

Renewable and low-carbon hydrogen

State of play and outlook

SUMMARY

Hydrogen is a feedstock used in the petrochemical industry and can also serve as an energy carrier. Currently, 96 % of hydrogen in the EU is produced from natural gas, a process that emits considerable amounts of CO₂. When the CO₂ is captured and stored, it is known as low-carbon hydrogen. Another technology for producing hydrogen is water electrolysis, which breaks water down into hydrogen and oxygen. If electrolysis is powered by renewable electricity, there are no CO₂ emissions, and the hydrogen produced is referred to as renewable hydrogen. Both low-carbon and renewable hydrogen can play a crucial role in the energy transition of the EU by replacing fossil fuels in carbon-intensive sectors. They can be used in iron and steel production, the chemical industry, and transport, as well as for generating industrial and residential heat and electricity.

In 2023, EU-27 hydrogen consumption stood at 7.3 million tonnes (megatonnes or Mt), equivalent to around 2 % of total EU energy consumption. Refineries, as well as the ammonia and chemical industries, account for the largest share of hydrogen demand.

Renewable hydrogen is more expensive than fossil-based hydrogen, hindering its development. However, its cost is expected to go down, especially in regions with abundant renewable electricity. Hydrogen infrastructure is currently in the project development stage. Rising interest rates have increased the cost of new projects in the hydrogen value chain, although there are EU schemes – in particular the European Hydrogen Bank – to assist with financing and establishing a lead market.

To complete the policy framework for this emerging market, the EU has adopted a hydrogen and decarbonised gas market package, updating EU gas market rules to prepare for renewable and low-carbon gases and laying the groundwork for dedicated hydrogen infrastructure and market. The latest revision of the Renewable Energy Directive sets targets for the uptake of renewable hydrogen in industry and transport. A European Court of Auditors' report recently confirmed that the EU regulatory framework is mostly complete but that its impact on the market has yet to be seen.



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Introduction

[Hydrogen](#) is an energy carrier that is expected to play an important role in the EU energy transition. The July 2020 EU [hydrogen strategy](#) set out a plan for expanding hydrogen production and use in the EU, moving away from fossil-based hydrogen, which causes CO₂ emissions, towards renewable and low-carbon hydrogen, which has little to no emissions and can help achieve the EU's climate ambitions. Currently, hydrogen is used in industrial processes (such as crude oil refining, ammonia production for fertilisers and methanol production). It is also used in [fuel cells](#) for electricity generation and for powering vehicles. Renewable and low-carbon hydrogen can replace fossil fuels in the energy system and in industrial processes, such as the production of iron and steel, chemicals, plastics and fertilisers. The European Commission [expects](#) renewable hydrogen to cover around 10 % of the EU's energy needs by 2050. To realise the potential of hydrogen and create a strong business case for producers and consumers, key enabling factors include price and infrastructure for production, distribution, storage and use.

Production of hydrogen

According to the [Clean Hydrogen Observatory](#), as of the end of 2023, there were 512 hydrogen production facilities in Europe¹ with a production capacity of 11.2 Mt. A comparison with the actual volume of hydrogen produced in 2023 (7.94 Mt) shows that 71 % of the existing capacity was utilised.

There are different hydrogen production pathways that result in varying amounts of greenhouse gas (GHG) emissions. These pathways include thermochemical conversion (steam methane reforming – SMR, partial oxidation and autothermal reforming), biochemical conversion and [electrolysis](#). Thermochemical conversion uses fossil fuels or [biomass](#) while biochemical conversion uses algae or biomass. Electrolysis uses electricity to split water into hydrogen and oxygen, and the amounts of GHG emissions produced can vary depending on the source of the electricity.

At present, [96 %](#) of the hydrogen produced in the EU is **fossil-based** and is created using natural gas (also known as grey hydrogen). This process leads to significant CO₂ emissions, which are subject to carbon pricing in the EU emissions trading system (ETS).

