MW_{el} electrolysis system at Yara's ammonia production site in Porsgrunn. Spain's Fertiberia commissioned a 20 MW_{el} at their ammonia plant in 2022. Another large deployment in the past years include Ovako's 20 MW_{el} in Sweden, used for industrial heat at a steel plant.

These are just some of the recent deployments. Chapter 3 provides more information about European and various country project pipelines and outlooks.

Clean hydrogen thermochemical projects have had more limited new deployments mostly focused on pilot and demonstration projects in the last few years and are thus not yet being reported.

FIGURE 1.4

Installed and operational water electrolysis capacity for the top 10 countries in Europe by September 2024 by year



Notes: For current deployment and state of various clean thermochemical hydrogen production projects, please see Hydrogen Europe's 2024 report, Clean Hydrogen Pathways.

Consumption of hydrogen in industry has not yet recovered after the gas prices increase in 2022

Hydrogen demand in the EU, EFTA, and UK was 7.9 Mt in 2023, a 3% decrease compared to the 8.2 Mt reported for 2022 and close to a 15% fall since 2020.

Hydrogen is mostly consumed as a feedstock in refining, fertilizer, and chemical sectors and its production is therefore directly linked to the utilisation of these industrial plants. In 2023, **refining was responsible for 58% of total demand in Europe,** followed by the ammonia sector with a 25% share.

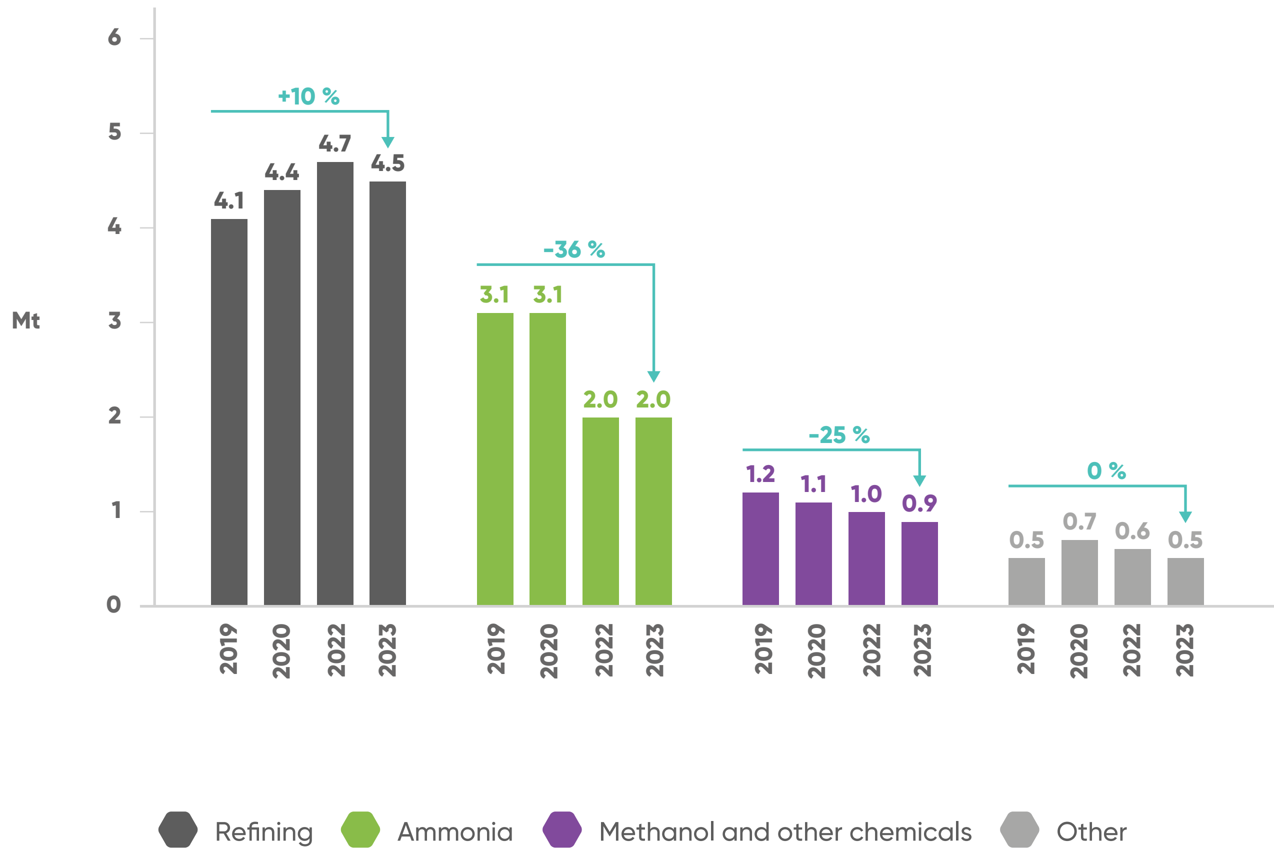
Consumption in refining has increased by over 10% since 2019, mostly due to increased needs for domestic supply of refined oil products after the embargo on imported products from Russia.

Hydrogen consumption for ammonia production decreased by 36% in 2022 to 2 Mt due to high natural gas prices. **While prices returned to around 40 EUR/MWh levels in 2023, consumption did not recover.** Some plants resumed operations while others chose to discontinue ammonia production in Europe in favour of imports. High operational costs, strict environmental measures, and Russian fertilizer imports were mentioned by these companies as key factors for their decision to decommission the plants. A similar trend is seen in the methanol and other chemical sectors.

Other uses include hydrogen used in industrial heating and mobility. Hydrogen consumed in transport is currently still a very small portion of total demand, with a negligible 0.07% market share at almost 5,000 tonnes consumed in 2023.

FIGURE 1.5

European hydrogen demand per sector 2019-2023



Notes: 2021 values are not available as Hydrogen Europe did not estimate hydrogen demand for that year. Total hydrogen demand in refining includes 2.5 Mt of dedicated hydrogen production and 2.0 Mt by-product hydrogen produced during refining processes and ethylene/styrene production. "Other" as an end-use refers to hydrogen used in industrial heating, mobility and unknown applications.

Germany, the Netherlands, and Poland accounted for 41.5% of total hydrogen consumption in Europe in 2023

A large part of **current hydrogen demand is located in European regions with limited access to cheap renewable energy sources,** which is a challenge to the decarbonisation of existing and future European hydrogen demand.

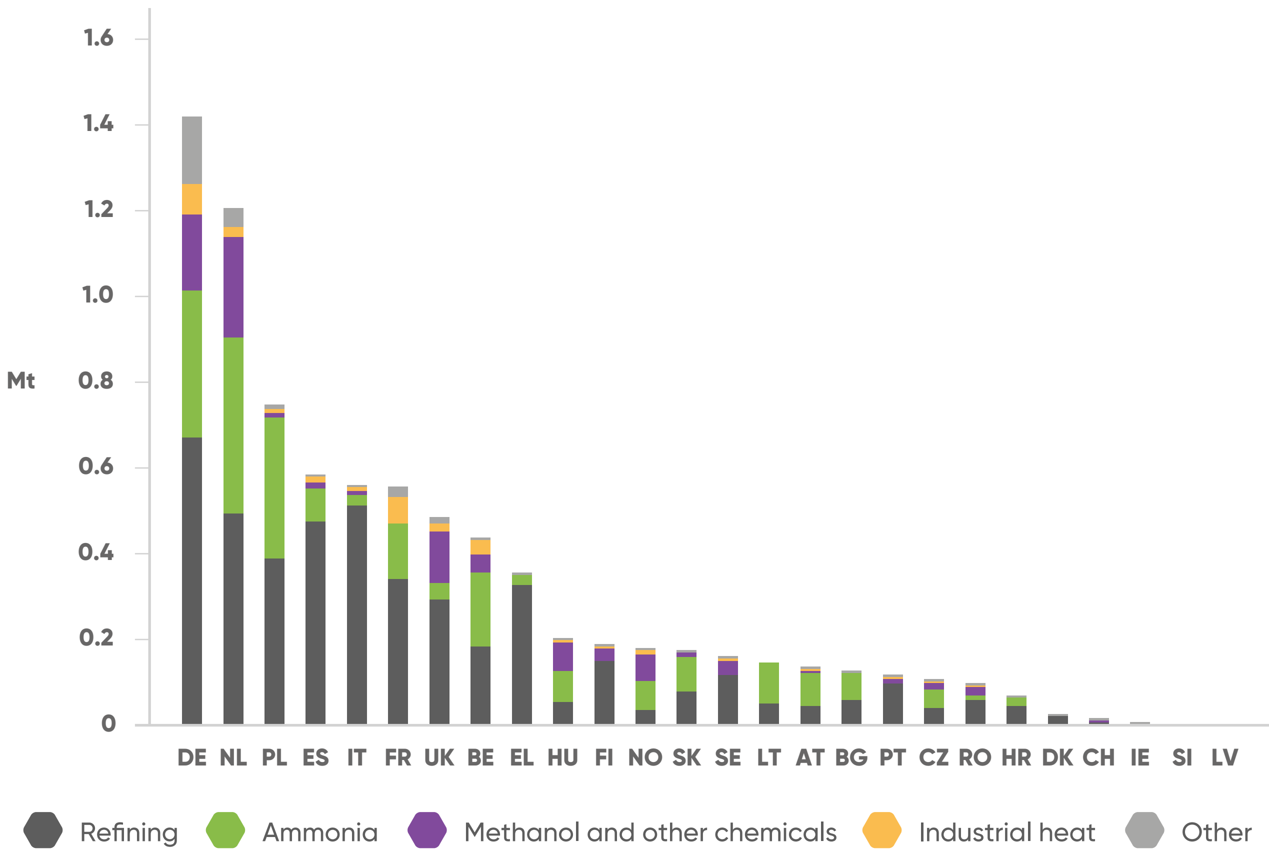
Germany, as the largest hydrogen consumer, also has the highest installed electrolysis capacity and ambitious plans for domestic production and imports, while Poland, as the third largest consumer, has, thus far, seen limited electrolysis development, and limited government ambitions and support. **The gap could be filled by regions with optimal production conditions such as Iberia and the Nordics but will require a developed transport infrastructure.**

In the majority of countries, hydrogen is mostly used in oil refining. In Italy, 92% of total consumption comes from this sector, following the shutdown of a major ammonia production site in the country.

The largest ammonia producers in Europe are Germany, Poland, the Netherlands, Belgium, and France. Ammonia producers face pressure to decarbonise their hydrogen consumption due to revision of the Renewable Energy Directive, requiring all Member States to ensure that **at least 42% of their industrial hydrogen consumption consist of renewable fuel of non-biological origin (RFNBO) by 2030,** excluding hydrogen used in fuel refining processes.

FIGURE 1.6

Hydrogen demand per country and sector in Europe in 2023



Notes: "Industrial heat" as an end-use includes the combustion of hydrogen in boilers for the production of steam, combined heat and power systems or other processes with the intention of producing heat in the industrial sector. In this graph, "other" as an end-use refers to mobility and unknown applications.

Ammonia and methanol are global commodities with imports being 16% of ammonia and 87% of methanol consumption in Europe

Ammonia and methanol are products that benefit from a well-established trade infrastructure and existing imports into Europe. In 2023, 16% of total ammonia supply to Europe was represented by imports. Both European production and imports of ammonia have been decreasing, resulting in an overall lower supply. This may be explained by increased imports of other derivative products such as urea and ammonium nitrate, used in the fertiliser industry.

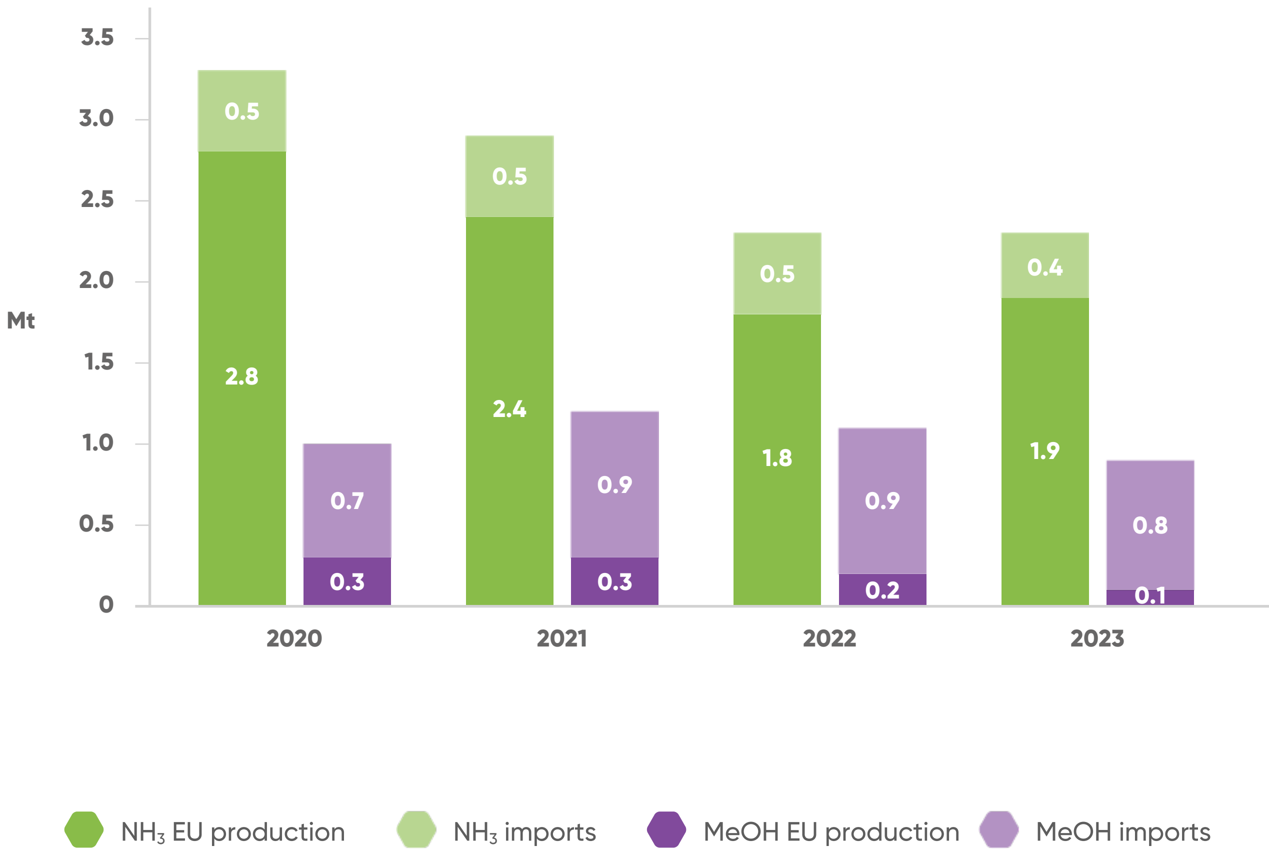
Methanol supply to Europe has relied mostly on imports, which reached 87% of total supply in 2023. In the past few years, European production has decreased as imports remained stable, testimony of the high energy prices.

RED industry targets affect industries consuming hydrogen today, with ammonia and methanol as the most impacted sectors. Current producers of these goods can either replace 42% of their hydrogen consumption with RFNBO or might be forced to reduce their consumption altogether, namely through the imports of methanol and ammonia (or derivatives) from outside of Europe.

Without the sufficient public support and speeding up of infrastructure, **there is a risk that RED targets are fulfilled by increased imports of unabated methanol and ammonia or fertilisers.**

FIGURE 1.7

Hydrogen consumed in the production of ammonia and methanol in the EU and their imports



Notes: EU production for 2021 and all the values for imports of methanol and ammonia were taken from Eurostat's International Trade database.

Overall consumption of hydrogen in mobility increased by 43% in 2023 compared to 2022

The overall number of fuel cell electric vehicles (FCEV) registered in Europe has been increasing over the years. The number of new registrations, however, has decreased in 2023 compared to 2022.

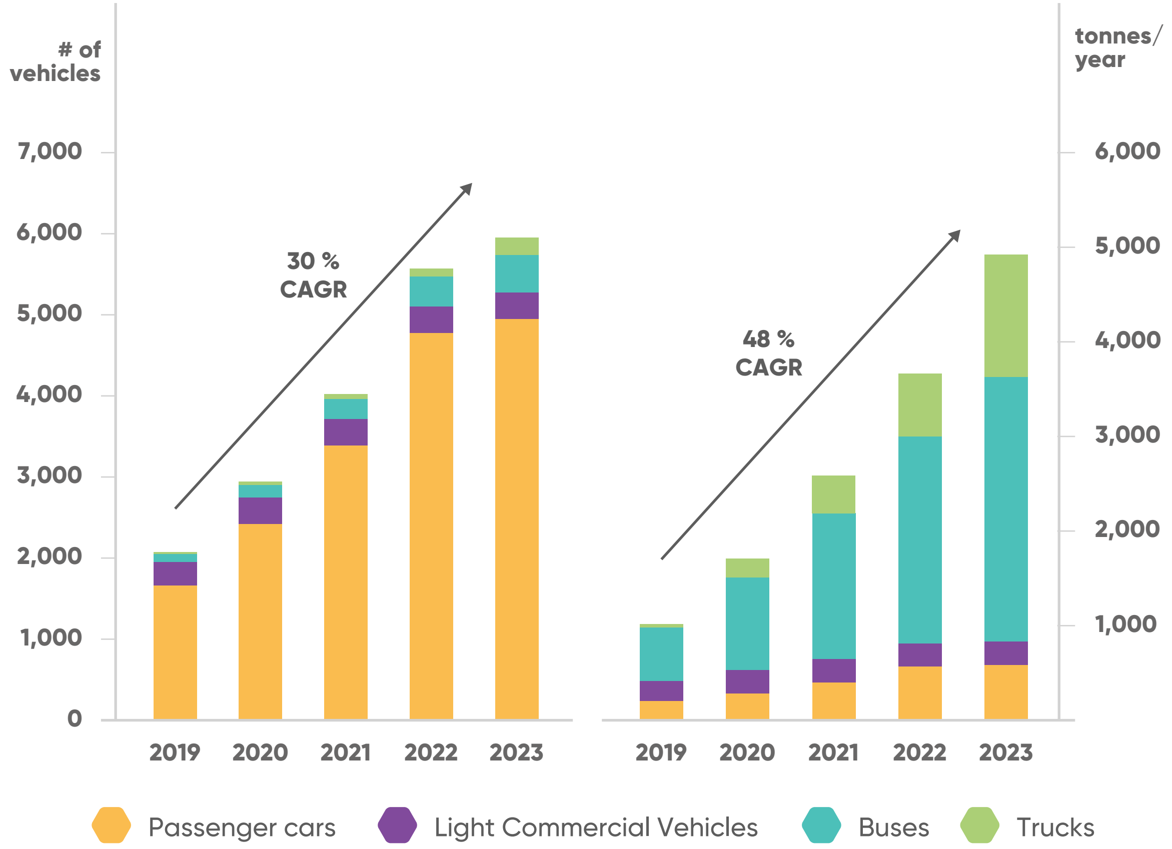
By the end of 2023, a total of **5,939[1] vehicles were registered in Europe,** with passenger cars representing 83% of this amount. Germany is the country with the highest number of registrations, with 2,122 passenger cars, 149 buses, 30 trucks and 16 light commercial vehicles.

Between 2022 and 2023, the number of hydrogen fuelled trucks doubled from 109 to 215. Due to higher mileage and energy requirements, trucks can consume 50 times more hydrogen than passenger cars, therefore a doubling of its fleet can significantly increase the overall consumption of hydrogen in mobility.

Based on the number of vehicles registered, the consumption of hydrogen in mobility was around 5,000 tonnes in 2023, with 2,900 tonnes dedicated to buses and 1,400 tonnes dedicated to trucks. This represents a **43% increase in consumption compared to 2022,** where overall consumption was around 3,500 tonnes.

FIGURE 1.8

Fuel cell electric vehicles fleet and their hydrogen consumption in Europe per year from 2019 until 2023 per vehicle type



Notes: Hydrogen consumption is estimated based on the number of vehicles registered each year and considering an average yearly consumption for each type of vehicle.

Methodological Note

GEOGRAPHICAL SCOPE: This chapter covers 32 countries in the EU, the European Free Trade Area, and the UK, which are referred to as „Europe" in the text. Results in this chapter may purposefully exclude some countries depending on the quantity and quality of the collected information. Reference to the EU covers only the 27 countries of the European Union.

TERMINOLOGY: Reforming (SMR, POX, etc) refers to conventional fossil-fuel based dedicated production of hydrogen, while Reforming (refinery off-gas) refers to the production of hydrogen as a by-product in refining processes (e.g., during catalytic reforming). A separate category is shown for hydrogen produced as a by-product from ethylene and styrene production, and another for hydrogen produced as a by-product from the electrolysis of brine. Water electrolysis projects include all potential sources of electricity. Reforming with carbon capture projects can include CCU projects where the captured carbon is used or CCS projects where the captured carbon is permanently stored. Further terminology explanation can be found at the end of the report in the Terminology section.

DATA SOURCES: Hydrogen production capacity data is collected mostly from public sources, with the validation from national associations and/or companies whenever possible. The authors collect this information to the best of their abilities but cannot guarantee the absolute completeness or accuracy of the collected data. The annual utilisation of total capacity is based on public announcements from the companies. Whenever this is unavailable, sectoral utilisation rates are taken from public sources such as Eurostat, the Energy Institute, Eurochlor, and CEFIC.

PRODUCTION CAPACITY ASSUMPTIONS: The conversion between electrolysis capacity expressed in MW_{el} and tonnes per year is made using a 53 kWh/kg efficiency and assuming 8760 full load hours.

CONSUMPTION ASSUMPTIONS: Actual production and consumption of hydrogen in Europe is estimated based on known utilisation of industrial conventional plants and electrolytic hydrogen production plants, the consumption of registered fuel cell electric vehicles and the balance between the imports and exports of hydrogen in Europe.

The following assumptions are taken regarding the annual consumption of hydrogen in fuel cell electric vehicles:

- 120 kg/vehicle for passenger cars
- 750 kg/vehicle for light commercial vehicles
- 6,000 kg/vehicle for buses
- 6,000 kg/vehicle for trucks.

Endnotes

1 / European Alternative Fuels Observatory, 2024


H2


MRC
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BCE ECB

02

Production costs and drivers

Hydrogen production costs for all key technologies decreased in 2023. On average, however, the cost gap between renewable hydrogen and fossil-fuel-based hydrogen increased in 2023 compared to 2022 – mostly due to fall in natural gas prices.

- Falling natural gas prices in 2023, following a price spike the previous year, have resulted in a 44% decrease of fossil-fuel-based hydrogen production costs in the EU, reaching around 3.2 EUR/kg. Costs of hydrogen production with CCS in the EU in 2023 are estimated at around 3.8 EUR/kg, falling from 6.3 EUR/kg in 2022.

- Renewable hydrogen production costs in Europe can be as low as 4.1 EUR/kg, but on most markets the cost gap to conventional hydrogen remains significant with the average renewable hydrogen production costs in Europe of around 6.6 EUR/kg.

- Electrolyser technology developments (reduction of CAPEX and improved efficiency) and renewable energy LCOE decrease, should reduce renewable hydrogen production costs by around 24%, narrowing the cost gap to less than 1 EUR/kg in a number of European markets and to approach cost parity in countries with high potential of low-cost renewables (Iberia and Greece for solar PV and Ireland, UK and Nordics for wind).

Falling natural gas prices in 2023 resulted in a 44% decrease of fossil-fuel-based hydrogen production costs in the EU – to an estimated 3.2 EUR/kg

Most hydrogen production in the EU (and globally) is derived from fossil fuels, primarily natural gas through steam methane reforming (SMR). Replacing fossil-fuel-based hydrogen is the most immediate market opportunity for clean hydrogen, and thus - SMR production costs offer a useful price benchmark.

