European Commission

Joint Research Centre

SCIENCE FOR POLICY BRIEF

Mapping the transition of the EU ammonia industry to carbon neutrality

2026

HIGHLIGHTS

- In the ammonia decarbonisation trajectory, solutions based on carbon capture and storage (CCS) may dominate in the short term due to their compatibility with existing plants, while electrolysis and biomass-based hydrogen gain momentum.
- The largescale adoption of renewable hydrogen depends on cost reduction, regulatory certainty and a resilient supply chain.
- Net-zero scenarios forecast around 70% production from renewable hydrogen by 2050, while the remaining emissions are abated by coupling steam methane reforming (SMR) with CCS.
- Policies are needed to improve CO_2 storage, support renewable infrastructures and incentivise low-carbon ammonia.

THE CHALLENGE

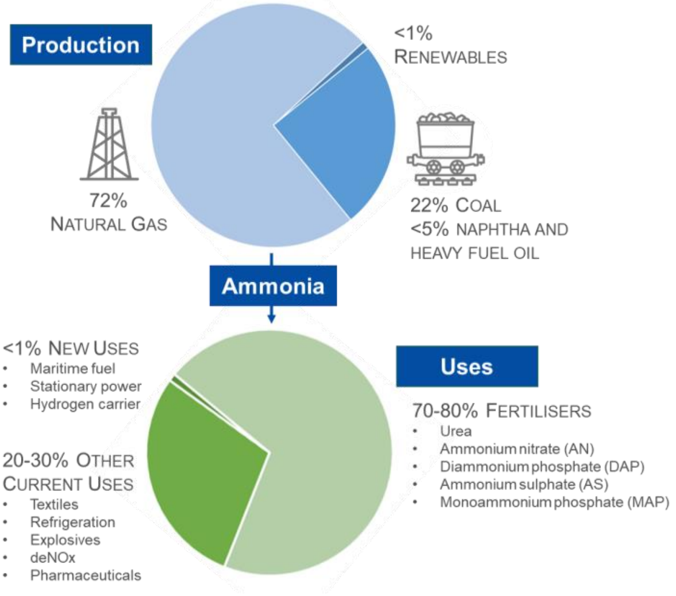
Introduction

The chemical industry is a cornerstone of the economy in the European Union (EU), driving growth and innovation across various sectors. The EU27 represents the world's second-largest chemical producer and accounted for 13% of global sales in 2023 [1]. The industry's international significance is proven by its role as a net exporter, with 34% [1] of sales generated outside the EU market. In 2021, total greenhouse gas (GHG) emissions from the EU chemical industry amounted to 155.5 Mt_{CO2e}, accounting for 5% [2] of total emissions in the EU. GHG emissions decreased by 9% between 2012 and 2021, while the gross value added (GVA) of the chemical industry increased by 23% between 2012 and 2020. The decrease of GHG emissions was particularly pronounced from 2012 to 2015. Total GHG emissions from the chemical industry remained stable between 2015 and 2021 [3]. Within the high complexity of the chemical industry, fertilisers are key products due to their role in food production. Nitrogen fertilisers are the most widely used fertilisers in the world, and ammonia is the basic building block of the nitrogen industry.

Ammonia production is representative of the chemical industry, since its global annual CO_2 emissions are over 420 Mt per year, which corresponds to almost 2% of global emissions [4]. Moreover, it is expected that ammonia will be the world most produced chemical by 2030 [5].

Of the 17.7 Mt of total EU27 capacity, about 70% [6] of ammonia is used for fertilisers, while the remainder is used for various industrial applications, such as plastics, explosives and synthetic fibres (Figure 1). While the use of ammonia as a fuel shows promise in the context of clean energy transitions, this application currently remains nascent. Although the use of ammonia is unavoidable, a significant quantity of GHG emissions comes from the methods currently used for its manufacturing.

Figure 1 - Production and uses of ammonia.



Source: JRC

This factsheet describes the sector's emission sources, the emissions breakdown and the technical paths forward to decarbonisation, with the associated CO_2 abatement costs and maturity status. Finally, it evaluates how these developments align with the relevant policy targets and objectives, providing an outlook for the ammonia sector's potential trajectory towards sustainability.