One way to avoid CO₂ emissions is through [carbon capture and storage \(CCS\)](#), which results in **low-carbon hydrogen**, or blue hydrogen. The [Hydrogen and Gas Market Directive](#) (EU) 2024/1788 defines low-carbon hydrogen as hydrogen derived from non-renewable sources that meets a GHG threshold of 70 %. This definition may also apply to hydrogen produced by electrolysis using [nuclear power](#). The delegated act defining the precise methodology for calculating the GHG savings from producing low-carbon hydrogen must be adopted by 5 August 2025. As part of the consultation process, the Commission published a [draft](#) version of this delegated act on 27 September 2024. After the delegated act is published, Parliament and Council will have two months (with a possible prolongation) to [scrutinise](#) and raise objections, but not to make any amendments to it.

Table 1 –EU definitions of hydrogen and other definitions based on colour

EU definitions of hydrogen	Colour definitions assigned to hydrogen	
Renewable hydrogen (also referred to as clean hydrogen)	Green hydrogen (renewable electricity through electrolysis)	Electricity from the grid (electrolysis)
Low-carbon hydrogen	Blue hydrogen (natural gas with carbon capture and storage (CCS))	
Fossil-based hydrogen (without CCS)	Grey hydrogen (natural gas), brown hydrogen (brown coal), black hydrogen (black coal)	

Source: G. Erbach with S. Svensson, [EU rules for renewable hydrogen](#), EPRS, April 2024.

The typical [production pathway](#) for **renewable hydrogen** (also known as green hydrogen or clean hydrogen) is electrolysis using renewable electricity. EU legislation treats renewable hydrogen as 'renewable liquid and gaseous fuels of non-biological origin' ([RFNBO](#))². This term includes renewable hydrogen produced from renewable energy sources in the form of heat or electricity and other renewable fuels (excluding biomass). In February 2023, the Commission adopted two delegated acts supplementing the Renewable Energy Directive, establishing the [detailed rules](#) regarding the production and certification of renewable hydrogen. The first one, the [Delegated Regulation on Additionality](#), establishes criteria for the temporal and geographical correlation of renewable electricity generation and hydrogen production. The second, the [Delegated Regulation on GHG Savings](#), establishes rules for calculating life-cycle GHG emissions for RFNBOs.

Cost of fossil, low-carbon and renewable hydrogen

Currently, the most cost-competitive method of producing hydrogen uses **fossil fuels**. In the EU, the most common method of producing hydrogen is through steam methane reforming (SMR) based on natural gas. According to industry organisation [Hydrogen Europe](#), in 2023, producing hydrogen through SMR in the EU-27 cost approximately €2.94 per kilogram (kg) excluding capital expenditure and other fixed costs. This was more than double the historical production costs before 2022 of €1.2-1.5 per kg, and is a direct consequence of the natural gas price hikes in recent times. In 2023, the levelised cost (which include capital expenditure and other fixed costs) of hydrogen produced through SMR was €3.20, down from €5.70 in 2022 when gas prices had soared.

The cost of **low-carbon hydrogen** includes the cost of carbon capture and storage (CCS). In 2023, the levelised cost of producing hydrogen through autothermal reforming with CCS (95 % CO₂ capture rate) in the EU-27 was estimated at €3.80/kg, which was 40 % lower than in 2022.

According to Hydrogen Europe, in 2023, the levelised production costs of hydrogen through **electrolysis with grid-mix electricity** varied from €4.1/kg (Finland) to €12.4 /kg (Poland), with an average of around €7.90/kg (compared to €9.80 in 2022).

The cost of producing **renewable hydrogen** through electrolysis depends on renewable energy sources' availability at a specific location. Power purchase agreements can be used to ensure a stable price for renewable electricity. While capital expenditure (such as for electrolyzers and pipelines) has a rough share of 38 % in the [total costs](#) of electrolysis, electricity (including wholesale price, taxes and charges) has the majority share (61 %). As interest rates rise, the cost of acquiring capital is becoming an increasingly important factor in the overall costs. The expected decrease in the cost of electrolyzers (the Commission anticipates their price to [halve](#) by 2030, although some [industry analysts](#) are less optimistic) could make renewable hydrogen competitive with fossil-based hydrogen, particularly in regions with cheap and abundant renewable electricity.