In 2023, **the estimated levelized production cost of hydrogen via SMR in the EU was around 3.2 EUR/kg, a 44% decrease compared to 2022.** Marginal costs, often more relevant for operational SMR plants, are estimated at 2.94 EUR/kg in the EU-27 for 2023. This reduction is directly linked to the decline in natural gas prices, from a spike of 123 EUR/MWh in 2022 (due to the Russian invasion of Ukraine and the subsequent natural gas embargo) to 41 EUR/MWh in 2023.

As natural gas costs are the main driver of hydrogen production costs through SMR, so any further decreases in gas prices would also further reduce production costs. However, this will be partially offset by the phase-out of ETS free allowances for hydrogen and the expected grow of emission allowances costs. However, this will be partially offset by the phase-out of ETS free allowances for hydrogen and the expected grow of emission allowances costs.

FIGURE 2.1

Breakdown of the levelized costs of hydrogen production via SMR in the EU-27 in 2023

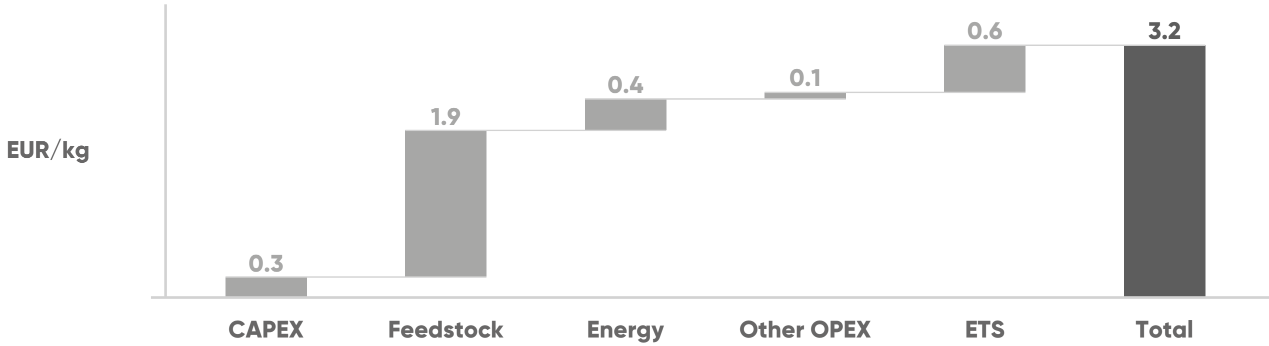
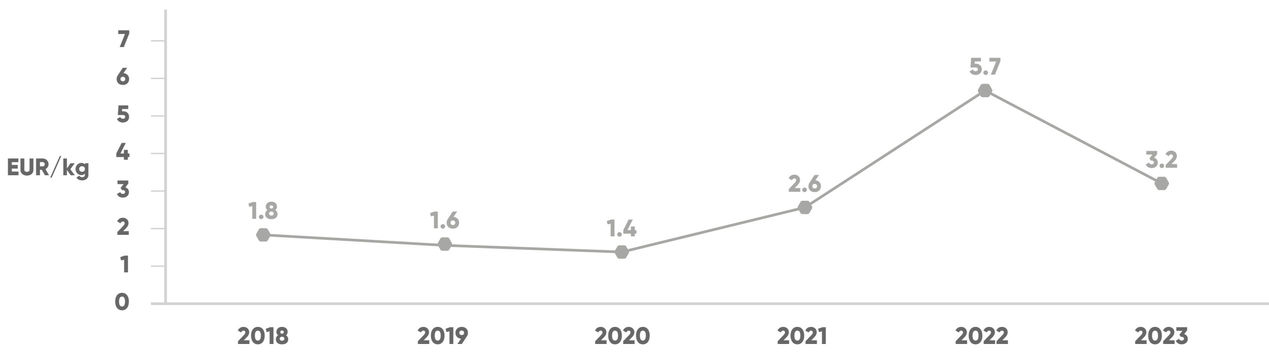


FIGURE 2.2

Levelized costs of hydrogen production via SMR in the EU-27 in 2018-2023



Notes: Key assumptions behind the estimated 2023 production costs are CAPEX: 550 EUR/kWH$_2$, gas consumption: 1.33 MWh/MWhH$_2$, gas costs (energy and network fees): 42 EUR/MWh, electricity consumption: 0.094 MWh/MWhH$_2$, electricity costs (energy and network fees): 128 EUR/MWh, other OPEX: 4% of CAPEX, CO_2 price: 83.2 EUR/tCO_2

The estimated cost of H2 production with CCS in the EU is estimated at 3.8 EUR/kg (for new plants with high CO_2 capture rates and 2023 gas prices)

For gas reforming with CCS, as with unabated fossil-fuel-based hydrogen production, natural gas feedstock remains the primary cost driver. As a result, production costs for gas-based low-carbon hydrogen dropped significantly in 2023 compared to 2022. **For 2023, hydrogen production via autothermal reforming (ATR) with CCS (95% CO_2 capture rate) in the EU-27 was estimated at 3.8 EUR/kg, a 40% decrease from 2022.**

These costs are based on the assumption of new ATR installations. Adding CCS to existing SMR units may be cheaper but achieving the required carbon capture rate could be challenging, potentially affecting the low-carbon qualification of the hydrogen. With over 95% of CO_2 emissions avoided, the impact of ETS emission allowances is limited, especially with the phase-out of free allowances.

The cost competitiveness depends heavily on CO_2 transportation and storage costs, estimated at 100 EUR/t based on industry feedback. As these costs can vary significantly between projects – it is one of key the risks for project developers, especially in the context of lacking CO_2 infrastructure. True storage costs will only become evident after extensive real-world experience is gathered, but studies suggest that these costs could be optimised to EUR 5-40/t[1]. In current market conditions, to achieve parity with unabated gas-based hydrogen, CO_2 management costs would need to remain under 35 EUR/t.

FIGURE 2.3

Breakdown of the levelized costs of hydrogen production via natural gas reforming with CCS in the EU-27 (green field plant with ATR technology, 2023 gas prices)

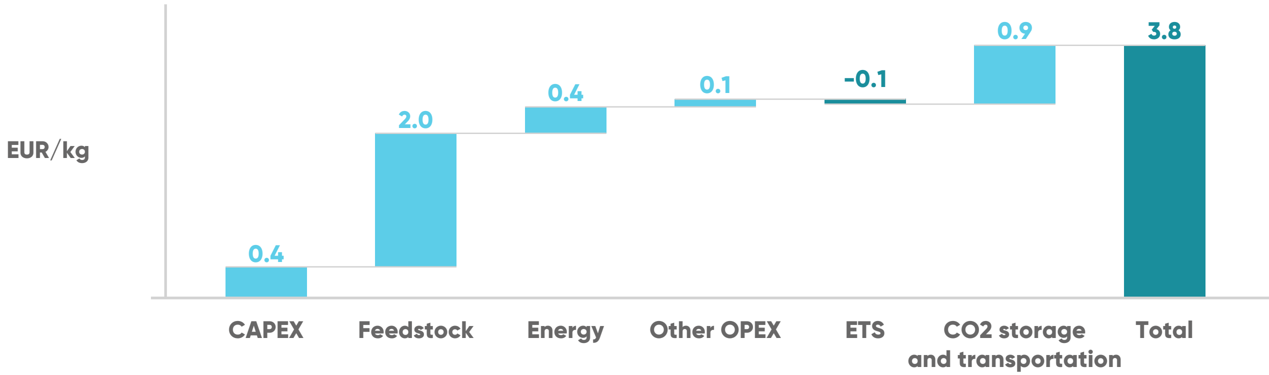
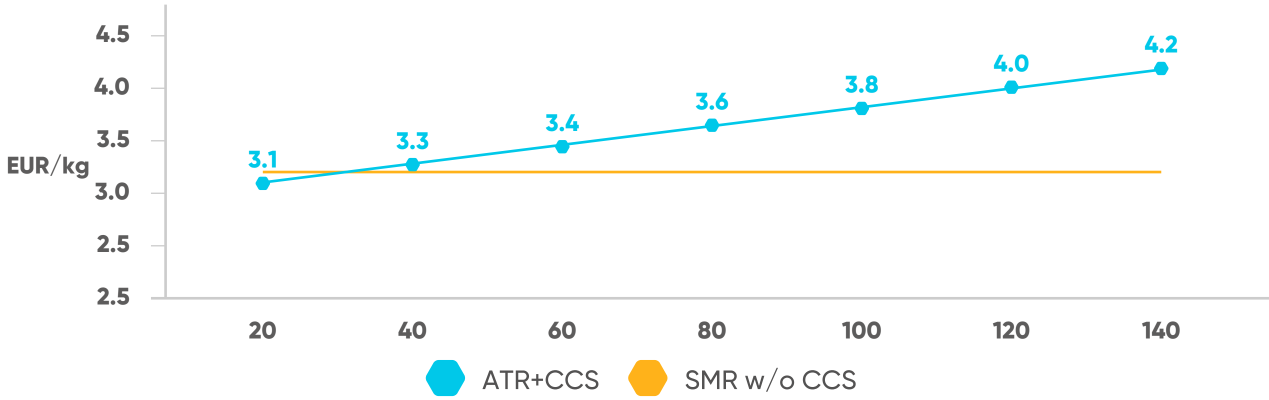


FIGURE 2.4

Levelized costs of hydrogen production via natural gas reforming with CCS depending on CO_2 transport and storage costs.



Notes: Key assumptions behind the estimated 2023 production costs are CAPEX: 900 EUR/kWH2, gas consumption: 1.45 MWh/MWhH₂, gas costs (energy and network fees): 42 EUR/MWh, electricity consumption: 0.094 MWh/MWhH₂, electricity costs (energy and network fees): 128 EUR/MWh, other OPEX: 4% of CAPEX, CO_2 price: 83.2 EUR/tCO_2, CO_2 storage and transportation costs: 100 EUR/tCO_2, CO_2 capture rate: 94%.

Fall in wholesale electricity prices in Europe in 2023 has led to a 20% decrease of grid connected hydrogen production costs, estimated at 7.9 EUR/kg

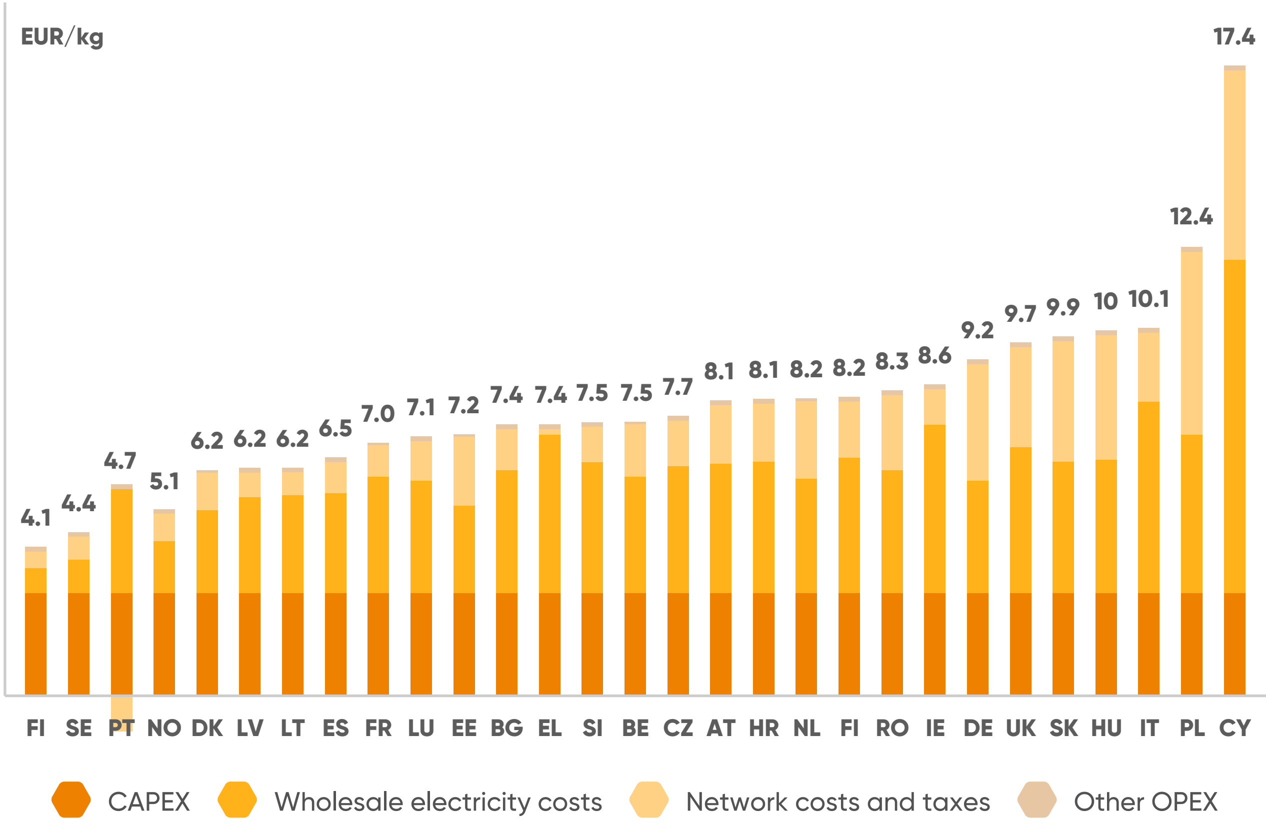
In 2023, the average levelized cost of hydrogen production via grid-connected electrolysis in Europe was about 7.9 EUR/kg, a nearly 20% decrease from 9.8 EUR/kg in 2022. This drop resulted from lower natural gas prices, as natural gas-fired power plants often set wholesale electricity prices in most EU markets.

Marginal costs account for the largest share (~61%) of the total cost on average. Within marginal costs, wholesale electricity costs accounted for over 70%, with an absolute share of 42% of the LCOH. CAPEX represents the second most significant portion, contributing ~38% to the overall cost.

Sweden and Finland have the lowest hydrogen production costs at 4.4 EUR/kg and 4.1 EUR/kg, respectively. Out of all the main hydrogen markets, Poland had the highest grid electricity hydrogen production costs, estimated to be around 12.4 EUR/kg, and was one of the few European countries where costs increased in 2022. The main factor driving these differences is electricity cost, but network fees and taxes also play a significant role. Some countries, such as Portugal, Greece, Bulgaria, and Latvia, have tax schemes that mitigate these costs, while in Poland, taxes and grid fees add over 5.1 EUR/kg, making production uneconomical even before factoring in investment and electricity costs. Please note all the figures are theoretical numbers based on average price values, and do not reflect the complexities of projects, which might require minimum higher number of operational hours, storage and other aspects.

FIGURE 2.5

Estimated levelized costs of hydrogen production via water electrolysis using grid-mix electricity in Europe in 2023 (excluding any possible transport, storage and conditioning cost)



Notes: Key assumptions behind the estimated 2023 production costs are CAPEX: 2,250 EUR/kW_{el}, electricity consumption: 52.4 MWh/tH_2, other OPEX: 2% of CAPEX, stack durability 80,000 h, annual running time: 4,000 full load hours during periods of lowest costs on the wholesale electricity market.

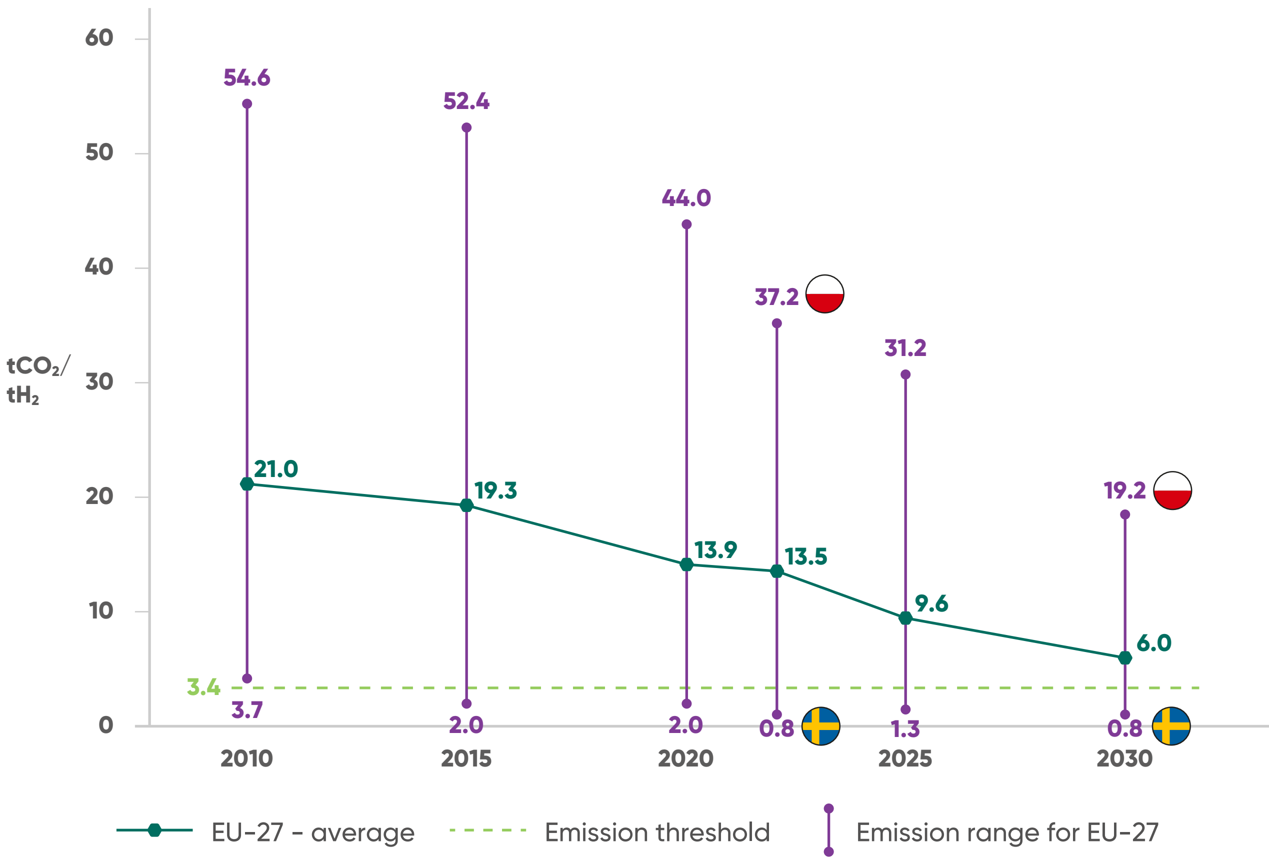
Today only three countries in Europe could produce low-carbon hydrogen by water electrolysis using grid electricity. By 2030 that number is expected to grow to nine

After years of declining GHG intensity in European electricity production, 2022 saw an increase from 238 to 258 gCO_2/kWh for the second consecutive year[2]. This means hydrogen production using the EU-27 average electricity mix in 2022 would result in GHG emissions of 13.5 tCO_2e/tH_2, exceeding emissions from unabated steam methane reforming, the dominant fossil-fuel-based hydrogen production method. This highlights the importance of low-carbon electricity for the production of hydrogen.

The GHG footprint of grid-powered water electrolysis varies significantly across Europe. In countries like Iceland, with nearly 100% decarbonised grids, hydrogen produced from the grid has a low GHG footprint, similar to renewable hydrogen. In other countries, including **Norway, Sweden, and France, the GHG intensity of grid electricity is also sufficiently low for the produced hydrogen to meet all emission benchmarks set by the EU,** including the EU taxonomy on sustainable finance, and the RED GHG limit for RFNBOs set at 3.38 tCO_2e/tH_2. Conversely, in countries like Estonia, Bulgaria, or Poland, which still rely heavily on coal for power generation, using grid electricity would lead to more than three times as much GHG emissions as natural gas reforming. While the situation is expected to gradually improve, as more countries decarbonize, **by 2030, using grid electricity in the EU is still, on average, projected to result in around 6.0 tCO_2e/tH_2.**

FIGURE 2.6

GHG intensity of hydrogen produced from grid electricity in the EU, compared to the low-emission benchmark defined in the EU legislation



Notes: Emission intensity data is provided for 2022 as data for 2023 is not yet available.

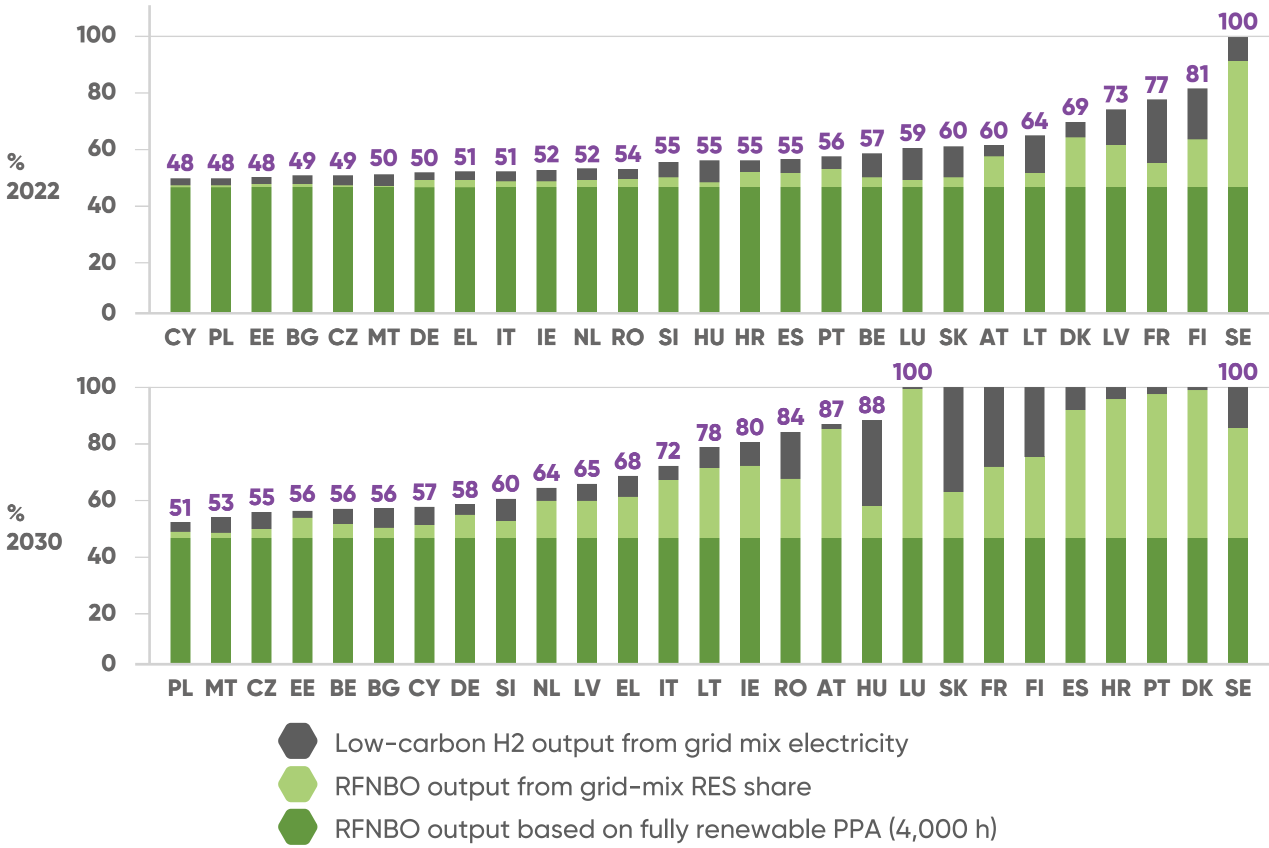
High average GHG intensity of electricity in the EU, combined with strict temporal correlation rules is proving to be a challenge for industrial offtakers

Using grid electricity can be valuable for RFNBO producers to increase electrolyser capacity utilisation and to manage variable renewable electricity, especially in industrial applications with limited flexibility. The renewable energy share in the electricity mix also boosts RFNBO output beyond the renewable portion used directly or via PPA. However, the average GHG intensity of electricity supplied to the electrolyser at any given hour cannot exceed around 18 gCO_2/MJ as otherwise it would disqualify even the renewable portion of output from being classified as RFNBO. This presents a challenge due to the high GHG intensity of European electricity.