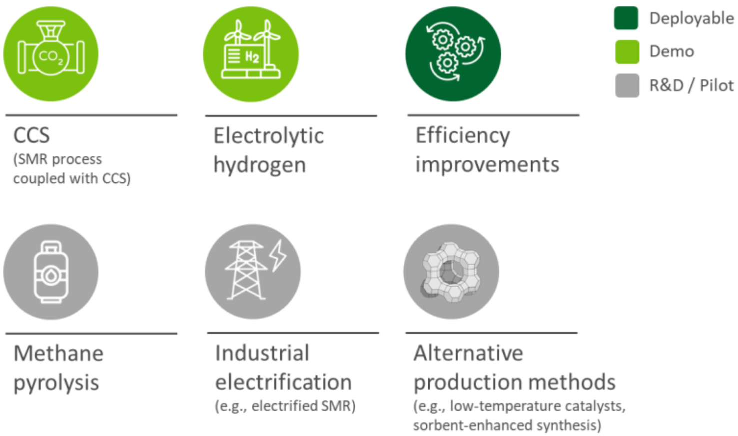
Production process

Most of the ammonia output in the EU and globally is produced synthetically via the Haber-Bosch process, which combines hydrogen and nitrogen over a catalyst according to the following equation: $N_2 + 3H_2 \rightarrow 2NH_3$.

Air is the primary source of nitrogen, typically supplied as ambient air, although in some plants (e.g., partial oxidation), nitrogen is derived from a purified gas produced by an associated air separation unit. The hydrogen required for ammonia synthesis is produced either by steam reforming (mainly of natural gas) or gasification (mainly of coal). The reforming-based processes, especially the steam reforming of natural gas (SMR), are the most common, accounting for about 72% of production [7]. The remaining production is primarily from coal gasification. The energy demand in the sector is predominantly met by natural gas and other hydrocarbons, particularly for process heat.

Ammonia is an emissions-intensive commodity, even though coal represents a smaller share of its energy inputs than in other sectors. At around 2.4 t_{CO2}[1] per tonne of product, it is four times more carbon-intensive than cement production on a direct CO_2 emissions basis [6]. China is the largest producer of ammonia, accounting for 30% of production (and 45% of CO_2 emissions, due to coal use), with the United States, the European Union, India, Russia and the Middle East accounting for a further 8-10% each [8]. The industry is increasingly focusing on decarbonisation, with leading strategies including carbon capture and storage (CCS), process electrification, and the integration of renewable hydrogen (hydrogen produced via water electrolysis using renewable electricity) (Figure 2). The latter is combined with nitrogen from air separation to produce renewable ammonia. Although renewable ammonia has been produced on a commercial scale since 1921, less than 0.02 Mt was produced in 2021 [9]. Looking ahead, the announced annual manufacturing capacity for renewable ammonia plants is projected to reach 15 Mt by 2030 (around 8% of the current ammonia market across 54 projects, notably in Australia, Mauritania, Chile, Saudi Arabia and Oman) [10].

Figure 2 - Stage of development of decarbonisation levers



Source: JRC

Several projects illustrate different hydrogen integration pathways in ammonia production. In Spain, Fertiberia's Puertollano plant operates a 20 MW photovoltaic-based hydrogen facility supplying nearly 10% of demand, with plans to scale up to 200 MW, while larger projects such as Onuba, H2DEAL, and Catalina envisage electrolysis capacities ranging from several hundred megawatts to over 2 GW, primarily for ammonia production. In Norway, Yara's Porsgrunn plant uses a 24 MW electrolyser to feed renewable hydrogen into an existing SMR, while