In the coming years, however, the price of renewable hydrogen is expected to remain higher than that of fossil hydrogen. The winners of the European Hydrogen Bank's [pilot auction](#) needed support ranging from €0.37 to €0.48 to bridge the gap between production costs and the price paid by industrial consumers. Indirect factors such as [policy](#), the industrial ecosystem, geopolitics, trading dependencies and the cost of capital and technology can all influence the future price trajectory.

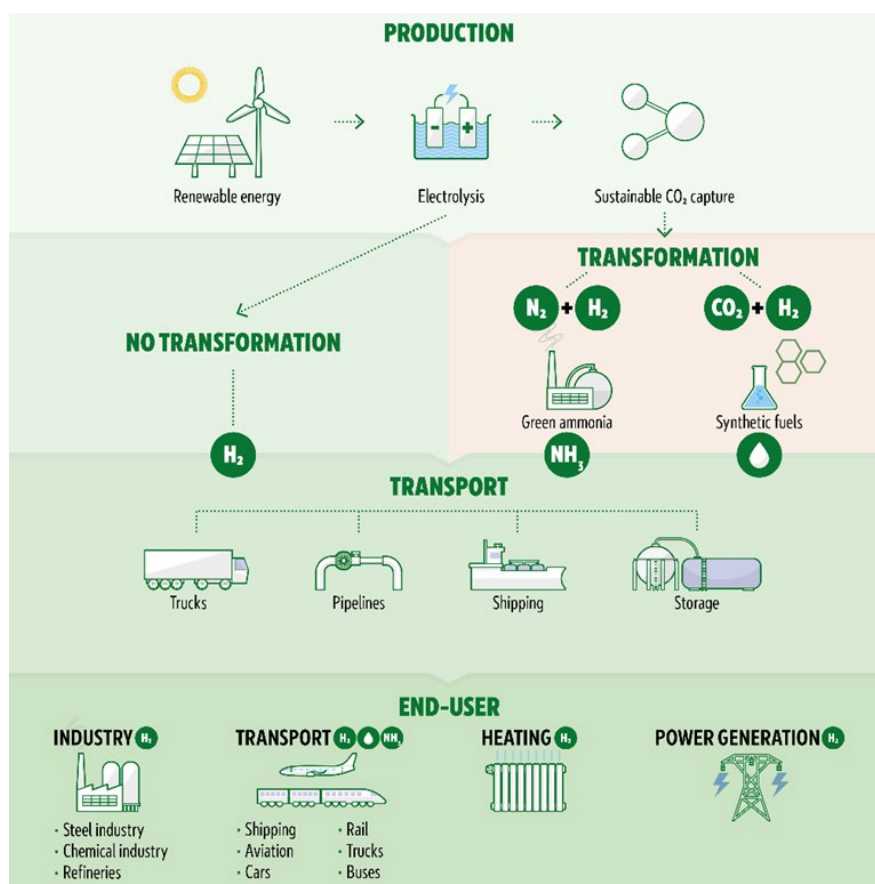
Uses of hydrogen

Currently, hydrogen is primarily used in the chemical sector (more specifically in refining and the production of plastics and fertilisers). In 2023, EU-27 hydrogen demand reached [7.3 megatonnes \(Mt\)](#), which is almost 2 % of energy consumption. The largest [share](#) of hydrogen demand in Europe came from refineries (57 %), the ammonia industry (25 %) and the chemical industry (11 %) in 2023.