Figure 2.7 shows how much an electrolyser supplied with fully renewable electricity covering 4,000 full load hours (marked as dark green) can increase its production using grid electricity without risking exceeding the emission intensity limit. In Sweden, with a low GHG-intensive electricity mix, an electrolyser could operate at full load with 83% of grid electricity contributing to RFNBO output (light green) and the rest classified as low-carbon hydrogen (grey). **By 2030, the situation is expected to improve with 9 countries being able to use grid electricity without limitations.** On the other hand, in Poland, only 9% of electricity consumed can be sourced from the grid without exceeding the emissions threshold, with little improvement expected by 2030.

FIGURE 2.7

Maximum achievable utilisation of electrolyser with a mix of electricity sources consisting of renewable PPA providing 4,000 full load hours combined with grid-mix electricity in selected European countries in 2022 and outlook for 2030



Notes: In case of France, if overseas territories would be excluded, the mainland bidding zone's carbon intensity is also low enough to enable the use of grid electricity.

The Hydrogen bank has delivered good projects with competitive hydrogen production costs. However, it requires transport infrastructure to make it a viable business case

Renewable hydrogen production costs in Europe show significant variability. As the results of the recent 1st Hydrogen Bank auction has shown the **renewable hydrogen production costs can be as low as 5.3 EUR/kg (average for Greece) and as high as 13.5 EUR/kg (average for Poland), with the median around 7.6 EUR/kg.**

The most powerful explanatory factor behind these differences is availability of low-cost renewable electricity, but other factors, like electrolyser utilisation, grid fees exemptions, need for hydrogen storage and transportation, can play a role as well. One of the reasons behind Sweden's cost competitiveness is the exemptions from the additionality requirement, project promoters in that country enjoy on the back of low GHG intensity of grid electricity allowing high utiltisation factors.

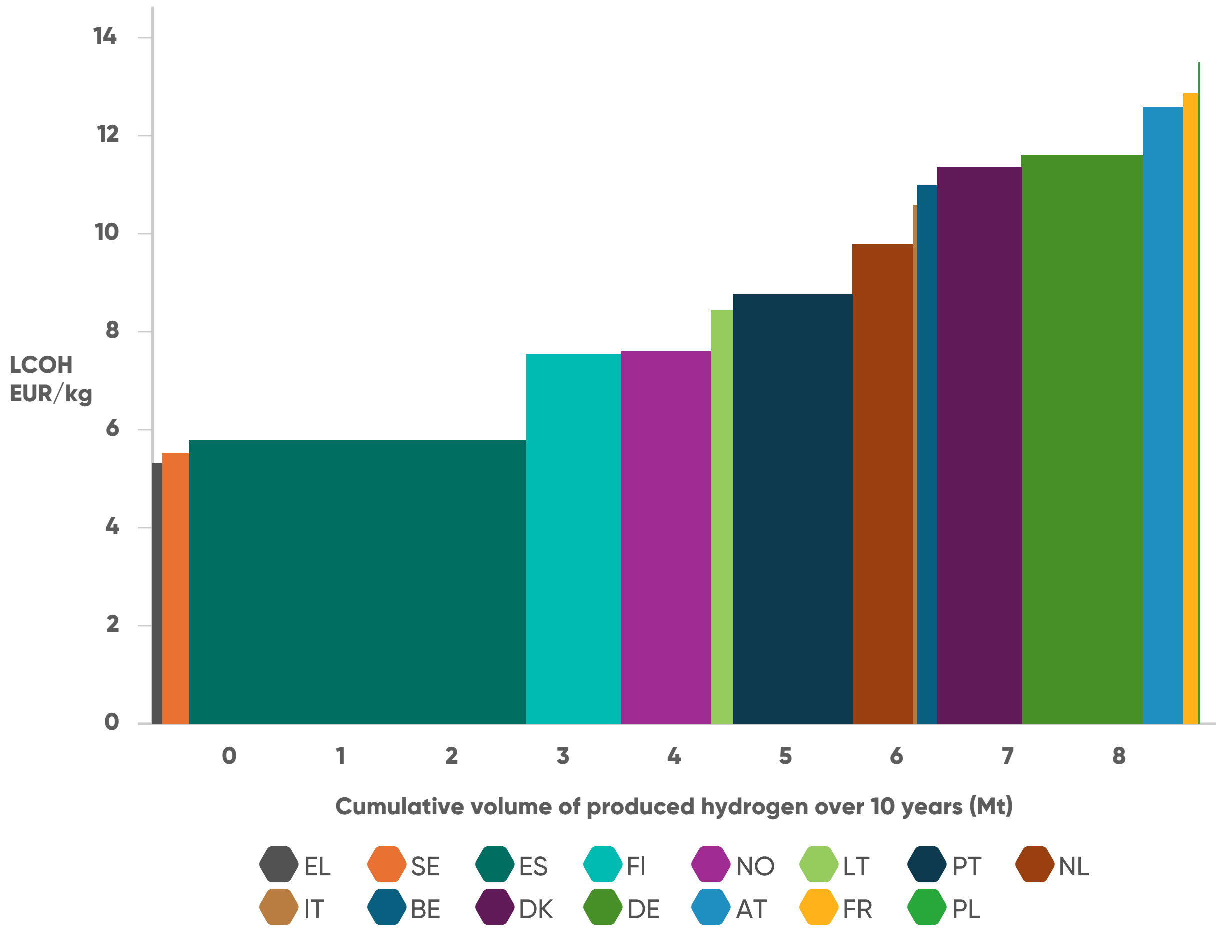
In countries with the lowest production costs, the price gap between renewable and fossil-fuel-based hydrogen is on average about 2-2.5 EUR/kg. However, in countries with significant current conventional hydrogen consumption, the gap is much larger, reaching even up to 6-10 EUR/kg in Germany, the Netherlands and Poland.

These differences in renewable hydrogen production costs across Europe create a strong case for developing a European hydrogen pipeline and storage network, as costs of hydrogen transportation by pipelines are estimated at 0.3 EUR/kg per 1,000 km.

It should be noted however that the sample of projects in the Hydrogen Bank is much smaller than the overall project pipeline (see next chapter) and might not be fully representative - especially for countries with relatively few bids.

FIGURE 2.8

Declared hydrogen production costs (average) in selected European countries (EUR/kg), in the 1st Hydrogen Bank auction



Methodological Note

The presented hydrogen production costs are not reported statistical costs gathered from real projects, but estimates based on annually updated cost assumptions. The production costs were estimated for several technologies and scenarios:

- Steam methane reforming without CCS,
- Auto-thermal reforming with CCS,
- Water electrolysis grid-mix electricity.

In all cases, the estimations are based on a levelized cost approach, where all expenditures (both CAPEX and OPEX) as well as revenues from co-products and ETS (if applicable) are discounted using a discount rate reflecting the average risk of hydrogen production projects, using the following formula:

$$\frac{I_0 + \sum_{t=1}^{n} \frac{I_t + E_t + M_t - CO2_t - R_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{H2_t}{(1+r)^t}}$$

Where, I_0 - investment expenditure in year 0; I_t – replacement investments (e.g., stack replacement costs); E_t – energy inputs costs, M_t - other operational and maintenance costs; $CO2_t$ – balance or revenues and costs from participation in the ETS system and captured CO2 transport and storage costs, R_t – revenues from sales of by-products; $H2_t$ – hydrogen production; r - discount rate; n - lifetime of the system in years.

The electrolysis system cost assumptions were based mainly on the latest information for current state-of-the-art 10 MW_{el} alkaline electrolysis with the following key assumptions:

- **CAPEX:** 2250 EUR/kW,
- **Economic life time:** 25 years,
- **Stack durability:** 80,000h,
- **Stack replacement costs:** 15% CAPEX,
- **Energy consumption:** 52.4 kWh/kg,
- **Stack degradation:** 0.0012 per 1000 hrs,
- **Other OPEX:** 2% of CAPEX.

For grid-connected electrolysis, the capacity factor of the electrolyser was assumed to be 4,000 hours, with the running hour set to fall in time with the lowest wholesale electricity prices (based on data from the ENTSO-E's transparency portal). Network costs, taxes and fees were included in this scenario (based on Eurostat data on electricity prices for non-household consumers in the consumption range from 20,000 MWh to 69,999 MWh per year).

Used data sources

- European Environmental Agency data on carbon intensity of grid electricity in the EU-27[2];

- Hydrogen Europe members survey on electrolysis system current CAPEX;

- European Network of Transmission System Operators for wholesale electricity prices in various EU Member States[3];

- Clean Hydrogen JU Strategic Research and Innovation Agenda for electrolyser efficiency, stack durability, stack degradation and O&M costs[4];

- Eurostat's and other national statistical office's statistical data for 2023 covering electricity and natural gas costs (costs of energy as well as taxes and grid fees) for non-household consumers[5].

For detailes assumptions with regards to the natural gas based technologies, please refer to the **Clean Hydrogen Production Pathways report 2024**[6].

Endnotes

1 / Smith et al., 2021

2 / EEA, 2024

3 / ENTSO-E, (2024)

4 / CH JU, 2022

5/ Eurostat, 2024

6 / Hydrogen Europe, 2024


H2
H2
H2

03

European clean hydrogen supply outlook to 2030

Clean hydrogen production announcements in Europe are increasing every year. Under the Current Trajectory, we are heading towards 2.5 Mt of clean hydrogen produced in Europe by 2030. Projects continue to grapple with challenging economics, finding long-term offtakers, regulatory constraints, and slowly developing infrastructure while binding regulatory demand is uncertain in most countries.

- Nordics and Iberia will likely become supply centres but in the short term, supply is limited to replacing existing demand (mostly refineries) until pipelines and port infrastructure are developed, helping to supply hydrogen and derivatives to other key demand centres in Europe. Some countries, like France, could be self-sufficient by 2030 while others, like Germany and Benelux, will need to focus both on domestic production as well as intra and extra European imports to meet their decarbonisation targets.

- Electrolytic hydrogen dominates the supply outlook with 1.7 to 3 Mt under the Current Trajectory and Accelerated Adoption scenarios respectively. Demand is driven by obligations in transport and industry. Thermochemical hydrogen supply reaches 0.8 Mt to 1.4 Mt by 2030 depending on the available funding and access to CO_2 transport and storage infrastructure, driven mostly by UK, Netherlands, Norway, and Germany.

- Refining, ammonia, and steel have been identified as the largest end-uses for clean hydrogen produced in Europe by 2030. Ammonia is popular as a derivative for export-oriented projects in the absence of infrastructure. Use of hydrogen as intermediate product in oil refining is driven by RED3 mobility targets. In case of green steel, the projects are often made possible by offtakers' willingness to pay a green premium.

- EU-level funding schemes have allocated approximately EUR 5 billion to support hydrogen initiatives since 2021, mainly driven by Innovation Fund and Horizon Europe. Member States have pledged EUR 18.9 billion to the sector through Important Projects of Common European Interest (IPCEIs). Additionally, we estimate committed national funding (past and upcoming) up to EUR 37 billion, with 40% coming from Germany, and 27% from the Netherlands alone. Majority of this national funding has yet to be granted to companies for diverse reasons.

Europe can expect a supply of 2.5 to 4.4 Mt of clean hydrogen by 2030, driven by regulatory demand but highly dependent on regulatory constraints, access to funding, and the development of pan-European infrastructure

The Current Trajectory scenario (CT) forecasts 1.7 Mt of electrolytic and 0.8 Mt of thermochemical hydrogen supply in Europe by 2030. With improved market conditions (see page 41), projects in Europe could supply 4.4 Mt of clean hydrogen by 2030. **The Accelerated Adoption (AA) scenario forecasts 3 Mt of electrolytic and 1.4 Mt of thermochemical hydrogen.** That represents 30%-54% of the current (2023) demand of 7.9 Mt and largely misses the ambitions set by the EU hydrogen strategy and REPowerEU.

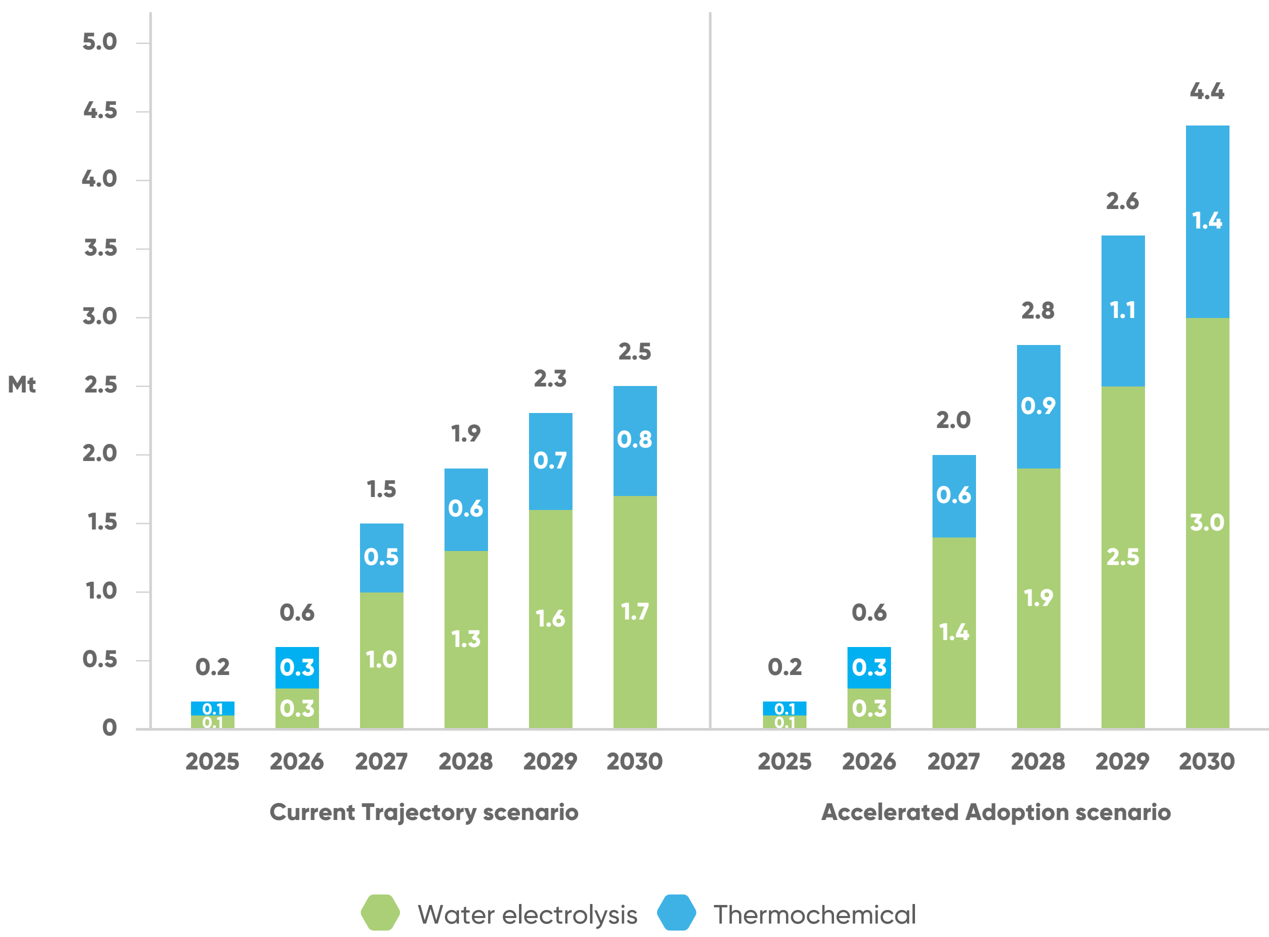
Both scenarios are based on the existing project pipeline, the known available funding, government strategies, binding targets, and the current state of the market.

The **CT scenario** represents the current market trajectory **with many, but not all, funded projects becoming commissioned.** Developers continue to grapple with increasing project costs, largely driven by high PPA costs to achieve decent utilisations (e.g., compliance with temporal correlation), tedious funding processes, missing infrastructure, as well as regulatory uncertainty for low-carbon hydrogen leading to less offtakers' appetite.

The **AA scenario takes a more optimistic perspective on the development of the clean hydrogen market** and assumes that some of the improvements to funding, European regulatory framework, national implementation, and infrastructure occur. That would lead to more projects deployed, allowing the industry to scale up faster and thus accelerate the expected cost reduction and help build a positive momentum before 2030.

FIGURE 3.1

Forecast of European clean hydrogen supply by 2030



Levers to reach the Accelerated Adoption scenario and 4.4 Mt of clean hydrogen produced in Europe by 2030

Lever	ISSUE:	
EU regulatory framework	**COMPLICATED OR MISSING REGULATORY FRAMEWORK FOR CLEAN HYDROGEN PRODUCTION**	Developers continue to delay or cancel projects due to regulatory uncertainty or regulatory compliance costs for producing renewable or low-carbon hydrogen. **Regulatory framework** – Create an investment friendly regulatory framework for all clean hydrogen production technologies that are aligned with the 2050 Climate targets. **Renewable fuels of non-biological origin (RFNBO) DA** – Review the definition of RFNBO by 2026 latest, making it a lot more pragmatic to spur deployment and scale-up the industry. **Low-carbon hydrogen DA** – Adopt a definition of low-carbon hydrogen that encompasses and enables all production pathways as long as they meet strict emissions criteria.
National implementation	**LACKING NATIONAL REGULATORY FRAMEWORKS**	National transposition of RED3 and Hydrogen and Decarbonised Gas Markets package creates uncertainty. Developers and offtakers are unsure whether and how should the targets be met, whether there will be obligations and penalties, which incentives are available and whether a hydrogen infrastructure will be in place to help deliver clean hydrogen. **Target structure** – Provide visibility on how the industry and transport targets will be transposed. **Penalties** – The Commission to clarify what penalties for Member States for non-compliance and encourage penalty uniformity if targets are implemented at company level. **Certification** – Attain Member State acknowledgment or adoption of certification schemes endorsed by the Commission. **Book and claim** – Get clarity on transferability of RFNBO credits and creation of a book and claim system for RED3 compliance (like for ReFuelEU Aviation).
Funding	**INADEQUATE FUNDING MECHANISMS AT EU AND NATIONAL LEVEL**	EU funding is limited and complex (Innovation Fund calls, EU Hydrogen Bank) while national level funding can be dispersed and not effectively supporting market uptake. Some countries still lack a clear funding scheme for clean hydrogen deployment. **European funding** – The EU Hydrogen Bank should evolve to further support offtaker risks and to include imports. Rules on accumulation need to be addressed to facilitate the funding of projects. **National funding** – Member States should develop mechanisms to address the cost gap between clean and conventional hydrogen. Mechanism to support production can be complemented with offtaker support in the form of CCfD. It is important to continue supporting innovation and industrialisation, with a reinforced focus on deployment through OPEX base schemes.
Infrastructure	**SLOW DEVELOPMENT OF HYDROGEN TRANSPORT, STORAGE, AND IMPORT INFRASTRUCTURE PREVENTING CONNECTING CLEAN HYDROGEN SUPPLIERS AND INDUSTRIAL CONSUMERS**	**Implementation** – Rapidly implement the Hydrogen and Decarbonised Gas Markets package at national level, designating a hydrogen network operator, clarifying the framework for third party access to infrastructure, and design a funding framework for infrastructure roll out. **Planning and modelling** – Incorporate energy storage into network development and strengthen cross-sectoral system planning via better scenarios and improved modelling tools. **Strategy** – Develop a European hydrogen grid and storage strategy that forms a fundamental pillar of the EU grid action plan.

4% of the project pipeline is under construction and 34% of the project pipeline is in an advanced stage

Hydrogen Europe is currently monitoring **903 announced clean hydrogen production projects with plans to come online by 2030 with total production volume of 14.4 Mt.**

These include 844 electrolytic projects amounting to 8.9 Mt/year by 2030 and 59 clean thermochemical projects amounting to 5.5 Mt/year; the latter planning to reform natural gas and capture the associated emissions, split methane, or otherwise produce abated hydrogen from various waste streams.

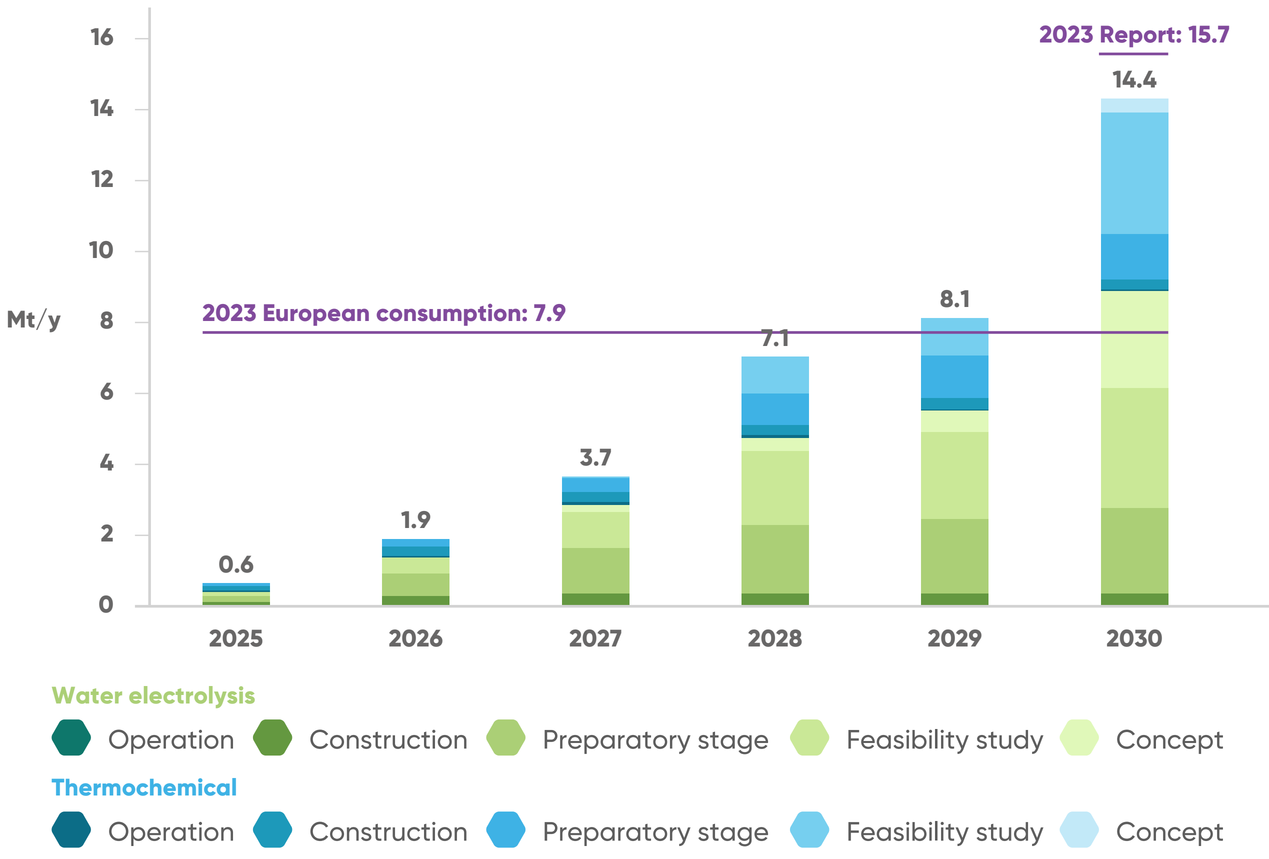
Compared to last year's report, the total announced clean hydrogen capacity by 2030 decreased by 8% from 15.7 Mt/year. The decrease doesn't represent a stark change in market dynamics, but rather a re-evaluation of project timelines from developers.

4% of the project pipeline is under construction compared to 2% last year. That equates to 3% or 0.3 Mt (2.6 GW_{el}) of water electrolysis and 5.3% or 0.3 Mt of clean thermochemical project pipeline being under construction. 34% of the project pipeline is in an advanced stage (pre-FEED, FEED, construction) compared to 28% last year equating to 2.8 Mt (26 GW_{el}) of electrolytic projects and 1.5 Mt of thermochemical projects.