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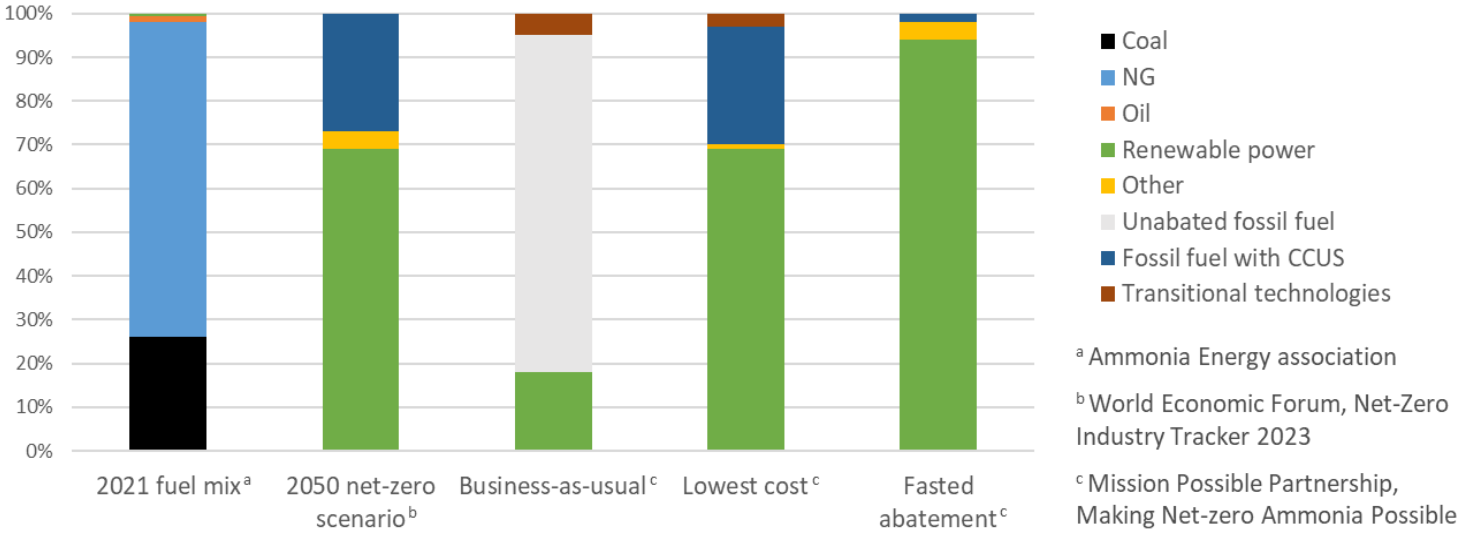
[1] From SMR. *Source*: [16]

Figure 3 - Comparison of production routes shares in different decarbonisation trajectories.



a Ammonia Energy association

b World Economic Forum, Net-Zero Industry Tracker 2023

c Mission Possible Partnership, Making Net-zero Ammonia Possible

Source: JRC

in Poland, Anwil blends chlor-alkali-derived hydrogen into its SMR process.

Current CO_2 emissions

In ammonia production using the SMR process, both direct and indirect emissions occur. Direct emissions arise primarily from the reactions involved in hydrogen production:

$CH_4 + H_2O \rightarrow CO + 3H_2$.

The carbon monoxide (CO) produced undergoes a secondary reaction, called the water-gas shift reaction, further increasing CO_2 emissions:

$CO + H_2O \rightarrow CO_2 + H_2$.

Additional CO_2 is released during the combustion of natural gas to generate the high temperatures required for the reactions. Indirect emissions also play a notable role, originating from the upstream supply chain, including methane leaks during natural gas extraction and transportation (up to an increase of 11% of the effective emissions intensity of ammonia) [11], as well as emissions associated with electricity use, which depend on the carbon intensity of the grid.

Policy targets and context

The EU chemical industry operates within a comprehensive regulatory framework that guides its activities and development[2]. The Clean Industrial Deal, proposed by the European Commission, focuses on accelerating industrial decarbonisation through investments in infrastructure, clean energy, and innovation, and a delegated act on low-carbon hydrogen has been announced. Previously, the Fit-for-55 package, part of the European Green Deal, set stricter emissions targets and expanded the scope of the EU Emissions Trading System (ETS), directly affecting the chemical sector. Moreover, the Carbon Border Adjustment Mechanism (CBAM), in its definitive regime from 2026, addresses carbon leakage risks for energy-intensive industries, like fertilisers. Finally, the SET Plan facilitates the alignment of research programmes of Member States and the EU, in order to enable the strategic acceleration of research timelines.