Renewable hydrogen can help decarbonise a range of sectors where cutting GHG emissions has been challenging. In the [chemical industry](#), it can replace fossil-based hydrogen. In [iron and steel-making](#), it could replace coking coal to reduce emissions coming from blast furnaces. In the [transport](#)

[sector](#), heavy-duty vehicles could operate on hydrogen fuel cells, and hydrogen-based e-fuels could be viable for aviation and shipping. Pilot projects on the use of hydrogen in [aviation](#) are underway.

Figure 1 – Renewable hydrogen production, transformation and end use



Source: EPRS based on [IRENA](#).

Hydrogen can also serve to generate industrial and residential heat and electricity. In theory, pure hydrogen and hydrogen blends (i.e. with natural gas) can be burned to produce electricity. Gas-fired power plant operators are looking at ways to add hydrogen to or replace natural gas.

Hydrogen is the smallest molecule, meaning that it can easily leak or cause corrosion of materials. Extra precautions are therefore needed when repurposing existing infrastructure for hydrogen, and [safety](#) issues must be addressed.

Each potential use of hydrogen competes with alternative technologies that may be cheaper, safer or more convenient. For uses in areas such as passenger transport or [residential heating](#), direct electrification through battery-electric vehicles or heat pumps appears to be the more cost-effective option.

A potential important application of hydrogen is as a medium for energy storage. Unlike electricity, hydrogen can be stored in large amounts for an extended time. It offers a way to support the integration of variable renewables in the electricity system. When renewable electricity production exceeds demand, the surplus can help to produce hydrogen. This hydrogen is stored and can serve during periods of low renewable output, ensuring reliable power supply.

Hydrogen infrastructure

The hydrogen infrastructure is currently in the project development stage. In Europe, there are 16 dedicated [operational hydrogen pipelines](#) with a total length of 1 564 km. They mostly deliver hydrogen to the petrochemical and chemical industries. The hydrogen pipeline system is still in its early stage [compared](#) to the extensive network of natural gas pipelines, which includes more than 200 000 km of transmission pipelines and over 2 million km of distribution networks. The EU's legislative package on [decarbonised gas and hydrogen](#), adopted in May 2024, is expected to provide momentum for the development of hydrogen infrastructure. [Regulation \(EU\) 2024/1789](#) supports coordinated infrastructure planning by all energy providers, requiring joint scenarios for electricity, gas and hydrogen in national network development plans. It also provides for a separate European network of network operators for hydrogen ([ENNOH](#)), which would be responsible for drafting an EU-wide 10-year network development plan (TYNDP) for hydrogen starting in 2028.

A current trend is the repurposing of natural gas infrastructure for hydrogen transportation. This can reduce investment costs for hydrogen development by [50–80 %](#). According to the European Network of Transmission System Operators for Gas ([ENTSOG](#)), there are currently approximately 70 ongoing retrofitting/repurposing projects. Each decision on repurposing must consider the composition of the pipelines, the impact on end users, safety issues and the risk of leakage. To address these challenges, the industry uses polymerisation of pipelines and ensures the integrity of all infrastructure used for transmission, distribution and conversion.

Establishing a proper hydrogen infrastructure requires a significant investment. A [report](#) for the Parliament's ITRE committee points out that the investment estimated in the Commission's [REPowerEU communication](#) (€86 to €126 billion) is lower than in alternative studies. One of these studies [estimated](#) the required cumulative investment in the hydrogen value chain at €300–450 billion by 2035, and €1.9 trillion to €2.5 trillion over the next 30 years. In addition, Member States need to adapt port infrastructure to enable the import of hydrogen and its derivatives, or alternatively, [hydrogen-based industrial raw materials](#). Moreover, electricity infrastructure will have to be [expanded](#) to supply around 500 terawatt-hours (TWh) of renewable electricity for electrolysis in the EU by 2030, in addition to the electricity supply needed for the direct electrification of end uses.

Table 2 – Investment needed in the hydrogen supply chain by 2054

Electrolysers	€790 bn - €1 500 bn
Low-carbon production technologies	€80 bn - €140 bn
Infrastructure	€850 bn

Source: [Hydrogen4EU report](#), 2022.