While new projects are being announced and some are being cancelled, **the project pipeline is maturing with 66% of the total project pipeline by 2030 being in early phases (concept or feasibility study) compared to 72% last year.**

FIGURE 3.2

Cumulative announced clean hydrogen production capacity up to 2030 by current development stage



Notes: Data does not represent a forecast but announced production project pipeline. For methodology and terminology clarifications, please consult the methodological note at the end of the chapter and the terminology section at the end of the report.

Only 3% of the electrolytic project pipeline capacity is under construction, representing 2.6 GW_{el}

Only 3% of the 8.9 Mt electrolytic project pipeline capacity (equivalent to 86.4 GW_{el}) is currently under construction, representing just 0.3 Mt (2.6 GW_{el}) of water electrolysis.

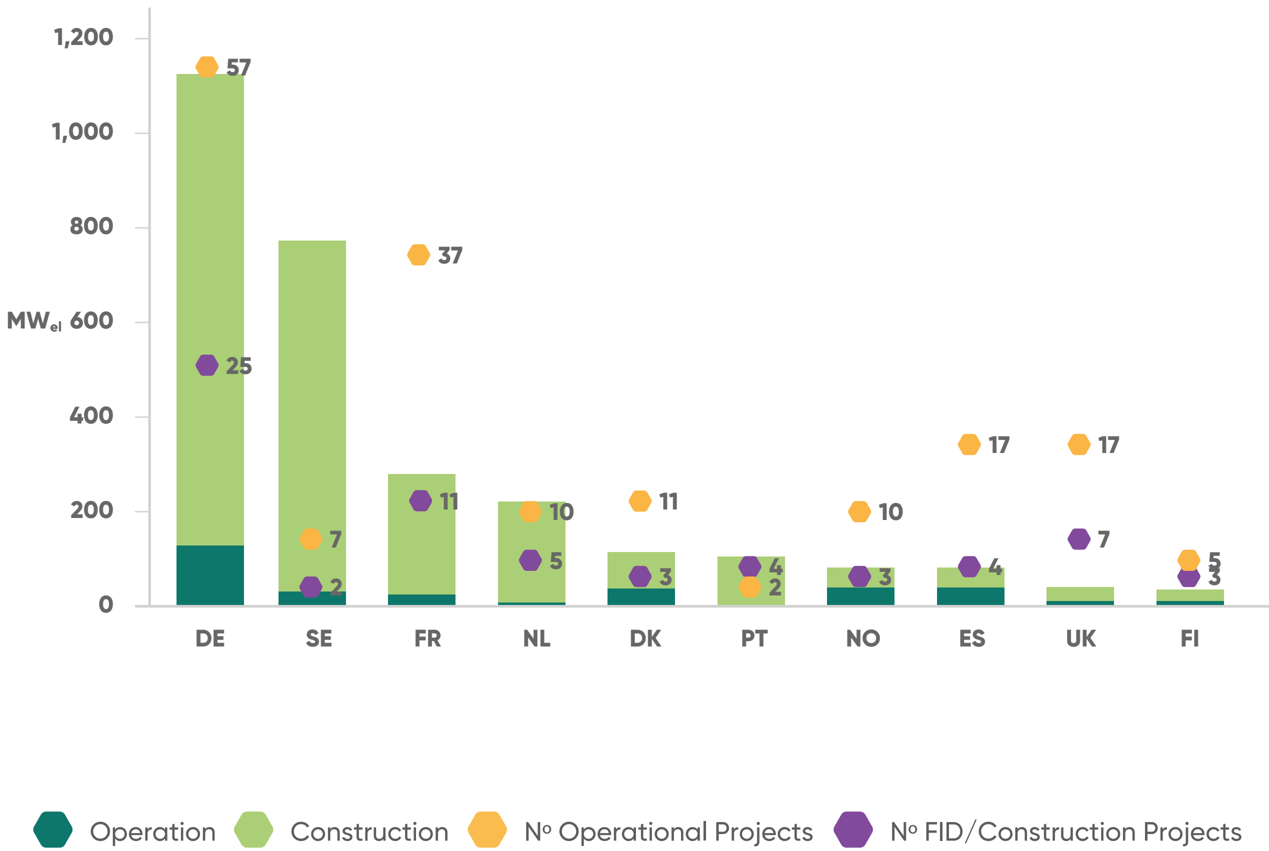
The electrolytic projects under construction are mainly concentrated in Nordic, Iberian, and Western European countries, driven by various factors such as the availability of renewable energy sources, low-cost grid electricity, access to gas and CO_2 infrastructure, government support, and willing offtakers. **The common trait is that these projects are driven by developers and offtakers who want to be first movers.** They choose Spain for available renewable energy potential while Nordics for their affordable and low-carbon grid electricity. German projects under construction are mainly located near existing industrial clusters where first movers aim to utilize existing real estate, take advantage of spare grid capacity, while gaining experience in electrolytic production.

The average size of projects is increasing. Operational projects typically have an average size of around 2 MW_{el}, while projects under construction already average above 50 MW_{el}.

More immediate investment decisions can be expected as countries continue to award national IPCEI funding or other European and national funds and RED3 targets are transposed at the national level. The major future markets with many expected investment decisions in the near future include Spain, France, Portugal, the Netherlands, Nordic countries, Germany and the UK.

FIGURE 3.3

Top 10 countries with largest operational and under construction water electrolysis capacity and number of projects in Europe by September 2024



Notes: The values represent installations larger than 0.5 MW_{el}. Hydrogen Europe's project tracking might omit installations smaller than 0.5 MW_{el} and in some cases the number of these installations can be significant.

Developers continue delaying the planned date of commissioning of their electrolytic projects, with growing numbers pushed beyond 2030

Figure 3.4 illustrates the number of clean hydrogen projects planning to come online each year, based on data from previous Clean Hydrogen Monitor publications. The number of electrolytic projects expected to be operational by 2030 has risen 4% year-on-year to 844, doubling compared to 2021.

Despite this positive trend, delays persist. In 2023, only 42 projects became operational, though 86 planned to do so. On average, currently operational projects are delayed by 1.2 years, while those under construction are delayed by 1.9 years, often due to challenges in technical design, execution, and commissioning.

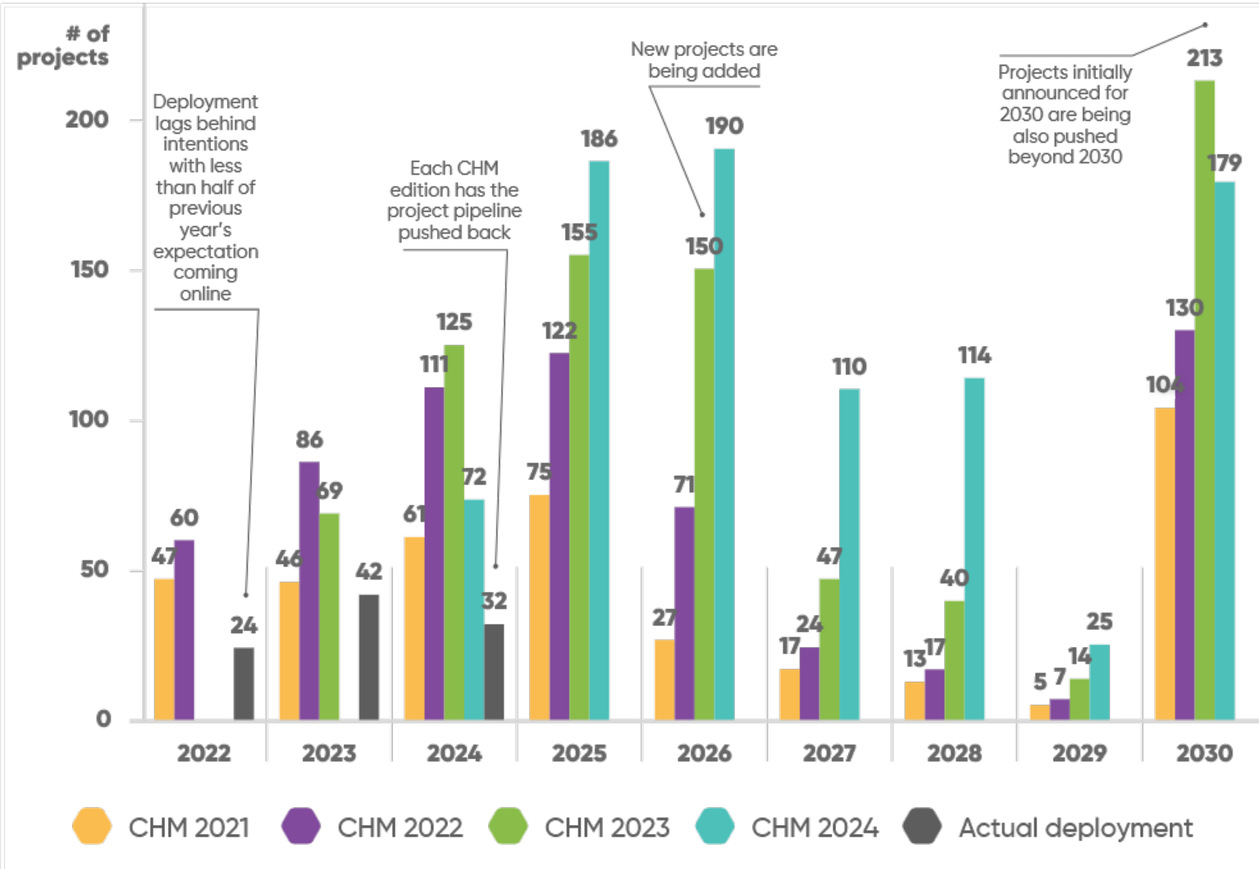
For projects planned between 2025-2028, there has been an increase in announcements, but their timelines are also being pushed back.

Development timelines of 50+ MW_{el} projects from concept to operation can take around six years, **a drop in announced projects to come online in 2030 can also be observed as they are postponed to after 2030.**

These delays are caused by similar reasons as last year and depend on the project stage. Less mature electrolytic projects continue to struggle with project economics, funding availability, uncertainty regarding national transposition of RED3 targets, finding offtakers, regulatory uncertainty on low carbon delegated act, and slow infrastructure development.

FIGURE 3.4

Annual number of electrolytic projects announced to come online that year and comparison to previous publications



Notes: Projects shown as being deployed in 2024 reflect deployment by September 2024.

Funding

EU support for clean hydrogen has grown over the last few years, but remains a small part of the dedicated climate funding

Deloitte estimates that EUR 480-890 billion is needed to scale up Europe's clean hydrogen sector between 2025 and 2035, requiring annual investments of EUR 50-90 billion. **The European Union has allocated EUR 125.6 billion to climate initiatives for 2021-2027, yet clean hydrogen has secured only EUR 5 billion since 2021. Of this, 56% comes from the Innovation Fund and 21% from Horizon Europe.**

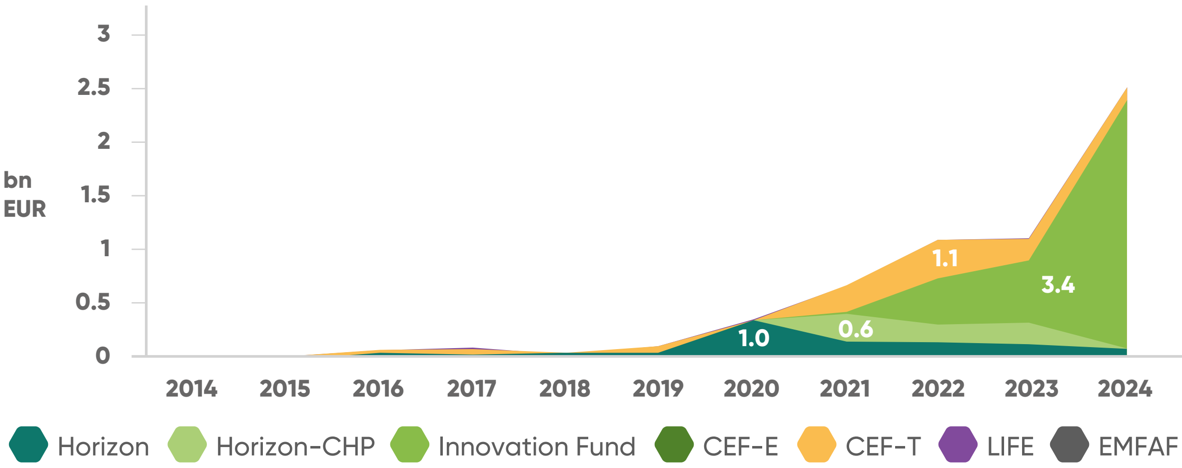
Assuming a 4x multiplier effect, meeting the lower end of the EUR 50 billion annual investment target would require at least EUR 10 billion in public funding each year. Despite efforts at both EU and national levels, this still falls significantly short. Even when accounting for national funding schemes (as covered in the next pages), the current financial commitments are insufficient to meet the sector's substantial investment needs.

The main drivers of EU-funding are the Innovation Fund (including the EU Hydrogen Bank) and the Clean Hydrogen Partnership (Horizon Europe). However, infrastructure funding remains limited, with only EUR 360 million spent so far on hydrogen infrastructure by CEF-E and CEF-T. Regarding infrastructure funding, competition is high, with AFIF funding for HRS far smaller than for EV charging stations.

Outlook: Looking ahead, the Innovation Fund should continue building on the success of the Hydrogen Bank, with a dedicate budget for hydrogen, on the support for manufacturing and the large-scale projects calls. Then, the next EU budget (2028-2034) should secure a dedicated funding line for hydrogen to support its growth. Beyond innovation and industrialisation, funds should also help large deployment.

FIGURE 3.5

Main EU-level funds spending in clean hydrogen (by September 2024)



EU-level Programme name	Timeline	Total Budget (EUR billion)	Climate/ Clean Tech dedicated budget (EUR billion)	Total Funding for H_2 (EUR billion)		
				Since 2021	2023	2024
ETS Innovation fund (without H2 Bank)	2020-2030	40.00	37.00	2.80	0.59	1.62
H2 Bank	-	-	3.00	0.72	0.00	0.72
CEF-E	2021-2027	5.84	3.50	0.003	0.003	N/A
CEF-T	2021-2027	25.80	15.50	0.36	0.21	0.15
ERDF	2021-2027	191.00	47.30	N/A	N/A	N/A
LIFE	2021-2027	5.40	1.90	0.02	0.08	0.00
Horizon Europe	2021-2027	94.50	32.40	0.48	0.12	0.08
Clean Hydrogen Partnership	2021-2027	1.00	1.00	0.68	0.20	N/A
Total		**367.5**	**125.6**	**5.0**	**1.1**	**2.6**

Notes: Under a 4x multiplier effect, 1€ of public funding attracts 4€ of private investment. This assumption comes from the observed split between public and private investments in Large scale projects funded by the Innovation Fund.

In the EU, Germany and the Netherlands lead the way in funding for hydrogen

Funding for clean hydrogen is growing at the national level, gradually moving from R&I support to market-making schemes that cover both CAPEX and OPEX and with hydrogen price or CO2 abatement price becoming the determining factor for project selection. **We estimate EUR 37 billion in cumulative national commitments to the sector (as shown in the graph) including ongoing and known future mechanisms. However, most of this money has not been granted, either because the scheme is not yet operational (e.g. France), or because the granted support is inadequate to help projects reach FID.** A prominent example is the Hydrogen IPCEI, where Member States have pledged EUR 18.9 billion. In the Netherlands, only one of seven projects selected under the IPCEI's second wave, "Hy2Use," has advanced to FID, hindered by unfavorable market conditions (e.g., higher grid charges, increased CAPEX due to inflation). This highlights the need to enhance the effectiveness of funding mechanisms.

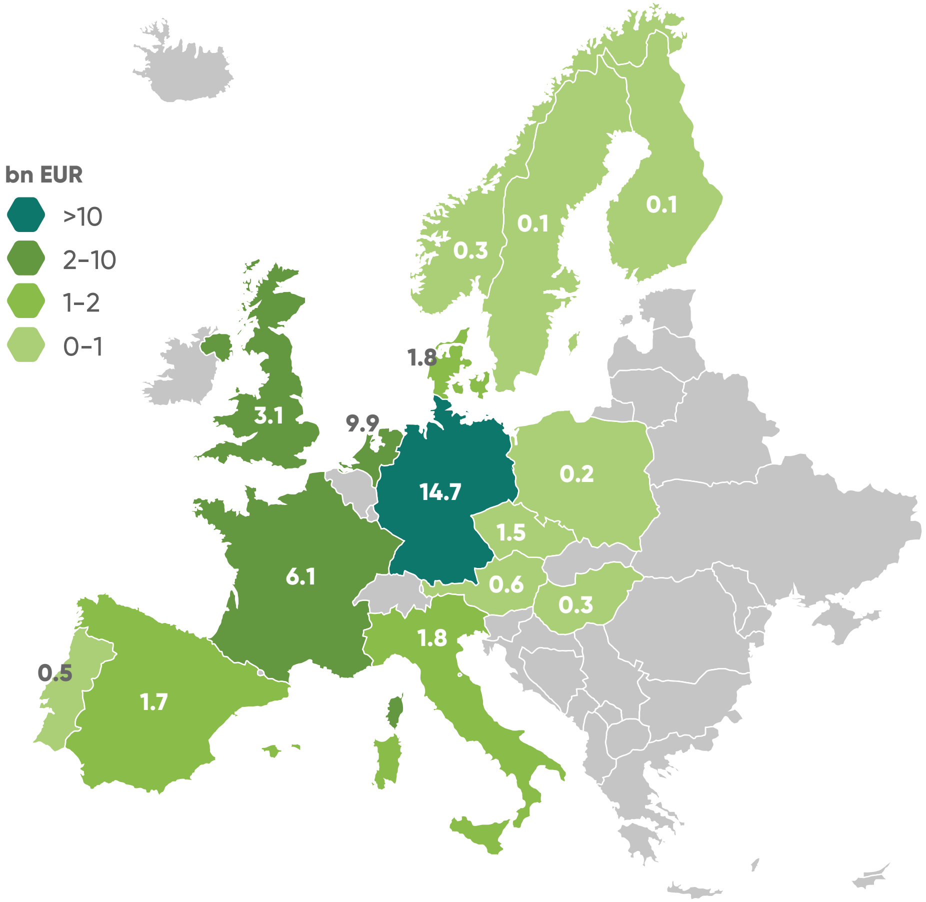
Highlights from national funding

- **Germany** leads Europe with several innovative schemes resulting in EUR 14.7 billion committed to clean hydrogen. For instance, Germany contributes with EUR 4.9 billion to H2Global, a mechanism that runs double-sided auctions to balance supply and sales prices.
- **The Netherlands** has multiple schemes supporting hydrogen, resulting to EUR 9.9 billion subsidy. One important scheme is the OWE scheme, which offers a 7-15-year CfD for renewable hydrogen production, with a EUR 1 billion budget.
- **France's** most important national scheme "Decarbonised Hydrogen Program" of EUR 4.2 billion has faced delays but could become a flexible production support tool for low carbon hydrogen.
- **Denmark's** PtX program attracted competitive bids at 1.05 EUR/kg for a total of 180 MW_{el} of electrolysis but faces uncertainty regarding renewal.
- **Spain** launched earlier this year a EUR 1.2 billion scheme supporting investments in production of hydrogen in clusters or valleys.

For detailed national schemes per country, please refer to Annex 1.

FIGURE 3.6

Estimation of announced and committed national schemes supporting clean hydrogen (by September 2024)



Notes: Selected national funding schemes often target more than just hydrogen. The authors generally estimate that 20% of national public funds are allocated to hydrogen, except for schemes with specific funding targets. This estimate is based on the average 20% investment in hydrogen related projects from The EU Innovation Fund (Grant, excluding IF23 results, as grants are not signed at publication of the report). A detailed list of national schemes and assumptions is provided in Annex 1 of the report.

The European Union needs to increase public funding in hydrogen to keep up with other international players, such as Japan or the USA

Global commitments for clean hydrogen increases, made by countries such as the US, Japan, and the UK. The EU needs to scale up its efforts to remain competitive in the global hydrogen landscape. Moreover, **while global schemes focus mostly on supply, a stronger emphasis on demand-side support is crucial for ensuring long-term competitiveness.**

- **UK:** Amongst other schemes, the Hydrogen Production Business Model (HPBM) funds clean and low-carbon hydrogen with an uncapped budget (target of 1GW by 2025). Its 15-year CfD model provides certainty for investors.

- **Australia:** Amongst others, Australia has committed EUR 2.4 billion to clean hydrogen investments and an additional EUR 4.2 billion through a Hydrogen Production Tax Incentive.

- **India:** Through its National Green Hydrogen Mission, India has allocated EUR 2.2 billion to support production, manufacturing, and R&D, positioning itself as a global partner to Japan and Europe.

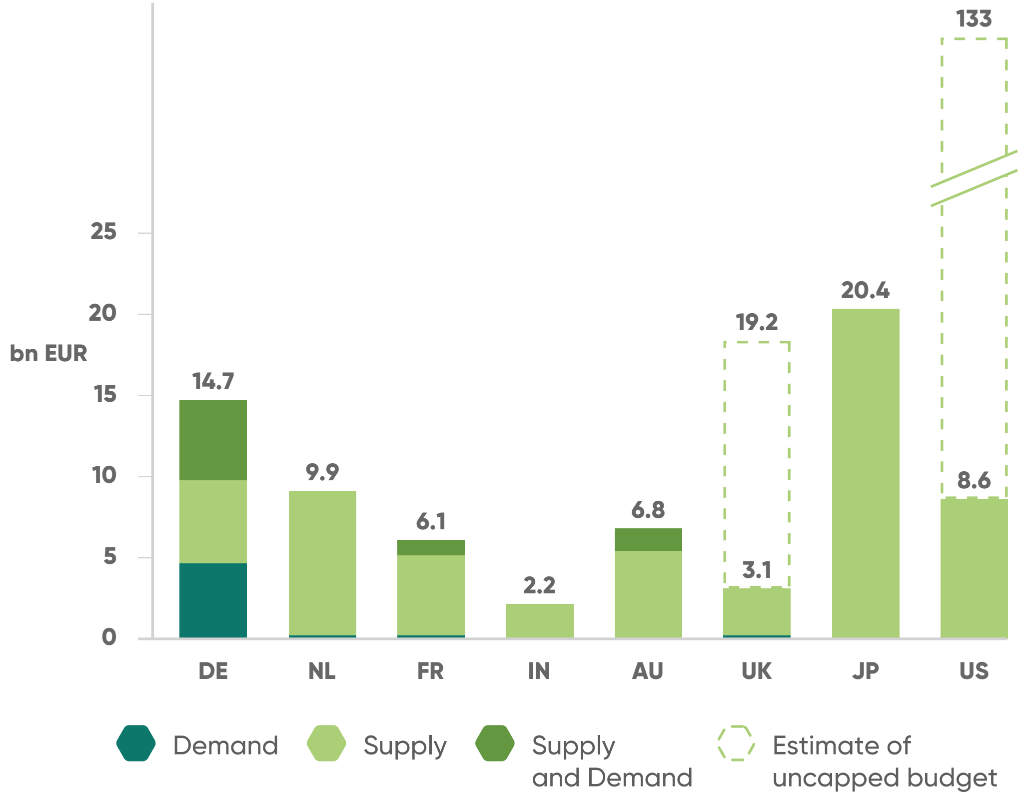
- **Japan:** Japan has allocated EUR 20.4 billion for a 15-year CfD program to produce renewable and low-carbon hydrogen, both domestically and for import, focusing on hard-to-abate sectors.

- **US:** The Inflation Reduction Act could unlock EUR 124 billion through tax credits (up to USD 3/kg for low-carbon H2), setting a global benchmark.

The biggest challenge remains securing long-term offtake agreements. To mitigate risks for investors, Europe must increase public investments and focus more on demand-side support.

FIGURE 3.7

Estimation of announced public funding for clean hydrogen by selected countries, split between supply and demand (by September 2024)



Notes: UK: For the UK, the first round of the Hydrogen Allocation Round 1 (HAR1) funded 125 MW of hydrogen capacity at €2.3 billion. To reach an additional 875 MW by 2025, the authors estimate that about €18.4 billion is needed at similar strike price. In the US, the IRA's uncapped hydrogen tax credits (45V and 45Q) are projected by BNEF to total public funding of up to $137 billion over the next ten years.

Regional perspectives

Nordics and Iberia lead the supply of electrolytic hydrogen by 2030 in both scenarios while most thermochemical volumes are expected in BeNeLux and UK

Figure 3.8 provides an overview of countries and regions with unique market dynamics based on resources, ambitions, and demand. **The Nordics have the highest electrolytic hydrogen supply outlook (0.5-0.9 Mt)** supported by a decarbonised grid that allows higher utilisations and lowers the price per kg, customer willingness to pay a green premium, and government support. The future of thermochemical projects in Norway depends on finding offtakers for that hydrogen and infrastructure to deliver it.

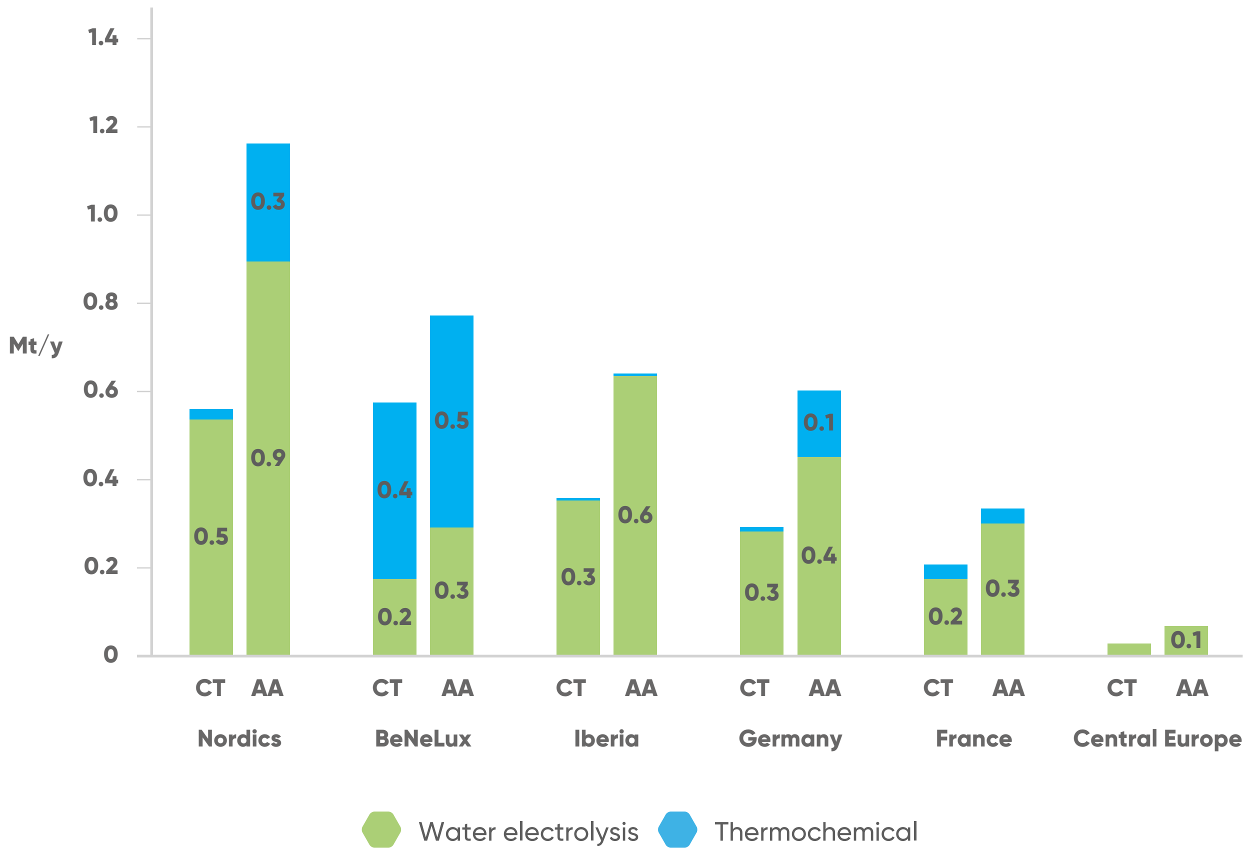
Iberia, with a comparable electrolytic project pipeline to the Nordics driven by renewable energy potential, lack of grid capacity, and structural oversupply of cheap renewables reaches **slightly lower volumes as the Nordics with 0.3 and 0.6 Mt impacted by the lower utilisations in Spain and Portugal.**

BeNeLux, a large hydrogen consumer (1.5 Mt in 2023), sees future supply driven by Dutch projects despite the electrolytic ones being hindered by high grid fees. The Netherlands is expected to lead the supply of thermochemical hydrogen, with three methane reforming projects under construction and others in development; this is due to a favourable funding environment for CO_2 infrastructure and strong industrial base. BeNeLux will be one of the first markets with regional hydrogen trade and maritime imports.

Central European countries such as **Poland, Czechia, Slovakia, and Hungary are currently supply stragglers** with only 0.02 Mt and 0.06 Mt forecasted by 2030 due to limited RES potential and government ambition despite significant existing demand of 1.2 Mt.

FIGURE 3.8

Clean hydrogen supply by 2030 in selected regions under Current Trajectory (CT) and Accelerated Adoption (AA) scenarios



Notes: Nordics includes Denmark, Finland, Norway, and Sweden; Iberia includes Spain and Portugal; Central Europe includes Poland, Czechia, Slovakia, Hungary.

Nordics, with a mostly decarbonised grid, high utilisation rates, and low grid costs is the region with the highest volumes of clean hydrogen by 2030 in both scenarios

The Nordics are forecasted to reach 0.55 Mt of hydrogen in the Current Trajectory and 1.16 Mt in the Accelerated Adoption scenario, with most volumes from electrolysis. Their largely decarbonised grids enable high utilisation, lowering hydrogen costs. Project pipelines reflect these favourable conditions, with **24 GW_{el} and 3 Mt of electrolytic hydrogen projects announced by 2030.**

Government ambitions align with industry, with Sweden and Denmark aiming for 5 GW_{el} of electrolysis each. Denmark has awarded EUR 170 million in their 2023 PtX auction to ~180 MW_{el} across five projects. Some key projects under construction include Stegra's 740 MW_{el} green steel project in Sweden, European Energy's 50 MW_{el} methanol facility in Denmark, and Yara's 24 MW_{el} green ammonia plant in Norway. Finland has Hycamite's methane-splitting plant, while Norway mostly focuses on reforming with carbon capture.

The very high supply potential and corresponding project pipelines are **limited by modest existing regional demand of 0.5 Mt** most of which is in refining and **the currently lacking export infrastructure to continental Europe and Baltics.** Large thermochemical projects are being impacted due to both lack of demand and export infrastructure. As a result, project developers focus on transportable hydrogen derivatives with the **outlook's Current Trajectory scenario forecasting ammonia to be the largest end-use of the produced clean hydrogen followed by steel and e-fuels.**

FIGURE 3.9

Clean hydrogen supply scenarios in the Nordics by 2030

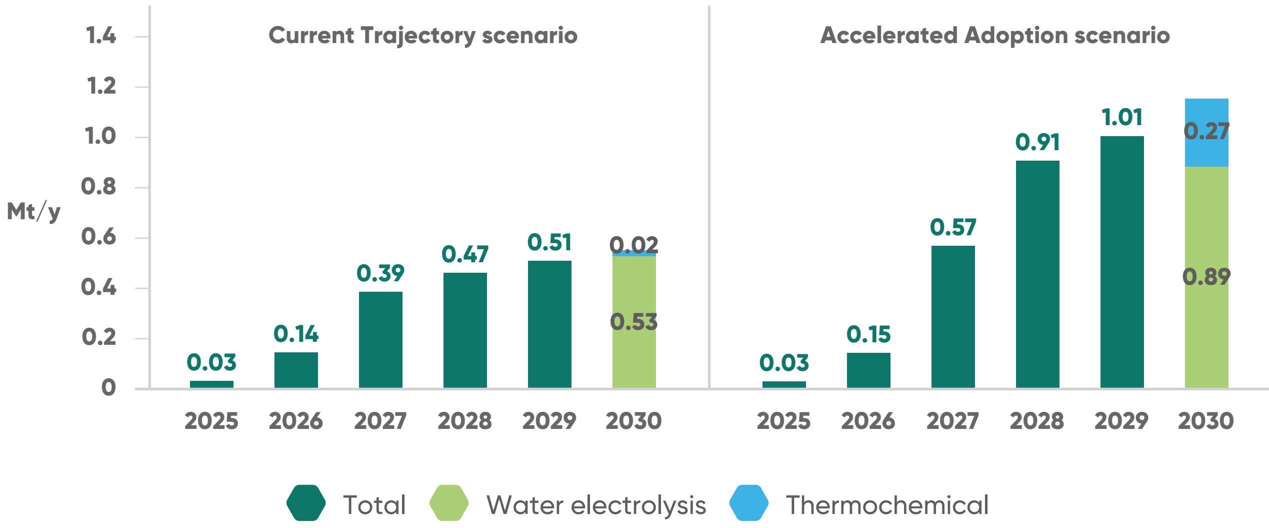
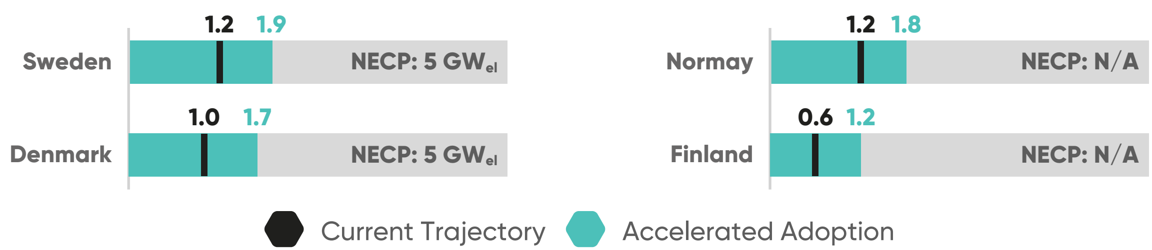


FIGURE 3.10

Electrolytic supply by 2030 and NECP or strategy targets where available



Notes: Finland's NECP aims to deploy 200 MWel of electrolysis by 2025 but has not defined 2030 ambition. Swedish values represent 5 GW_{el} proposed by the Swedish Energy Agency.

BeNeLux, with large existing demand and limited supply opportunities, will be a major importing region from inside and outside the EU

The BeNeLux region is forecast to achieve 0.55 Mt of clean hydrogen production under the Current Trajectory and 0.78 Mt under an Accelerated Adoption scenario, compared to a project pipeline of 2 Mt. Unlike other regions, **thermochemical volumes dominate the overall hydrogen output.** With industrial clusters and major ports, BeNeLux consumes 1.6 Mt of hydrogen per year. The Netherlands aims to establish 3-4 GW_{el} of electrolysis capacity by 2030, while both **Belgium and the Netherlands are positioning themselves as key hydrogen import and transport hubs.**

The majority of expected hydrogen production will be in the Netherlands, supported by the OWE scheme and a EUR 1 billion budget for electrolytic hydrogen development. The Netherlands also saw Shell's Holland Hydrogen One project in Rotterdam become the first 100+ MW_{el} initiative to reach FID in 2022. In contrast, Belgium's hydrogen sector is less active, with Virya's 25 MW_{el} HyoffWind achieving FID in 2024. **Further development in the Netherlands is constrained by high electricity grid fees, limiting additional final investment decisions.**

On the thermochemical front, Air Products and Air Liquide plan to retrofit their existing SMRs in Rotterdam with carbon capture technologies. Refining is expected to be the largest end-use of clean hydrogen by 2030. **However, neither scenario is projected to meet the BeNeLux RED3 target of approximately 0.42 Mt of RFNBO hydrogen.**

FIGURE 3.11

Clean hydrogen supply scenarios in BeNeLux by 2030

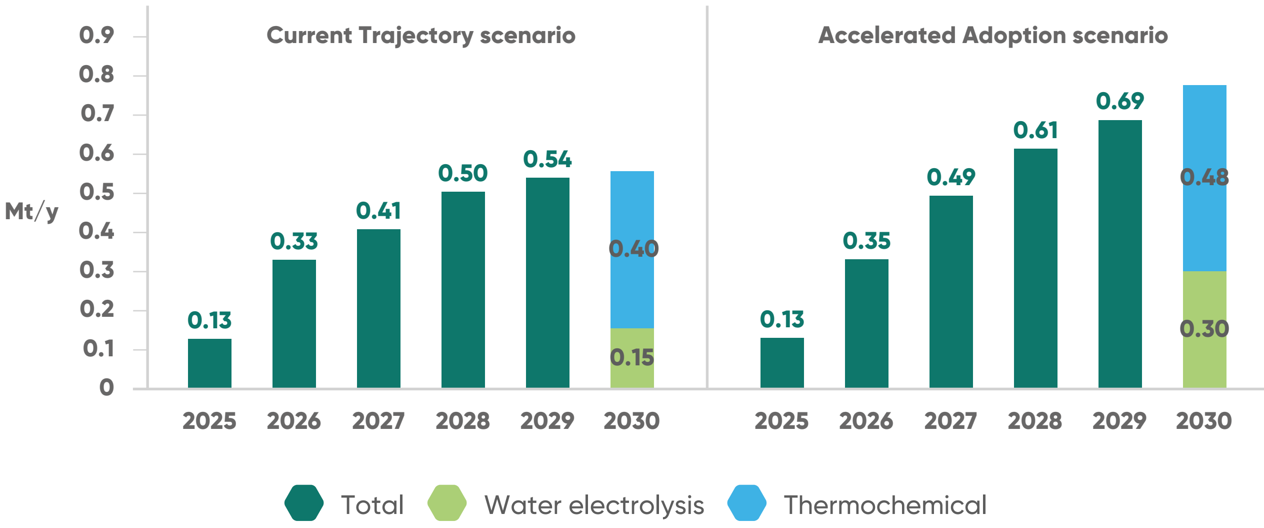
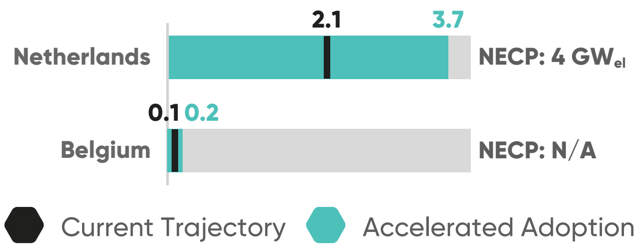


FIGURE 3.12

Electrolytic supply scenarios by 2030 and NECP or strategy targets where available



Notes: RED3 targets are calculated based on 2023 consumption and do not omit any volumes from the target due to specific exclusions. Belgium NECP aims to deploy 150 MW^{el} of electrolysis by 2026, but does not have a defined 2030 ambition.

Iberia's unparalleled renewable conditions attract developers from around the continent but further volumes are hindered by lacking export infrastructure

The supply forecast for Iberia (Spain and Portugal) **reaches 0.35 Mt in the Current Trajectory scenario and 0.63 Mt in the Accelerated Adoption scenario** with electrolytic volumes accounting for most of the total. **The region's renewable energy potential, lack of grid capacity, and structural oversupply of cheap renewables make it a key future hydrogen producer.** Reflecting this, 24 GW_{el} and 2 Mt of electrolytic hydrogen projects have announced to be operational by 2030. Spain and Portugal's updated NECPs target 12 GW_{el} and 5.5 GW_{el} of electrolysis, respectively, by 2030, with multiple government funding schemes having already been awarded.

The largest projects under construction are GALP's 100 MW_{el} refinery project in Sines and BP/Iberdrola's 25 MW_{el} project in Castellon. Some of the other notable projects in development include Hydrogen Bank winners Catalina (Spain) and MadoquaPower2X (Portugal).

Thermochemical project development is limited with early deployments of various gasification/pyrolysis technologies using biowaste, municipal solid waste, or plastic waste.

Of Iberia's current 0.7 Mt hydrogen demand, 0.6 Mt is for refining. **Like in the Nordics, the projected supply significantly exceeds local demand. Without pipeline export infrastructure, project developers focus on transportable hydrogen derivatives such as ammonia.** As reported by project developers, the largest future end-uses of the produced hydrogen by 2030 will likely be refining, ammonia, and undefined industry.

FIGURE 3.13

Clean hydrogen supply scenarios in Iberia by 2030

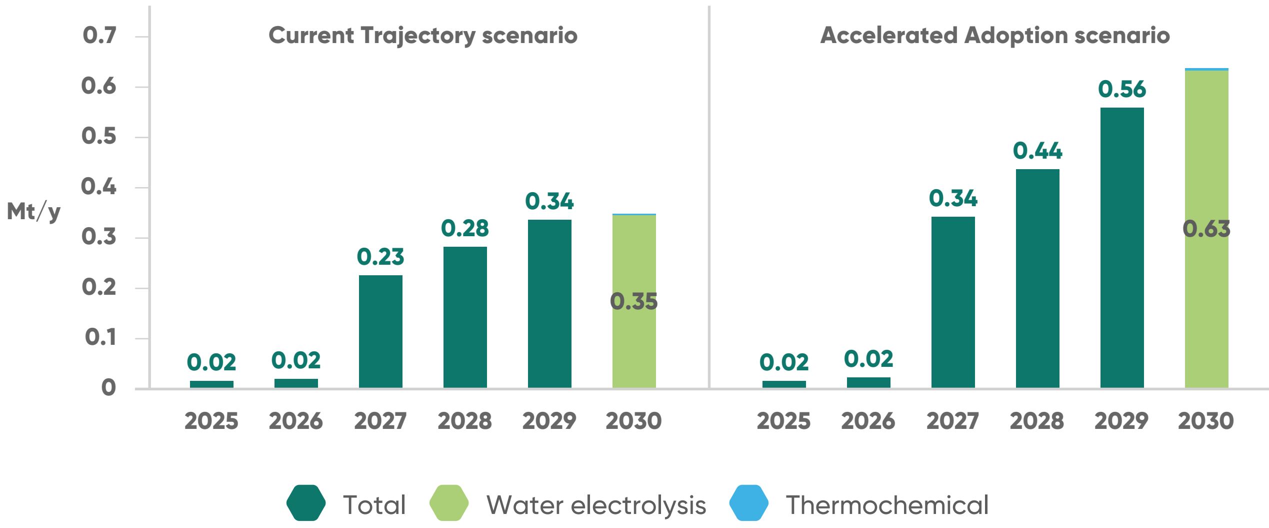
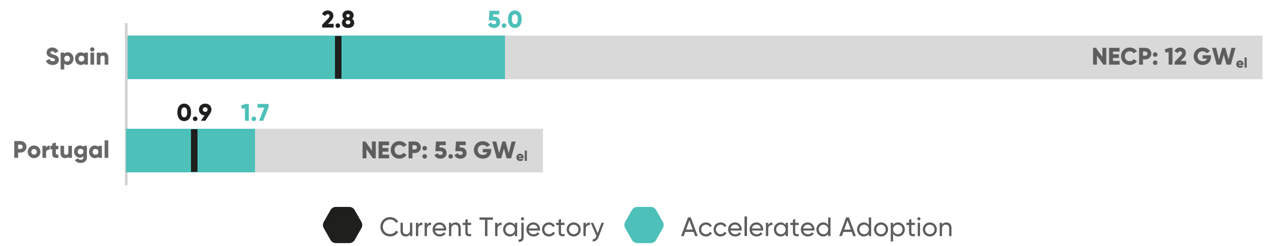


FIGURE 3.14

Electrolytic supply scenarios by 2030 and NECP or strategy targets



Germany is a large hydrogen consumer with strong ambitions driven by government support, limited domestic supply potential, and strong future reliance on imports

Germany's forecasted clean hydrogen supply reaches 0.29 Mt in the Current Trajectory and 0.6 Mt in the Accelerated Adoption scenario, with most coming from electrolytic hydrogen. This accounts for 19% and 40% of Germany's clean hydrogen project pipeline, which totals 1.5 Mt, including 1.15 Mt from electrolysis (11.7 GW_{el}) and 0.36 Mt from thermochemical processes. The government aims to develop 10 GW_{el} of electrolysis capacity under its NECP, with nearly 1 GW_{el} already under construction. Key projects include EWE's 280 MW_{el} Clean Hydrogen Coastline, RWE's 300 MW_{el} GetH2Nukleus, and Shell's 100 MW_{el} Refhyne 2.

In 2023, 0.7 Mt (50%) of Germany's 1.4 Mt hydrogen demand went to refining, and 0.3 Mt to ammonia production. By 2030, domestic clean hydrogen supply is likely to go to refining, steel, and other industries. **Notably, nearly 50% of project volumes in the accelerated scenario have yet to identify end-use sectors, with many planning to supply future consumers via the hydrogen core network.**

For thermochemical project development, the Accelerated Adoption scenario assumes at least one large scale thermochemical project will come online by 2030.

Based on 2023 consumption, **German RED3 targets would require 0.39 Mt (excluding steel use),** theoretically achievable with domestic supply. However, Germany's ambitious import strategy (1.35–2.7 Mt) expects to import more competitively priced hydrogen and derivatives. First green ammonia deliveries from Egypt supported by H2Global are expected by 2027.

FIGURE 3.15

Clean hydrogen supply scenarios in Germany by 2030

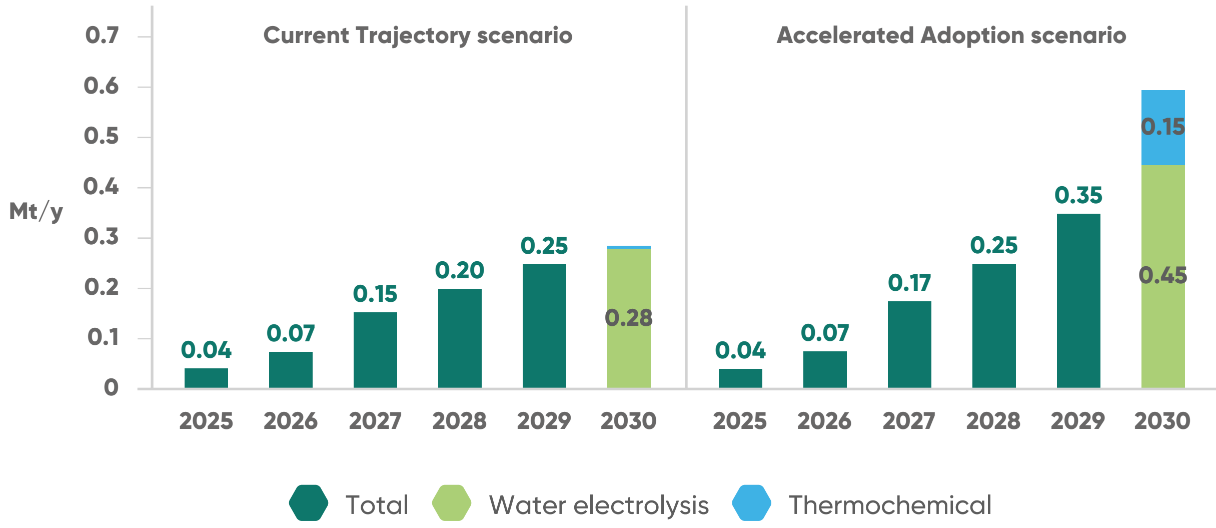
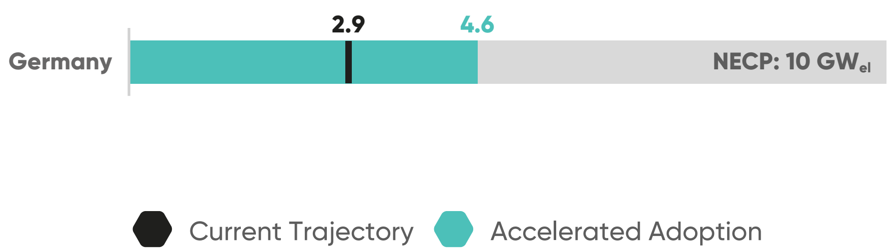


FIGURE 3.16

Electrolytic supply scenarios by 2030 and NECP or strategy targets



Notes: RED3 targets are calculated based on 2023 consumption and do not omit any volumes from the target due to specific exclusions.