Important tools and initiatives to support hydrogen infrastructure development include:

- [projects of common interest \(PCI\)](#) under the revised [TEN-E Regulation](#). These are key cross-border infrastructure projects selected by the Commission to enhance energy networks and market integration. In 2024, the [PCI list](#) included, for the first time, 65 hydrogen and electrolyser projects out of a total of 166. Fossil gas projects are no longer supported;
- [important projects of common European interest \(IPCEI\)](#). This is a scheme under the EU State aid rules that enables Member States to directly fund integrated [cross-border hydrogen projects](#) (subject to Commission approval);
- the [Innovation Fund](#). Funded through the EU emissions trading system, it offers funding to businesses for investing in highly innovative technologies and projects that could help reduce emissions. It also allows for risk sharing with project promoters;
- the [European Hydrogen Backbone](#). Developed by energy infrastructure operators, this initiative aims to support the establishment of a future hydrogen network based

on five pipeline corridors. The plan is to build 31 000 km of infrastructure by 2030 (60 % repurposed natural gas pipelines) and 53 000 km by 2040;

- [hydrogen valleys](#). These are geographical areas (cities, regions, islands or industrial clusters) with multiple hydrogen applications combined into an integrated hydrogen ecosystem covering the entire value chain: production, storage, distribution and various end uses;
- the public-private [Clean Hydrogen Partnership](#). It supports R&I activities in hydrogen technologies and helps finance the creation of hydrogen valleys. Total expected investment is €2 billion; half of this amount is to be funded by the EU. A 2024 Commission [report](#) details the challenges and opportunities of hydrogen valleys.

Policy framework

The EU [hydrogen strategy](#) of 2020 establishes a number of actions to promote investment, boost demand for hydrogen, scale up its production in Europe, design a supportive framework, and strengthen international cooperation. The legislative package on [hydrogen and the decarbonised gas market](#), adopted in May 2024, provides a comprehensive framework for the development of the hydrogen market. [Regulation \(EU\) 2024/1789](#) revises internal market rules to prepare the gas sector for the transition towards low-carbon and renewable gases. The newly established ENNOH will support the development of hydrogen infrastructure. National regulatory authorities will retain the right to set their own network tariffs in the hydrogen market but will have to consult with neighbours on tariff methodology. Furthermore, the Parliament secured significant tariff discounts for hydrogen. As requested by Parliament, there will be a voluntary mechanism to support the market development of hydrogen (as a pilot project for five years), in line with the activities of the European Hydrogen Bank. Before the pilot project expires, the Commission will have to submit a report to the Parliament and the Council. If the results are encouraging, the Commission will propose legislation for a mechanism for voluntary demand aggregation and joint purchasing of hydrogen. In June 2024, the Commission launched a [tender](#) for service providers charged with designing a demand aggregation tool for hydrogen and operating it from mid-2025.

[Directive \(EU\) 2024/1788](#) lays down common rules for the internal market in renewable and natural gases and hydrogen, including their transmission, distribution, supply and storage. It covers market access, authorisation procedures and system operations. Additionally, it outlines plans for an EU-wide hydrogen network. It separates gas and hydrogen supply and production from the operation of transmission networks, thus retaining both horizontal and vertical unbundling. These elements aim to ensure favourable conditions for the use of hydrogen in hard-to-decarbonise sectors, such as the steel and chemical industries, which are central to the development of the hydrogen market. The [Renewable Energy Directive](#), as revised in October 2023, sets targets for the uptake of renewable hydrogen in industry and transport by 2030. There is a combined sub-target of 5.5 % for advanced biofuels and RFNBOs (mostly hydrogen-based) in the total energy supplied to the transport sector. Within this target, one percentage point must come from RFNBOs. Additionally, it sets an indicative target to raise the share of renewable energy in the industry sector's energy consumption by an annual average of 1.6 percentage points over the 2021-2030 period, while 42 % of the hydrogen used in industry must come from RFNBOs by 2030 and 60 % by 2035 (these percentages may be reduced by Member States under certain conditions). The [ReFuelEU Aviation Regulation](#) and the [FuelEU Maritime Regulation](#) also set targets for the use of RFNBOs (mostly renewable hydrogen and hydrogen-based synthetic fuels) in aviation and maritime transport.