France could be self-sufficient and will likely satisfy its RED3 target, but progress is slow due to regulatory uncertainty on low-carbon hydrogen definition

The **two scenarios expect France to supply between 0.2 Mt and 0.4 Mt. This compares to its project pipeline of 0.9 Mt.** Electrolytic hydrogen accounts for most of the supply with 1.7 GW_{el} and 3 GW_{el} of installed capacity respectively. Demand in 2023 amounted to 0.55 Mt.

French government is targeting 6.5 GW_{el} of electrolysis by 2030 and is preparing to launch a landmark national CfD to support clean hydrogen production from both renewable and nuclear electricity, aiming to become self-sufficient. Considering its position between Iberia and Germany, it can play a key role on infrastructure development and pan-European hydrogen trade.

Based on 2023 consumption, **French RED3 target of 0.11 Mt could be achieved with domestic supply in both scenarios.**

Due to France's focus on supporting nuclear electricity for electrolytic production, **investment decisions have been limited as the government clears up state-aid approval from the European Commission and as developers wait for regulatory clarity expected in the Low-Carbon Delegated Act.**

Thermochemical projects are being developed mostly for local industrial clusters. In addition to reforming with carbon capture, various companies pursue methane splitting, biowaste-to-hydrogen, and other production pathways.

Next to the refining sector, the projects have indicated steel, and e-fuels as their primary end-uses.

FIGURE 3.17

Clean hydrogen supply scenarios in France by 2030

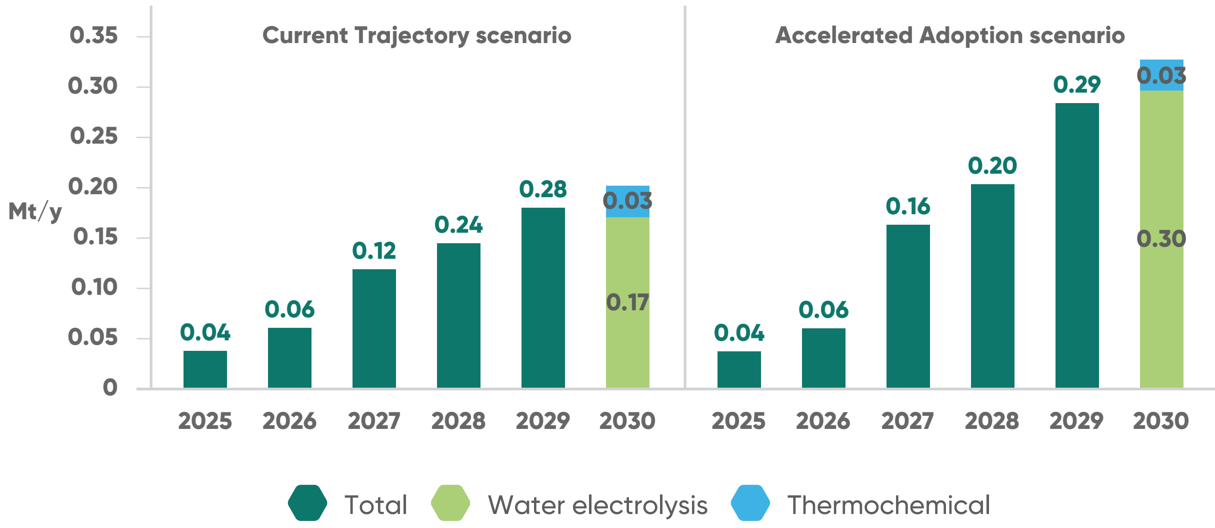
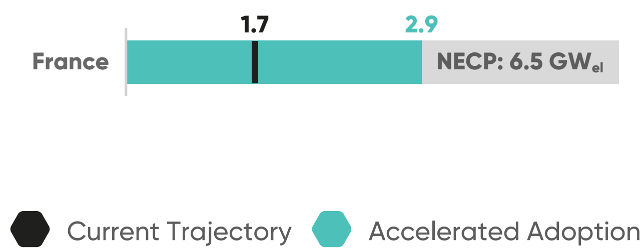


FIGURE 3.18

Electrolytic supply scenarios by 2030 and NECP or strategy targets



Notes: RED3 targets are calculated based on 2023 consumption and do not omit any volumes from the target due to specific exclusions.

Central Europe is the largest laggard due to slow RES development and lack of a clear government framework to support clean hydrogen production

Central Europe (Czechia, Slovakia, Poland, and Hungary) represents countries with similar constraints regarding clean hydrogen production. **The region is forecast to supply only between 0.02 Mt and 0.06 Mt depending on the scenario,** compared to a project pipeline of 0.1 Mt.

The region consumed 1.2 Mt of hydrogen in 2023 and is the least ambitious region in this outlook when compared to its current consumption. While Poland wants to have 2 GW of hydrogen output installed by 2030, Czechia aims at 400 MW_{el} and Hungary at 240 MW_{el} of electrolytic capacity, the project pipeline in all these countries is small. Slovakia does not have any supply objectives in its NECP or strategy.

Domestic supply is constrained by a lack of government support, high electricity prices due to an inadequate renewable energy deployment which limits PPA availability. As a result, **neither scenario sees a fulfilment of their RED3 target (~0.32 Mt of RFNBO hydrogen).** Therefore, imports will be necessary to help them reach the 2030 targets, but infrastructure rollout is lagging behind in the region and will need to accelerate to change the region's dynamics. Infrastructure projects of common interest (PCIs) are being developed to bring hydrogen from the Baltics and to connect to the hydrogen backbone through the Czech-German border.

The largest operational clean hydrogen project in the region is the 10 MW_{el} in MOL's Százhalombatta refinery.

FIGURE 3.19

Clean hydrogen supply scenarios in Central Europe by 2030

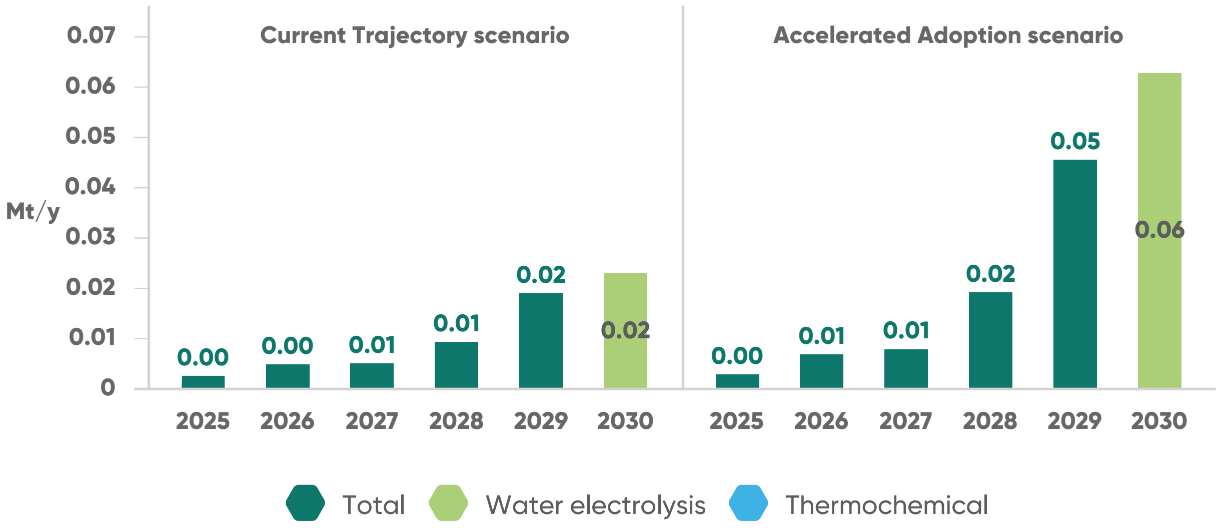
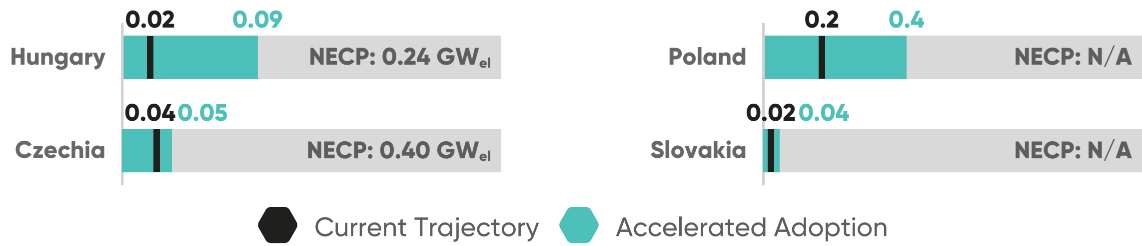


FIGURE 3.20

Electrolytic supply scenarios by 2030 and NECP or strategy targets where available



Notes: RED3 targets are calculated based on 2023 consumption and do not omit any volumes from the target due to specific exclusions. Polish NECP mentions around 2GW for low carbon sources by 2030, this includes both electrolytic and thermochemical.

The supply outlook across the EU is far from reaching national and EU ambitions, more efforts are needed to ramp-up the clean hydrogen market

In 2020, the EU's Hydrogen Strategy set a non-binding target of up to 10 Mt of renewable hydrogen production (around 100 GW_{el}). However, the European Commission's 2030 projections show that current policies will deliver 3 Mt, less than half this amount, as indicated in the Impact Assessment of Europe's 2040 climate targets document.

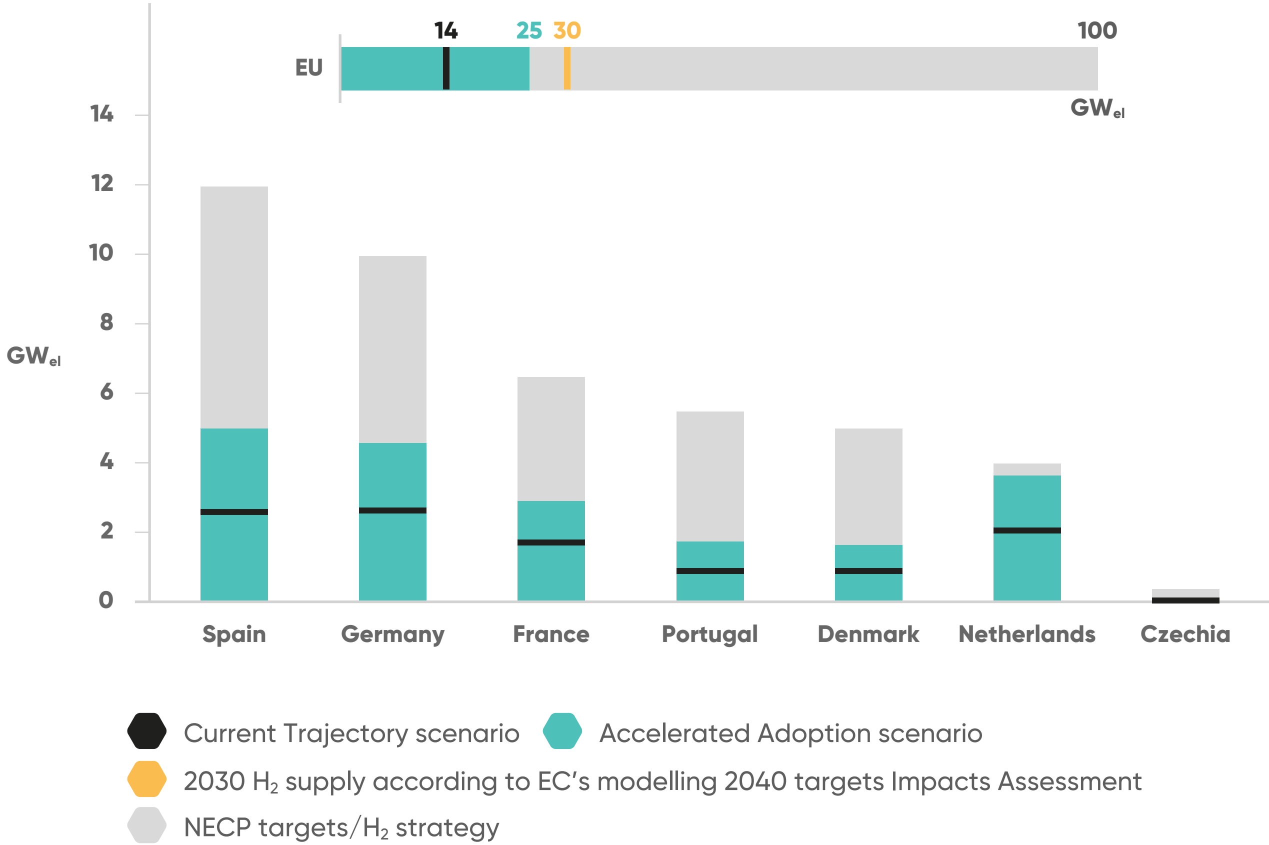
This outlook's Current Trajectory and Accelerated Adoption scenarios are lower than the European Commission's projections due to persisting difficult market and regulatory conditions. Even though binding hydrogen targets are already adopted at EU level, the right market levers remain absent.

Binding regulatory demand is uncertain in most countries as Member States have yet to fully transpose industry and mobility mandates from RED3, which is making end-users hesitate in committing as long-term offtakers. At the same time, projects continue to grapple with challenging economics, regulatory constraints, limited available funding, and slowly developing infrastructure.

At national level, most countries' NECPs have significantly higher objectives than what is likely to be deployed. Ambitious goals are set, and this is very positive, but existing market and regulatory conditions are not sufficient to trigger the needed investments in clean hydrogen. Most countries will likely achieve only 30–40% of their NECP ambition by 2030.

FIGURE 3.21

Comparison of NECPs, EU Hydrogen Strategy, and electrolytic supply scenarios by 2030



Note: Europe's 2040 climate targets document refers to the "Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society" communication.
The European Commission's modelling forecasts 3.15 Mt per year of renewable hydrogen supplied by 2030, for which this report assumes 30 GW_{el} of installed electrolyser capacity to be needed. The EU Hydrogen Strategy calls for the supply of at least 40 GW in hydrogen output and up to 10 Mt by 2030, for which 100 GW_{el} of installed electrolyser capacity would be required.

The likelihood of EU Member States to comply with RFNBO targets with domestic production is very different from region to region

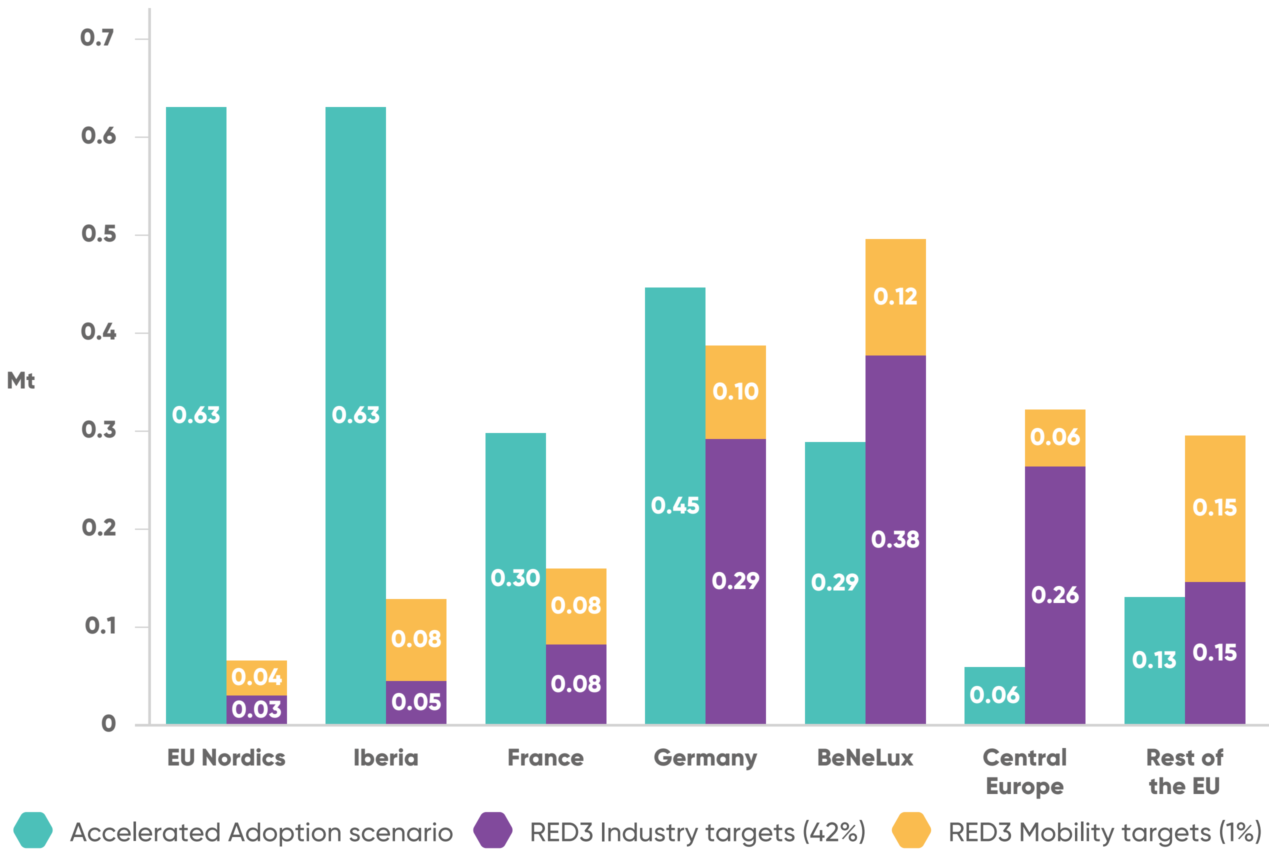
The RED3 industry targets mandate that RFNBOs fulfil at least 42% of total industrial hydrogen consumption (excluding conventional fuel production) in each Member State by 2030, rising to 60% by 2035. In transport, RFNBOs must account for at least 1% of total fuels supply, in combination with a specific target of 1.2% in the aviation sector from ReFuelEU Aviation.

At the EU level, based on 2023 demand, compliance with **RED3 could require 1.85 Mt of RFNBO by 2030.** This amount might significantly increase once clean hydrogen assumes a greater role in steel manufacturing and industrial heating. Meanwhile, estimates suggest that 1.7-2.5 Mt of electrolytic hydrogen could be available domestically, some of it destined to other sectors not affected by the targets (power generation, residential heating…). This means that **the success of the targets depends on a strong regulatory and funding framework that will stimulate the conversion of the current project pipeline into commissioned installations.**

It must be noted, however, that targets must be met at Member State level and results show varying progress across countries. BeNeLux and Central Europe, for example, are unlikely to meet their targets through domestic production, while the Nordics and Iberia are expected to have surplus supply. This underscores the **need for the right infrastructure to efficiently match supply and demand,** ensuring that the decarbonisation goals are met.

FIGURE 3.22

RFNBO demand by 2030 from RED3 targets vs electrolytic hydrogen supply in the EU in the Accelerated Adoption scenario



Notes: RED Industry targets are calculated based on 2023 consumption in the EU. It excludes hydrogen foreseen in steel manufacturing and a possible increase for industrial heating. BeNeLux includes Belgium, the Netherlands, and Luxembourg. Central Europe includes Slovakia, Czechia, Poland, and Hungary; Iberia includes Spain and Portugal; EU Nordics include Denmark, Finland, and Sweden, with Norway excluded due to not being part of the EU, hence out of the scope of the targets.

Hydrogen trade could enable achieving Europe's 2030 RED3 targets if the infra-structure is built on time to support trade flows from within and outside Europe

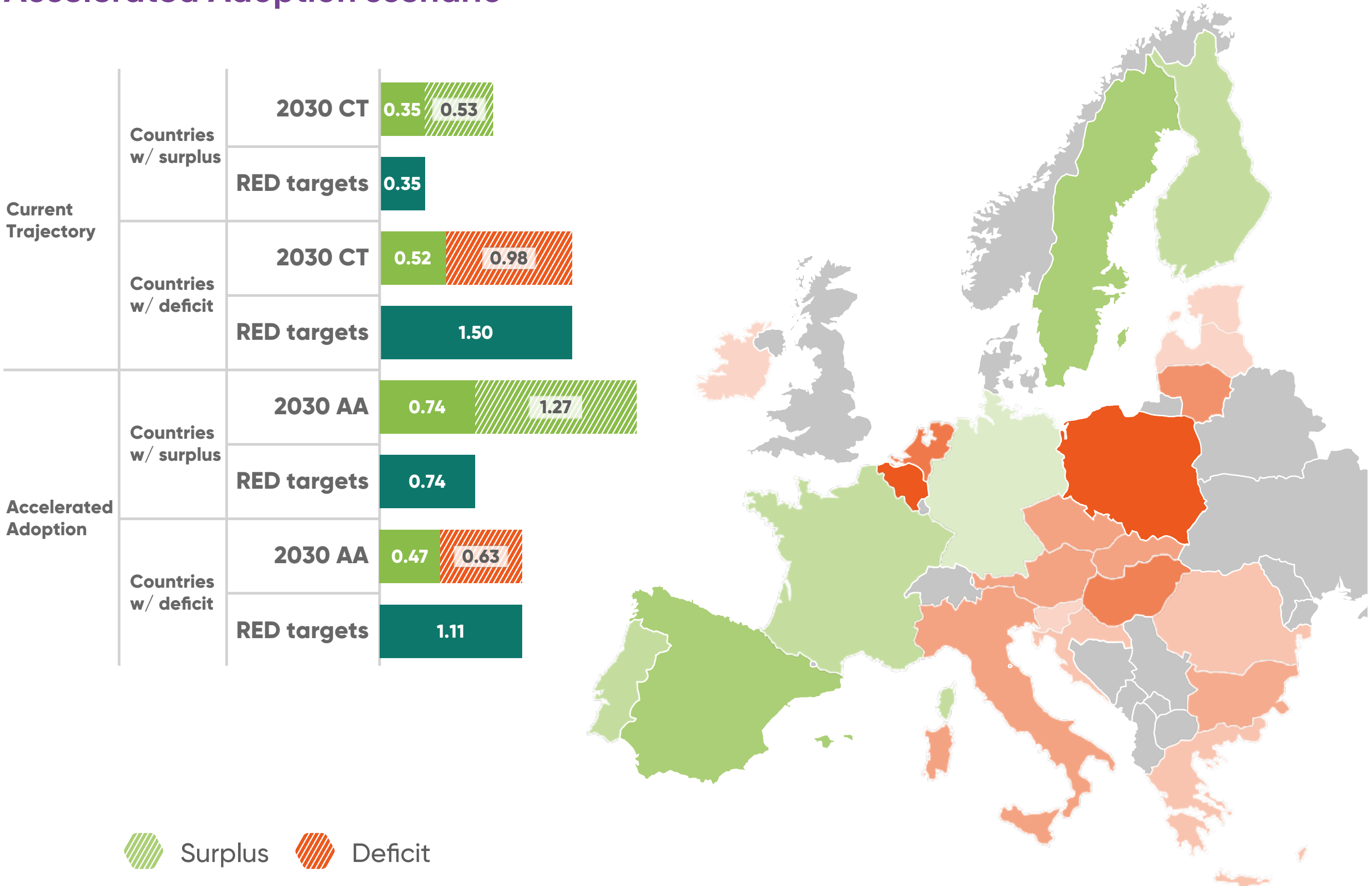
RED3 targets imply the supply of around 1.85 Mt of renewable hydrogen to the EU. **For countries with limited renewable energy capacity but high industrial demand, such as BeNeLux, Germany, and Central Europe, competitively producing those volumes of clean hydrogen might not be possible.**

In the Accelerated Adoption scenario, the deficit in the highlighted regions (0.63 Mt) could be entirely covered by intra-EU trade, as Iberia and the Nordics are expected to produce 1.27 Mt more than their local needs to satisfy RED3 targets, underlining the need for intra-EU hydrogen pipeline infrastructure and EU-wide funding mechanisms to support supply. However, if Europe doesn't accelerate, extra EU imports will be needed for Member States to meet the targets (overall deficit of 0.44 Mt/year).