The [Net-Zero Industry Act](#), adopted in June 2024, establishes a framework for scaling up the manufacturing capacity of 19 strategic net-zero technologies in the EU, including hydrogen technologies (electrolysers and fuel cells) and RFNBO technologies. The act sets a benchmark of at least 40 % of the EU's annual deployment needs to be covered by EU manufacturing capacity by 2030, with a view to reaching 15 % of world production by 2040. It establishes enabling conditions for the domestic production of these technologies, for instance, through streamlined administrative

procedures and facilitated access to the market. It grants priority status to net-zero strategic projects and sets rules for net-zero acceleration valleys hosting clusters of industrial activity and regulatory sandboxes to test innovative net-zero technologies. It also establishes mechanisms to support skills development (European net-zero industry academies). While the regulation itself does not provide additional funding sources, it encourages Member States to allocate 25 % of their annual ETS revenues to support clean tech manufacturing. The [Net-Zero Europe Platform](#) assists in the implementation of the regulation and offers advice on obtaining private and public funding. The Strategic Technologies for Europe Platform ([STEP](#)) supports European industries and facilitates investment in critical technologies including hydrogen technologies.

The [European Hydrogen Bank](#), launched in 2022, is not an institution but a financing instrument designed to unlock private investments in hydrogen value chains. The Commission [communication on the hydrogen bank](#) describes its main areas of action: **domestic** (connecting supply with demand, awarding financing as a fixed premium per kilo of RFNBOs, carrying out EU-wide auctions for hydrogen projects), **international** (coordination of hydrogen imports) and **coordination** (information and support instruments). In the first [auction](#), six projects were awarded €695 million to produce 1.52 Mt of renewable hydrogen over 10 years. Moreover, the hydrogen bank operates an ['auctions as a service'](#) scheme to facilitate Member States' support for renewable hydrogen.

Outlook

The International Renewable Energy Agency [estimates](#) that meeting the goals of the Paris Agreement implies an annual global hydrogen demand of 613 Mt by 2050, compared to [around 100 Mt](#) today. The [International Energy Agency](#) observes that low-emission hydrogen is rapidly expanding and could reach 49 Mt in 2030, based on announced projects. As stated in the RePowerEU plan, by 2030 the EU [aims](#) to produce 10 Mt of renewable hydrogen a year and import another 10 Mt.

A 2024 European Court of Auditors (ECA) [report](#) remarks that these targets are not well supported by data and are overly ambitious, and that the EU is not on track to achieving them. The ECA recommends that the EU set itself realistic targets and consider regional and industrial sector specificities and the role of low-carbon hydrogen. If new targets for hydrogen production are set, their fulfilment will largely depend on investment, especially in infrastructure. Assessing and documenting the main users' demand for decarbonised hydrogen, as well as securing financing for the entire value chain, could help minimise investment risks. One solution to ensure the continuous expansion of infrastructure is to make more EU-level funds available to projects. Therefore, the ECA report recommends assessing whether the current EU funding arrangements are appropriate for the future development of the hydrogen value chain across the EU. Another option to address infrastructure development issues is to carefully plan the risk-sharing among projects and involve national authorities in the process. There is a clear need for structured dialogue between market participants and operators in the planning of infrastructure under the TYNDP processes. Another essential element is swift permitting and approval by the national regulatory authorities.

One way to mitigate a potential 'chicken and egg' dilemma (where industry does not invest in hydrogen-powered technologies due to unconfirmed supply and companies avoid building hydrogen production capacity because of uncertain future demand), is by setting sectoral targets. The 2030 targets for the consumption of renewable hydrogen in industry and transport (REDIII) mentioned above are a way to ensure large and centralised demand from hard-to-abate sectors.