Germany and Belgium's hydrogen and import strategies highlight this need. Belgium is aiming to establish 3 import terminals for renewable molecules, with the first hydrogen imports expected by 2026. Germany's strategy aims to import 50-70% of 2030 hydrogen demand. The government allocated EUR 4.5 billion for hydrogen derivative imports through the H2Global initiative. The winner of the first H2Global auction, Egypt's Fertiglobe project will supply around 40,000 tonnes/year of green ammonia to Europe. The Netherlands has also allocated EUR 300 million for imports through H2Global. Additionally, Member States are signing partnerships with countries like Chile, Morocco, Egypt, Oman, Saudi Arabia, Canada, and others for future imports.

FIGURE 3.23

Hydrogen supply deficit and surplus relative to the minimum RED3 targets by country based on both scenarios for 2030. The map shows results for the Accelerated Adoption scenario



Notes: RED3 targets are calculated based on 2023 consumption and do not omit any volumes from the target due to specific exclusions. For the purposes of this calculation, electrolytic hydrogen supply from the two scenarios equals RFNBO hydrogen supply. Countries in grey on the map are not included in the analysis.

End-use perspectives

Ammonia, refining, and steel constitute ~45% of the declared end-uses in the two scenarios

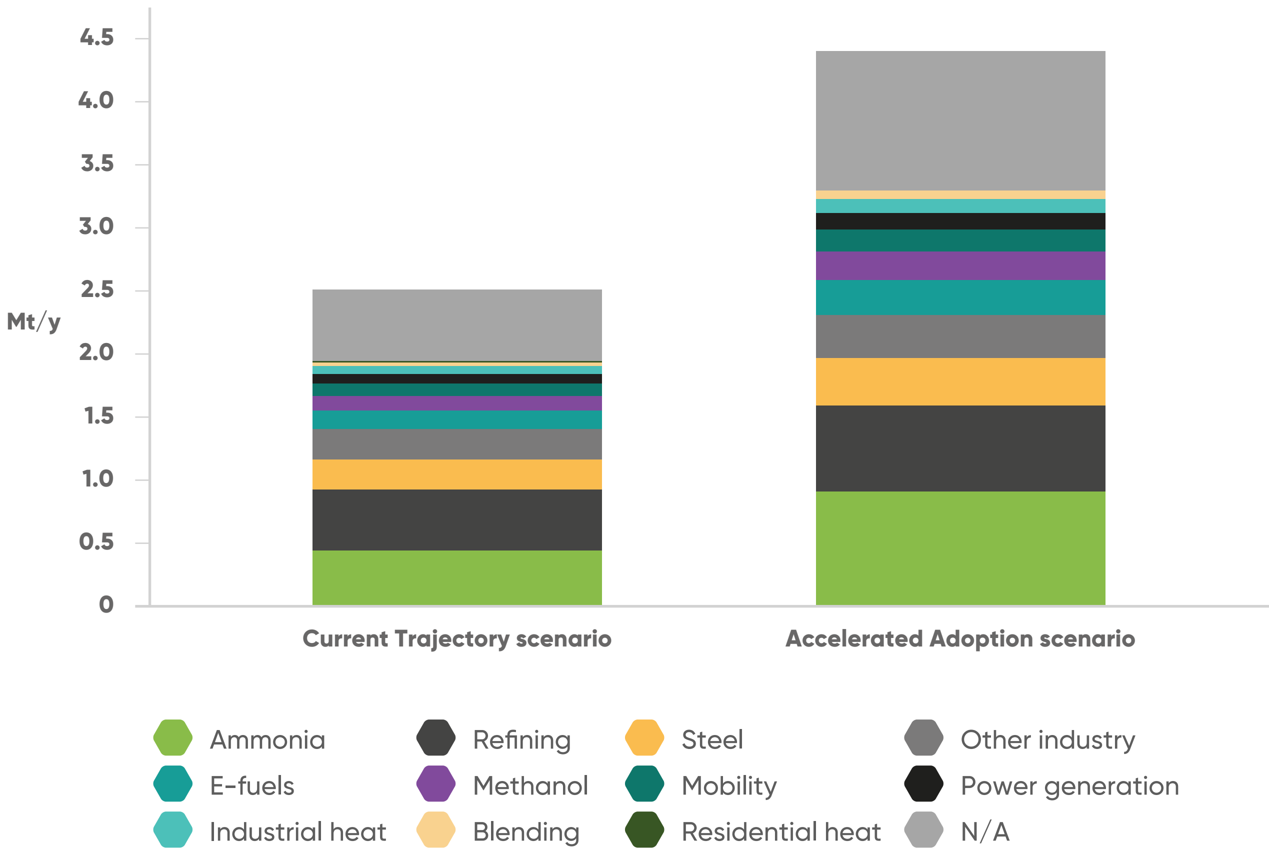
From projects with an already announced end-use, ammonia production is the most common. Under the Accelerated Adoption scenario, around 0.92 Mt are estimated to supply this sector by 2030 both for existing fertilizer plants as well as for new applications. 70% of this supply is to come from electrolytic hydrogen, hence, not enough to replace 42% of current hydrogen consumption in the ammonia sector with RFNBO. Furthermore, if the renewable ammonia and methanol produced are applied to the maritime sector, the RFNBO will count towards the mobility target rather than the industry one.

Industrial end-uses for refining, ammonia, steel, methanol, other industry, and industrial heating could account for 60% of the expected clean hydrogen supply by 2030. Refineries will be a key offtaker of clean hydrogen by 2030, mostly using hydrogen as an intermediate product to reduce their conventional fuels footprint. Hydrogen intended to produce e-fuels or direct application in mobility represents only 10% of supply but is expected to increase its relevance post-2030.

Around 25% of the expected supply has yet to announce a planned end-use. Redistribution of supply among sectors can therefore still take place, but it will always be limited by the availability of transport infrastructure. Steel manufacturers and refineries have announced tenders to buy renewable hydrogen from external suppliers. **Around 0.8 Mt/y of renewable hydrogen are currently under procurement** by these companies in Europe.

FIGURE 3.24

Intended end-uses of the two clean hydrogen supply scenarios by 2030



Notes: No assumptions regarding how much hydrogen supply will be assigned to a specific end-use were made by Hydrogen Europe. End-uses for the Current Trajectory and Accelerated Adoption scenarios are based on the announced projects' end-uses. See methodological notes for more details. Tenders for procuring renewable hydrogen in Europe include Salzgitter AG and Thyssenkrupp Steel Europe AG0's for steel production and TotalEnergies' for refining.

Refineries, representing 57% of Europe's industrial hydrogen demand, can play a key role in achieving RED3 mobility targets

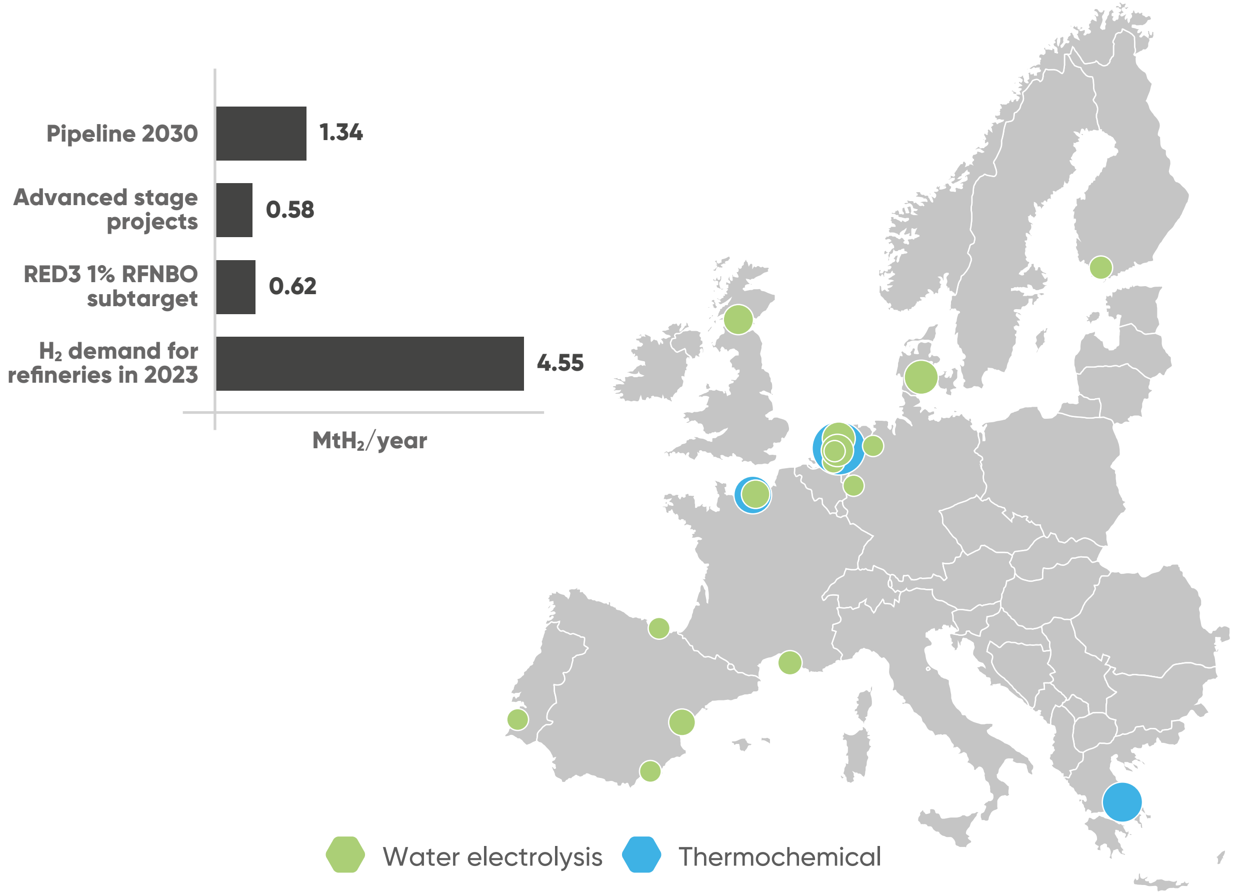
The refining sector plays a pivotal role in Europe's decarbonisation efforts, **with around 57% of Europe's hydrogen demand (4.5 Mt/year) coming from refineries.** Refineries might use clean hydrogen to produce alternative fuels such as biofuels and e-fuels. They can also use RFNBOs as intermediary in the production of conventional fuels, as this also counts towards the achievement of their obligations under RED3. Refining processes are included but not significantly affected by RED3 industry targets.

In Europe there are 68 announced clean hydrogen projects by 2030, targeting the decarbonisation of the refining sector **with a total capacity of 1.34 Mt/year, including 0.49 Mt/year from water electrolysis.** Of this, 0.58 Mt/year is in advanced stages, with 0.30 Mt/year from water electrolysis. Nevertheless, these projects cover about 30% of the current demand in the sector, underscoring the need to scale up clean hydrogen production.

In the Netherlands, the largest projects under construction include Holland Hydrogen's 200 MW_{el} electrolysis plant in Shell's Rotterdam refinery. In the same area, Air Liquide and Air Products have carbon capture projects retrofitting existing SMRs that plan to deliver hydrogen to other Rotterdam's refineries. In France, the 200 MW_{el} Normand'Hy project aims to contribute to decarbonising the Gonfreville refinery. Other notable large projects that reached FID and/or are under construction include GET H2 Nukleus's 300 MW_{el} in Lingen, REFHYNE's 100 MW_{el} in Wesseling, Germany, Galp's 100+200 MW_{el} project in Sines, Portugal, and BP's 24MW_{el} in Castellon, Spain.

FIGURE 3.25

Selection of large-scale clean hydrogen production projects in advanced stage in Europe with refining as intended end-use



Notes: Hydrogen demand estimated for 2023 in Europe including United Kingdom, Norway, Switzerland, and Iceland. Pipeline 2030 refers to the total number of announced projects with expected start dates by 2030 and intended end-use of hydrogen to refining. Advanced projects on the map encompass those that are operational, under construction, or in the preparatory stages and larger than 4,000 tonnes/year.

Ammonia projects concentration in Iberia and Nordics is driven by low renewable electricity prices and orientation towards exports

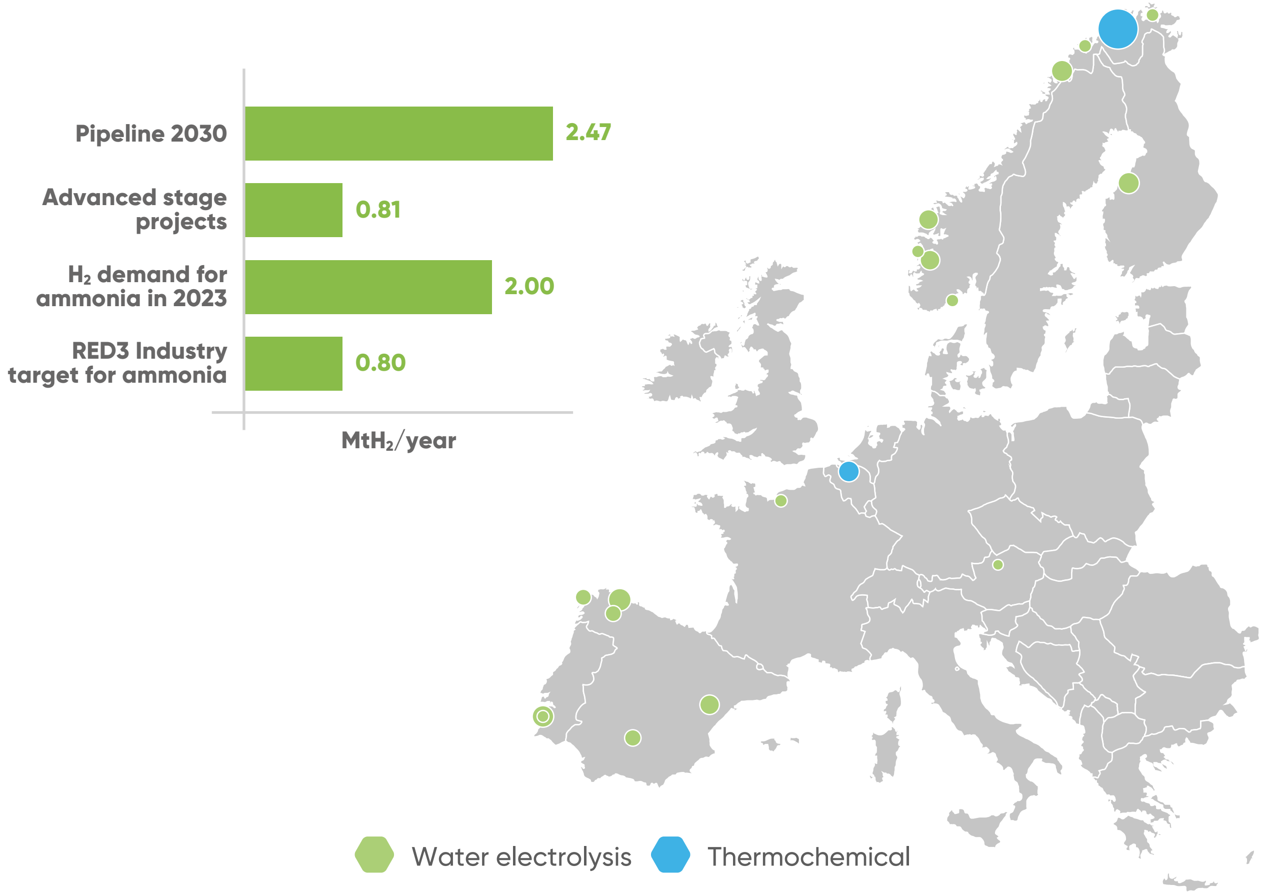
Europe has around 30 ammonia production facilities, generating around 17.7 Mt_{NH3}/year, and **consuming about 2 Mt/year of hydrogen, accounting for 25% of Europe's total hydrogen demand.** Ammonia is mainly used in the fertilizer sector and as a feedstock in the chemical sector. Its potential as a future energy carrier could drive additional demand.

Decarbonising this sector is reinforced by the EU's RED3 industry targets, which would require, based on current consumption and trade balance, **0.80 Mt/year of RFNBOs for ammonia production by 2030.** While use of clean hydrogen can nearly eliminate GHG emissions in this sector, high clean hydrogen costs could push countries to use imports to meet the targets. Despite Germany and the Netherlands currently being the largest ammonia producers, cheaper renewable energy is driving clean ammonia projects to the Nordics and Iberia.

In total, announced **clean ammonia projects are set to consume about 2.47 Mt/year of hydrogen by 2030, with 0.81 Mt/year in advanced stages of development** which would be enough to meet the RED3 target. Notable green ammonia projects include H2F Fertiberia in Spain (20 MW_{el} operational + 200 MW_{el} under development) and Catalina (500MW_{el}), and SKREI Yara (24 MW_{el} operational) for the decarbonisation of existing plants. Norwegian project Holmaneset as well as Hydrogen Bank auction winners Hysencia, Madoquoa, and Skiga are planning to build new ammonia production facilities, with much of it likely destined for exports.

FIGURE 3.26

Selection of large-scale clean hydrogen production projects in advanced stage in Europe with ammonia as intended end-use



Notes: Hydrogen demand estimated for 2023 in Europe including United Kingdom, Norway, Switzerland, and Iceland. RED3 targets are estimated based on EU-27 2023 consumption. Pipeline 2030 refers to the total number of announced projects with expected start dates by 2030 with intended end-use of hydrogen to ammonia. Advanced projects on the map encompass those that are operational, under construction, or in the preparatory stages and larger than 4,000 tonnes/year.

Clean methanol for the maritime sector is the main demand driver, with 0.11 Mt/year of hydrogen projects in advanced stage

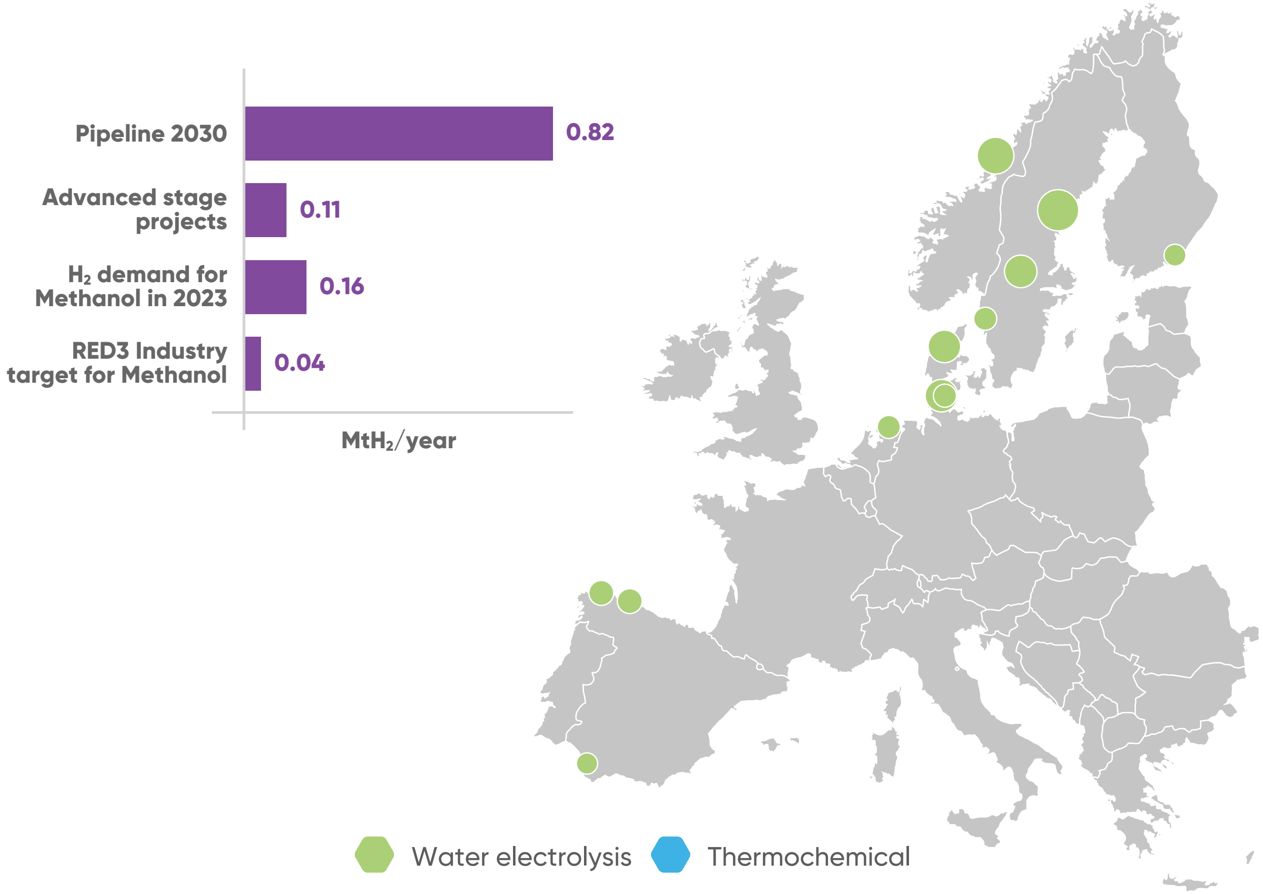
Methanol is primarily used in the chemical sector, and most of Europe's supply is currently imported. Domestic **methanol production accounts for 2% of Europe's hydrogen demand, approximately 0.16 Mt/year in 2023.** Methanol is still mainly produced from natural gas, a high-carbon-intensity process, but decarbonisation would be possible using clean hydrogen. Producing renewable methanol requires both the supply of renewable hydrogen and a sustainable CO_2 source. In the long-term, direct air capture, biogenic CO_2, and waste are the only sources compliant with RFNBO rules, which adds significant costs compared to other non-carbon-based hydrogen derivatives.

Clean hydrogen projects for methanol are mostly driven by maritime sector decarbonisation, which could increase methanol demand, supported by the **FuelEU Maritime regulation.** In the chemical sector, the methanol decarbonisation is incentivised by **EU's RED3 industry target aiming for 0.04 Mt/year of RFNBO hydrogen for methanol by 2030.**

Announced hydrogen projects total 0.82 Mt/year of hydrogen production for methanol by 2030, with 0.11 Mt/year in advanced stages. The projects are mostly in the Nordics, Iberia, and the Netherlands, due to favourable renewable energy prices and extensive maritime fleet. Some notable projects under development include European Energy's plants in Kasso (50 MW_{el}) and Aalborg (100 MW_{el}) in Denmark, Triskelion (60 MW_{el}) in Spain, and HyNetherlands (100 MW_{el}) in Netherlands.

FIGURE 3.27

Selection of large-scale clean hydrogen production projects in advanced stage in Europe with methanol as intended end-use



Notes: Industrial demand estimated for 2023 in Europe including UK, Norway, Switzerland, and Iceland. RED3 targets are estimated based on EU-27 2023 consumption. Pipeline 2030 refers to the total number of announced projects with expected start dates by 2030 with intended use of hydrogen to methanol. Advanced projects encompass those that are operational, under construction, or in the preparatory stages and larger than 4,000 tonnes/year.