The regulatory and support framework for renewable and low-carbon hydrogen is critical for safeguarding the [competitiveness](#) of EU industries. There is a [balance](#) to be struck between strict criteria to ensure maximal GHG savings and flexibility to grow the market and accelerate deployment. Future regulation, including delegated acts, should bring clarity and solutions. The large-scale uptake of renewable hydrogen would be encouraged if the cost gap between fossil and renewable hydrogen were narrowed. This shift is likely to occur as fossil hydrogen becomes more expensive, potentially due to a higher carbon price. Recent reports all forecast that the [price of](#)

[allowances in the ETS](#) will exceed €100 per tonne in 2030,³ which is much higher than amount forecast in the [impact assessment](#) accompanying the ETS revision proposal (between €50 and €85 in 2030). Moreover, the falling prices of electrolysers and renewable electricity could make renewable hydrogen more competitive. While the price is expected to drop across all markets, China may once again establish a competitive edge, as seen with other renewables before. As of 2023, China held [60 %](#) of the global electrolyser manufacturing capacity. The European industry [warns](#) that subsidies provided by the Chinese government distort competition and has asked the Commission to tackle this imbalance by introducing temporary non-price criteria for European Hydrogen Bank auctions. This measure would aim to reduce the risk of dependency on imported technology and bolster the resilience of the European electrolyser industry.

Another step forward in the right direction is the voluntary mechanism proposed in the gas and hydrogen package to improve transparency and support the development of the hydrogen market. This mechanism draws inspiration from the [gas demand aggregation tool](#) (temporarily implemented during the 2022 gas crisis and later made permanent with the Gas and Hydrogen Regulation), but is less ambitious. If successful, the hydrogen mechanism and the gas demand aggregation tool could encourage the Commission to propose the establishment of a unified platform for all energy sources and critical raw materials. In her political guidelines for 2024–2029, the President of the European Commission, Ursula von der Leyen, [committed](#) to extending the existing [aggregate demand mechanism](#) beyond gas and to include hydrogen and critical raw materials in its scope.

Despite the challenges ahead, hydrogen is likely to become a key component of the EU's energy transition. The period leading up to 2032, which marks the end of the hydrogen market transition phase in EU legislation, should be used wisely to lay the groundwork for a large-scale uptake. Parliament's role is crucial in ensuring that there is a compelling business case for European companies seeking to integrate hydrogen into their processes. This can be achieved by implementing Parliament's long-standing proposals (such as [demand aggregation](#) and the [phasing out of fossil fuels subsidies](#)), while also taking into account the recommendations of the [Draghi report](#) to ensure that hydrogen regulation strengthens EU competitiveness, rather than creating burdens. Parliament's scrutiny of the forthcoming delegated act on low-carbon hydrogen should focus on establishing clear and feasible criteria to prevent legal uncertainty and promote investment in European hydrogen production and infrastructure.

Main references

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International Energy Agency, [Global Hydrogen Review 2024](#), October 2024.

ENDNOTES

- ¹ EU-27, EFTA and UK. Germany (2.15 Mt), the Netherlands (1.42 Mt), Poland (1.1 Mt), Italy (0.83 Mt), and France (0.82 Mt) together account for 56 % of Europe's overall hydrogen production capacity. Most hydrogen production facilities are co-located with the industrial installations where the hydrogen is used.
- ² RFNBO was first defined in the 2018 recast of the Renewable Energy Directive (RED II), which limited its scope to the transport sector. RED III widens the definition and counts RFNBOs renewable energy regardless of the end-use sector.
- ³ Ecologic Institute, [GHG Market Sentiment Survey 2023](#), 2022; IETA, [The EU-ETS Price Through 2030 and Beyond](#), 2023; ERCST, [2024 State of the EU ETS Report](#), 2024.

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