E-SAF projects focusing on aviation amount to 0.95 MtH_2/year, enough to reach the ReFuelEU Aviation 2030 goals, but securing offtakers remains challenging

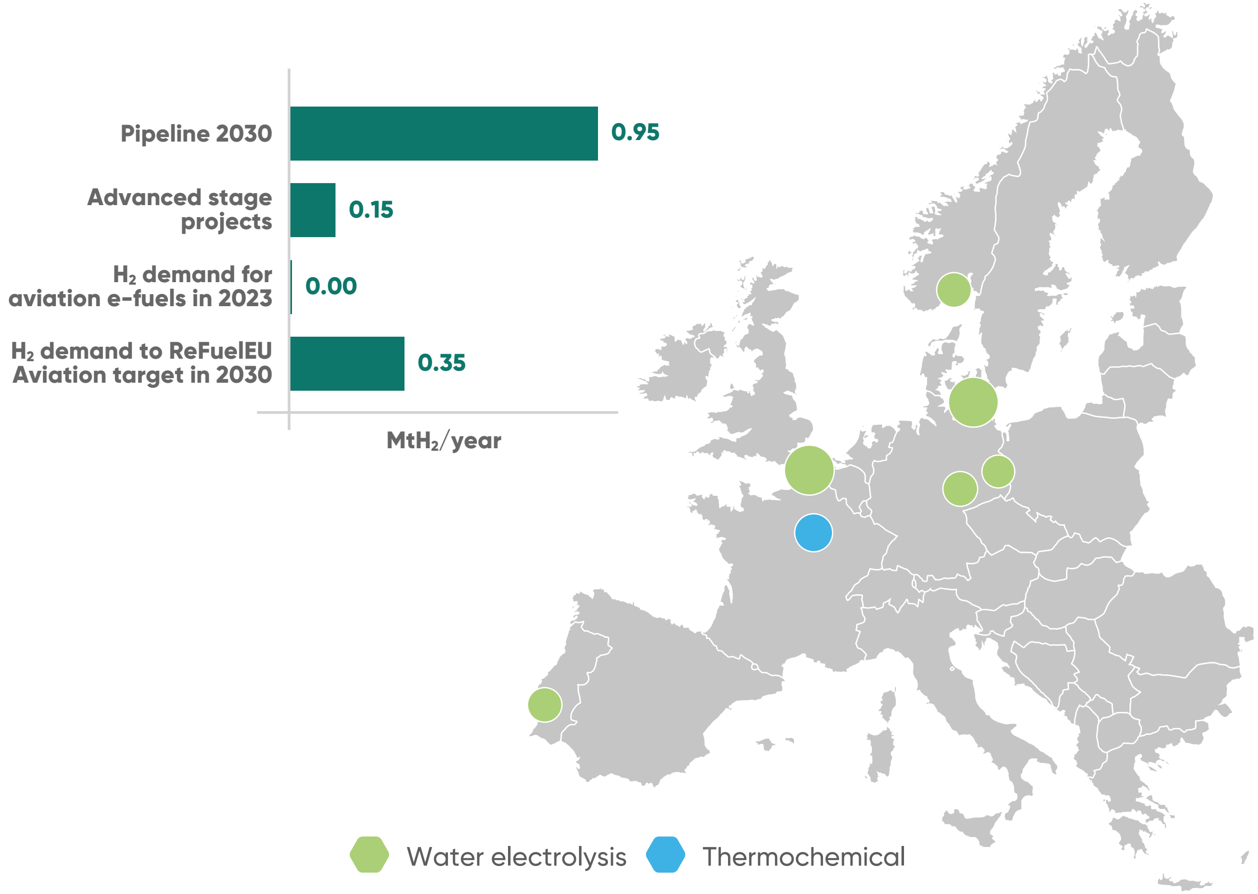
E-fuels will play a crucial role in decarbonising the aviation sector, which contributes to approximately 2–3% of total GHG emissions in Europe. The industry is actively pursuing emissions reductions through the adoption of Sustainable Aviation Fuels (SAF). Under the ReFuelEU Aviation regulation, the EU has set ambitious targets for the use of SAFs and e-fuels in the sector. **By 2030, at least 6% of the aviation fuel used at EU airports must be SAFs, with a sub-quota of 1.2% for synthetic fuels, representing around 0.35 Mt/year of electrolytic hydrogen.**

Renewable hydrogen projects are heavily dependent on early-on of taker commitments to derisk the investments and achieve advanced stages of development. In this context, e-SAF producers face additional challenges as they try to reshape the market and secure long-term agreements with airlines that conventionally sign fuel supply contracts only one year in advance. Policy measures that incentivise these airlines to support and sponsor projects early on can be pivotal for the success of the sector.

Currently, around **0.95 Mt/year of clean hydrogen production by 2030 has been announced for production of e-fuels for aviation, with 0.15 Mt/year in advanced stages.** Notable large projects under development to come before 2030 include the Arcadia Vordingborg (280 MW_{el}) in Denmark, and the Reuze Project (400 MW_{el}) in Dunkirk, France and Jangada (100MW_{el}) in Germany.

FIGURE 3.28

Selection of large-scale clean hydrogen production projects in advanced stage in Europe with e-fuels as intended end-use



Notes: Industrial demand estimated for 2023 in Europe including United Kingdom, Norway, Switzerland, and Iceland. Pipeline 2030 refers to the total number of announced projects with expected start dates by 2030 with intended end-use to e-fuels for aviation. Advanced projects encompass those that are operational, under construction, or in the preparatory stages and larger than 4,000 tonnes/year. Hydrogen demand estimated to meet the 1.2% of synthetic fuels by 2030 under the ReFuelEU targets and assuming current aviation fuel demand in the EU of 60 million tonnes.

Steel projects present a pipeline of 0.98 Mt/year of clean hydrogen production, capable of decarbonising 14% of the primary steel production by 2030

Europe produces around 126 million tons of steel annually accounting for about 7-8% of CO2 emission 4. By adopting hydrogen-based Direct Reduced Iron (DRI) and Electric Arc Furnace (EAF) technologies, **Europe could save up to 225 million tons of CO_2 emissions per year.** This shift would require **an estimated 6.9 million tons of renewable hydrogen annually.**

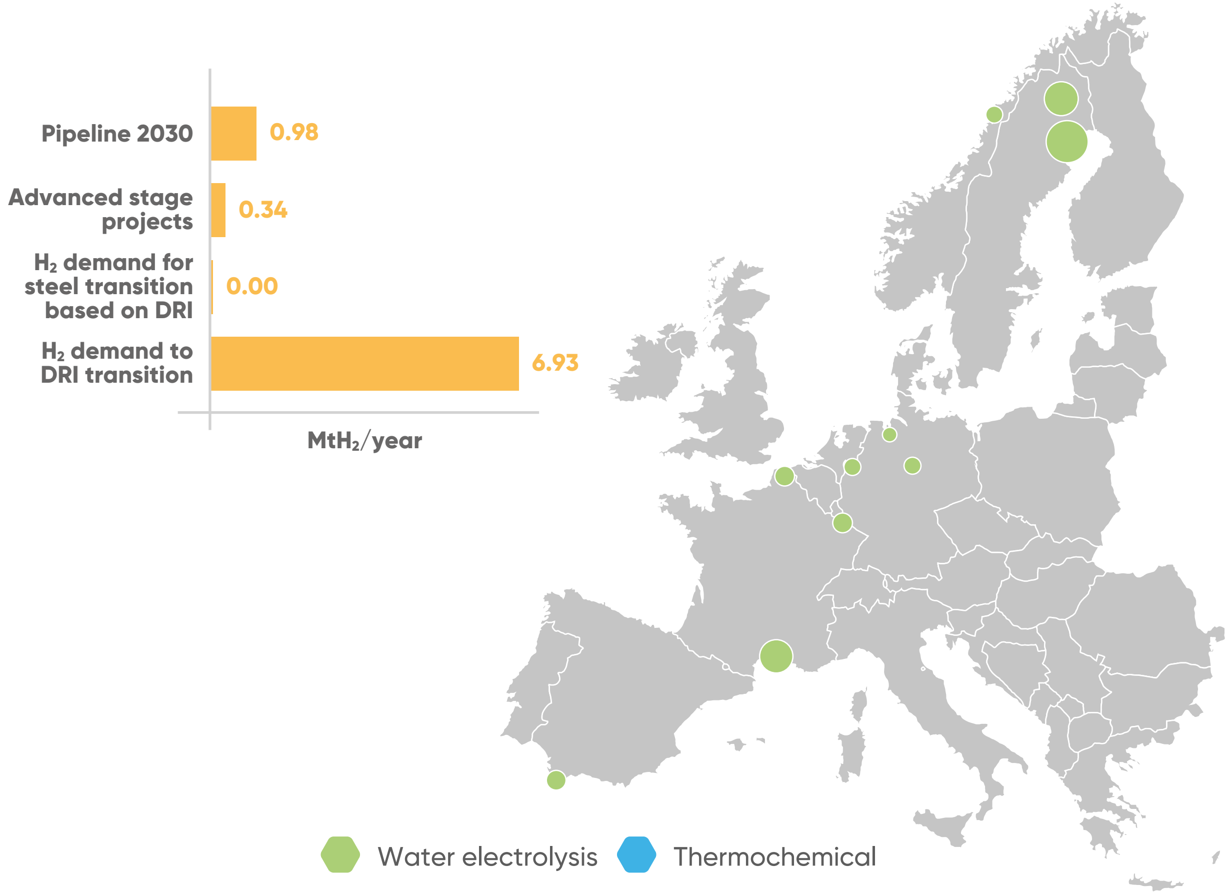
Automotive companies, as major consumers of steel, are the first demand driver for green steel, often directly investing in these projects. Their final products (e.g., cars) can absorb the premium cost of clean steel without heavily impacting the overall price.

In Europe, announced clean steel projects **account for about 0.98 Mt/year of hydrogen by 2030, with 0.34 Mt/year in advanced stages.** If all projects succeed, they could decarbonise around 14% of current primary steel production, highlighting the need for increased efforts and investment to the sector transition.

While some companies focus on decarbonising and modernising existing plants, new players are emerging in regions like the Nordics and Iberia. Stegra is developing a greenfield (~740 MW_{el}) hydrogen-based steel production in Northern Sweden, close to where SSAB and LKAB are also advancing their large-scale Hybrit project (500 MW_{el}). Meanwhile, other projects aim to decarbonise existing steel production such as GravitHy (500 MW_{el}) in France and SALCOS (100 MW_{el}) in Germany.

FIGURE 3.29

Selection of large-scale clean hydrogen production projects in advanced stage in Europe with steel as intended end-use



Notes: Industrial demand estimated for 2023 in Europe including United Kingdom, Norway, Switzerland, and Iceland. Pipeline 2030 refers to the total number of announced projects with expected start dates by 2030 and intended end-use to steel. Advanced projects encompass those that are operational, under construction, or in the preparatory stages and larger than 4,000 tonnes/year. Hydrogen demand estimated based on current annual primary steel production in Europe and its full transition to H-DRI with the assumption of 55kg of hydrogen per 1 ton of steel.

Methodological Note

GEOGRAPHICAL SCOPE: This chapter covers 32 countries in the EU, the European Free Trade Area, and the UK, which are referred to as "Europe" in the text. Results in this chapter may purposefully exclude some countries depending on the quantity and quality of the collected information. Reference to the EU covers only the 27 countries of the European Union.

PROJECT PIPELINE METHODOLOGY: The list of projects that form a basis for the project pipeline and subsequent supply outlook analysis have been collected by Hydrogen Europe from both public and confidential sources. The authors collected this information to the best of their abilities but cannot guarantee the absolute completeness or accuracy of the collected data. The authors have adopted an inclusive approach when compiling this list of projects to develop the most exhaustive compilation of European power-to-hydrogen/water electrolysis and clean thermochemical projects. The data collection closed in early September 2024.

The authors are not judging the feasibility of announced facilities but are reporting various public and private data points. As a result, project pipeline outputs include projects in all stages from concept, feasibility study, preparatory stage (FEED, detailed design, and permitting), and construction (post FID). Advanced projects refer to projects either under construction or in a preparatory stage. If the authors of this report refer to specific projects and provide any project details, this information is public. Years refer to end of the year. By 2030 refers to "by the end of 2030". While project announcements are common for hydrogen production projects, cancellations are rarely publicised. The authors cancel projects if they find confirmation or if there are no news for at least 18 months. If only estimate ranges have been given for capacity or start dates, the authors adopted the average of the provided values.

The term "project" refers to an individual project or a project phase with a separate FID. One project can have multiple phases that gradually enlarge its capacity. For the purposes of this report, each phase of a project with three phases of 10 MW_{el}, 100 MW_{el}, and 300 MW_{el} in the same location and with the same project partners is counted as a separate project.

UTILISATION ASSUMPTIONS: The data on collected projects tracks their production capacity in MW_{el} (electrolysis) and MW (thermochemical) respectively. To achieve outputs in Mt of hydrogen, the following utilisation assumptions have been used: Thermochemical - 8,000 hours a year at full capacity. Power-to-hydrogen/water electrolysis – For projects connected to the grid, capacity factors are based on the results from European Hydrogen Bank pilot action. For countries with no or few projects in the European Hydrogen Bank pilot auction, assumptions were based on country characteristics. In real life, there will be grid connected projects that will have significantly higher and lower utilization than those assumed. For projects that are planning to be directly connected to their renewable energy sources and do not plan to rely on a grid connection, the electrolyser capacity factor is equal to solar/onshore wind/offshore wind's capacity factor for the top 10% available locations in that Member State as reported by Joint Research Centre's ENSPRESSO dataset from 2019 and adjusted for oversizing the renewables to the electrolyser.

SUPPLY OUTLOOK METHODOLOGY: It was created using a bottom-up approach based on the project pipeline for each country adjusted for different project maturity, development timelines, country ambitions, and available funding.

The assumed conversion factor for projects before country specific adjustments:

PHASE	CURRENT TRAJECTORY	ACCELERATED ADOPTION
Construction/FID	1	1
Preparatory stage with funding	0.6	0.9
Preparatory stage with offtaker	0.4	0.75
Preparatory stage	0.3	0.5
Feasibility with funding	0.3	0.5
Feasibility with offtaker	0.1	0.25
Feasibility	0.05	0.25
Concept	0	0.1

The Current Trajectory (CT) scenario represents the current market trajectory with many, but not all, funded projects reaching FID and becoming commissioned. Country individual adjustments have been made based on government ambitions, available and expected funding, and industry ambitions.

The Accelerated Adoption (AA) scenario takes a more optimistic perspective on the development of the clean hydrogen market and assumes that some of the improvements to funding, European regulatory framework, national implementation, and infrastructure occur. That would lead to more projects deployed, allowing the industry to scale up faster and thus accelerate the expected cost reduction and help build a positive momentum before 2030. In countries with minimal project pipelines, it assumes effort towards minimum compliance with country ED3 mobility targets. Country individual adjustments have been made based on government ambitions, available and expected funding, and industry ambitions.

END-USES:

- The supply volumes for various end-uses for both scenarios is a result of the above-mentioned supply methodology applied to every single project and its announced end-use (or N/A when no specific end-use has been announced). No further assumptions were made with respect to which end-uses will have a higher likelihood to come online in specific countries.

- "Steel" as an end-use refers to hydrogen used as a reducing agent in the H-DRI production process.

- "Industrial heating" as an end-use refers to hydrogen burned to produce heat for industrial purposes, which includes hydrogen used for the hot rolling of steel.

- "Other industry" refers to hydrogen used as a feedstock in the production of chemicals other than methanol and ammonia or projects targeting big industrial clusters without specifying the exact final consumer.

- "E-fuels" as an end-use includes all synthetic fuels produced using clean hydrogen as a feedstock, excluding methanol and ammonia. This includes mostly e-methane and e-kerosene/e-SAF production projects.

- "Mobility" as an end-use refers to the direct use of hydrogen in fuel cell electric vehicles.

- "Blending" as an end-use refers to the direct injection of hydrogen in the gas grid.

- In case a project has announced multiple end-uses for its produced hydrogen, only the largest end-use is taken into account. Authors realise this methodological limitation and will seek to remedy it in future publications.

CONVERSION ASSUMPTIONS: The conversion between electrolysis capacity expressed in MW_{el} and tonnes per year is made using a 53 kWh/kg efficiency and assuming 8760 full load hours.

FUNDING METHODOLOGY: The authors assume a *4x multiplier effect*. Applicants to the Innovation Fund have communicated a general 4x multiplier between funding needed and total CAPEX for projects[2]. The authors assume the validity of this multiplier for the whole hydrogen market.

Selected national funding schemes often target more than just hydrogen. The authors generally estimate that 20% of national public funds are allocated to hydrogen, except for schemes with specific funding targets. This estimate is based on the average 20% investment in hydrogen related projects from The EU Innovation Fund (Grant, excluding IF23 results, as grants are not signed at publication of the report). A detailed list of national schemes and assumptions is provided in Annex 1 of the report.

For the UK, the first round of the Hydrogen Ambition Report (HAR) funded 125 MW of hydrogen capacity at €2.3 billion. To reach an additional 875 MW by 2025, the authors estimate that about €18.4 billion is needed at similar strike price. In the US, the IRA's uncapped hydrogen tax credits (45V and 45Q) are projected by BNEF to total public funding of up to $137 billion over the next ten years.[3]

Endnotes

1 / IFP Energies Nouvelles, SINTEF Energi AS, Deloitte Finance, 2021

2 / Directorate-General for Climate Action (European Commission), 2022

3 / BNEF, 2023

4 / Eurofer, 2024

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Terminology

Clean hydrogen refers to hydrogen produced using production methods that have the potential to reduce emissions compared to conventional (non-abated fossil-fuel based hydrogen production). When referring to clean hydrogen, this report refers to hydrogen produced by electrolytic (water electrolysis) and thermochemical production methods. The thermochemical in this report refers to clean thermochemical production methods (reforming with carbon capture projects, methane splitting, biowaste-to-hydrogen, non-biological waste-to-hydrogen). The developers using these production pathways want to produce abated hydrogen and thus the assumption is that the emissions will be maximum 3.38 $kgCO_2/kgH_2$.

Renewable hydrogen is used interchangeably with RFNBO hydrogen (Renewable Fuel of Non–Biological Origin) in this report and refers to hydrogen produced from renewable electricity and satisfying the conditions outlined in delegated acts of the Renewable Energy Directive.

Water electrolysis/power–to–hydrogen/electrolytic are used interchangeably. Water electrolysis or power–to–hydrogen (PtH) refers to electrolysers splitting water with electricity with hydrogen being the main product. This excludes brine electrolysis.

Thermochemical refers to clean thermochemical hydrogen production. This includes the following hydrogen production pathways reforming, gasification, or partial oxidation of fossil fuels coupled with carbon capture of the emissions, methane splitting, biowaste-to-hydrogen, non-biological waste-to-hydrogen. The developers using these production pathways want to produce abated hydrogen and thus the assumption is that the emissions will be maximum 3.38 $kgCO_2/kgH_2$.

Conventional/non-abated fossil-fuel based hydrogen refers to hydrogen produced by steam reforming, partial oxidation, gasification, and autothermal reforming of fossil fuels without any CO2 abatement. Popularly referred to as "grey" hydrogen.

Reforming refers to hydrogen production from steam reforming, partial oxidation, gasification, and autothermal reforming of fossil fuels. These processes account for the largest hydrogen production capacity.

Reforming refinery off-gas/reforming by-product refers to hydrogen produced in refineries as a by–product, e.g., during catalytic reforming.

By–product (ethylene, styrene) refers to the hydrogen production capacity as a by–product of ethylene and styrene production.

By–product (electrolysis) refers to by–product hydrogen production capacity from electrolytic chlorine and sodium chlorate production.

ANNEX 1

Funding analysis: schemes covered and assumptions

GERMANY

Program	EUR in Billion	Comments
Subsidy plan for H2-ready plants	3.2	2.5GW out of the total 12.5GW (20% of 16 billion EUR) are allocated directly to increase the capacity of total H2 power plants. The remaining budget goes to H2-ready gas power plants (switch to H2 8 years after commissioning of the plants).
NIP	1.4	
Lufo-Program	0.1	
NIP 2	0.2	
Climate Protection Contracts	4.6	Total scheme is 23 bn EUR. Assumption that 20% are spent on hydrogen as in IF.
H2 Global	5.0	
H2 Bank AaaS	0.4	
Total	**14.9**	

NETHERLANDS

Program	EUR in Billion	Comments
SDE++	8.4	Total scheme is 42 billion. Assumption that 20% are spent on hydrogen as in IF.
DEI+	0	
OWE	1.3	
Hydrogen in Mobility Subsidy Scheme	0.1	
H2Global	0.3	
Total	**10.1**	

FRANCE

Program	EUR in Billion
Decarbonized Hydrogen production	4.2
Hydrogen Ecosystem	0.5
Technological Bricks Hydrogen	0.4
PEPR Decarbonised Hydrogen	0.1
Hydrogen and Hybrid plane deployment	0.1
Production of liquid fuels from biomass & renewable hydrogen	0.9
Total	**6.2**

SPAIN

Program	EUR in Billion
H2 VALUE CHAIN Program 3	0.1
Incentive Programs for the innovative value chain and knowledge of renewable hydrogen	0.1
IDEA - H2 Pioneers	0.3
Production of renewable hydrogen for Valleys	1.2
Total	**1.7**

NORWAY

Program	EUR in Billion
Ammonia in Vessels	0.1
Hydrogen in Vessels	0
Green Technology Grants	0.1
Hydrogen production for maritime	0.1
Joint Nordic Hydrogen Research Programme	0
Total	**0.3**

PORTUGAL

Program	EUR in Billion	Comments
Hydrogen and Renewable Gases	0.1	
Production of renewable hydrogen	0.1	
Centralised purchase of hydrogen and biomethane	0.1	
State Aid: Investment in sector to foster energy transition	0.2	Total scheme is 1 billion EUR. We assume 1/6th of 1 billion EUR goes to hydrogen, as multiple sectors are being funded (batteries, solar panels, wind turbines, heat-pumps, electrolysers, and equipment for carbon capture usage and storage (CCUS))
Total	**0.5**	

DENMARK

Program	EUR in Billion
EUDP	0.5
Power-to-X tender	0.2
Carbon Capture Scheme	1.1
Joint Nordic Hydrogen Research Programme	0
Total	**1.8**

ITALY

Program	EUR in Billion
Hydrogen Research and Development	0.1
Hydrogen HRS for road transport	0.2
Hydrogen HRS for rail transport	0.3
Support to electrolyser production	0.1
Hydrogen use in hard-to-abate sectors	1.0
Total	**1.7**

FINLAND

Program	EUR in Billion
Production of renewable methane & methanol	0.1
Joint Nordic Hydrogen Research Programme	0
Total	**0.1**

POLAND

Program	EUR in Billion	Comments
Foster transition to net-zero economy	0.2	Total scheme is 1.2 billion EUR. We assume 1/6th of 1.2 billion EUR goes to hydrogen, as multiple sectors are being funded (batteries, solar panels, wind turbines, heat-pumps, electrolysers, and equipment for carbon capture usage and storage (CCUS))

AUSTRIA

Program	EUR in Billion	Comments
Decarbonization of industrial production processes	0.6	Total scheme is 2.7 billion EUR. Assumption that 20% are spent on hydrogen as in IF

HUNGARY

Program	EUR in Billion	Comments
Accelerated investments in sectors strategic for the net-zero economy	0.3	Total scheme is 2 billion EUR. We assume 1/6th of 2.01 billion EUR goes to hydrogen, as multiple sectors are being funded (batteries, solar panels, wind turbines, heat-pumps, electrolysers, and equipment for carbon capture usage and storage (CCUS))

CZECH REPUBLIC

Program	EUR in Billion	Comments
Programme ENERG ETS	0.5	Total scheme is 4.5 billion EUR. Assumption that 20% are spent on hydrogen as in IF

SWEDEN

Program	EUR in Billion
Industrial Leap	0.1
Joint Nordic Hydrogen Research Programme	0
Total	**0.1**

UNITED KINGDOM

Program	EUR in Billion	Comments
IDHRS	0.3	
Industrial Hydrogen Accelerator Programme	0	
Hydrogen BECCS Innovation Programme	0.3	
Clean Maritime Demonstration Competition	0	
Net Zero Hydrogen Fund (NZHF)	0.2	
Hydrogen Production Business Model	2.3	For 125MW, 2.3 billion have been spent. Until 2025, UK wants to achieve 1GW of capacity. Hence, we assume that the commitment under HAR2 is equal to 16.1 billion
Total	**3.1**	

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