THE WAY FORWARD

Decarbonisation trajectories[3]

In the EU, decarbonisation trajectories for the ammonia industry integrate multiple technologies (e.g., CCS and renewable hydrogen) to reach net-zero emissions. By 2050, CCS and renewable-based hydrogen adoption are expected to play dominant roles, depending on policy incentives and renewable energy availability. The Roadmap for the European Fertilizer Industry [12] proposes an ambitious 50% shift to electrolysis-based ammonia by 2030 that would require 86 TWh of energy and an extra EUR 1.2 billion[4]. The IEA Ammonia Roadmap [6] and Net Zero by 2050 [13] reports anticipate a more gradual increase to 27% and 15–20%, respectively, while maintaining the carbon-neutrality goal by 2050. The

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[2] Reach regulation (EC 1907/2006); CLP regulation (EC1272/2008); The industrials emissions directive (2010/75/EU); Biocidal Products regulation (BPR, regulation EU528/2012); Seveso Directive (2012/18/EU)

[3] This factsheet avoids using the term ‘pathways’ to prevent confusion with the sector-specific decarbonisation pathways published by the European Commission in November 2025. Those sector-specific pathways are intended as a voluntary tool to support companies set their individual decarbonisation targets in line with the European Climate Law. See EC, Making finance flows consistent with climate goals – Climate Action, 2025

[4] Based on 7.5 Mt of ammonia production, no changes in the other 50%, natural gas price 37 EUR/MWh, LCOE of renewable electricity of 39 EUR/MWh, CO_2 price 100 EUR/t_{CO2}.

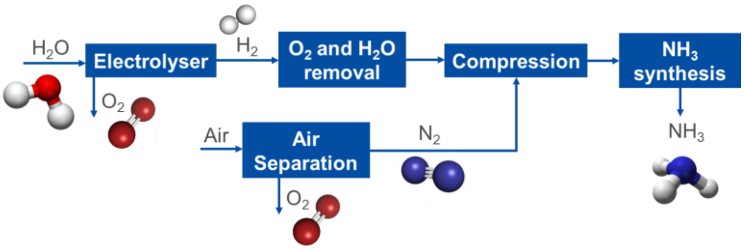
CETO 2024 [14] CCUS report, by contrast, emphasises widespread CCS deployment in the short term rather than a rapid transition to renewable hydrogen. Novel decarbonisation methods, such as methane pyrolysis, autothermal reforming, and sorbent-enhanced Haber-Bosch loops, are under development but not yet commercially available, therefore the early deployment of these technologies only plays a minor role in achieving the objectives. Insights from the Making Net-Zero Ammonia Possible [15] report suggest that renewable ammonia will ultimately dominate the market, but in the interim, CCS-coupled ammonia will play a significant role. The report proposes three different scenarios: business-as-usual, lowest cost and fastest abatement, which will result in emission intensity by 2050 equal to 1.8, 0.1 and 0.0 t_{CO2}/t_{NH3}, respectively. The WEF Net-Zero Industry Tracker [16] notes that ammonia production is among the hardest sectors to abate and remains heavily reliant on fossil fuels. The report stresses that both CCS and green hydrogen technologies need rapid scaling (Figure 3). The global investments required for enabling infrastructure are estimated at up to USD 2 trillion for clean power generation and USD 50 billion for CO_2 transport and storage.

Decarbonisation technologies

Today, the majority of hydrogen used in ammonia production is derived from natural gas via SMR. CCS can be retrofitted to existing plants, capturing 85-95% of process emissions in an Auto-Thermal Reformer (ATR) and around 85% in retrofitted SMR plants. However, upstream methane leaks remain identical for CCS and non-CCS ammonia production, and downstream CO_2 emissions must also be accounted for, limiting the overall lifecycle reduction of GHG emissions to 60-85%. In addition, despite its potential for decarbonisation, CCS does not eliminate the reliance on fossil fuels.

A possible alternative is hydrogen production via water electrolysis using renewable electricity (Figure 4). This approach eliminates direct CO_2 emissions, with the potential of achieving a carbon footprint of 90 kg of CO_2 per tonne of ammonia, by 2050 [17]. However, production costs remain a key barrier, currently estimated at USD 720 per tonne and expected to decrease to USD 480 per tonne by 2030 and USD 310 per tonne by 2050. At the moment, a carbon price of USD 150 per tonne of CO_2 is required to be cost-competitive with fossil-based methods [10]. Proton Exchange Membrane (PEM) and Alkaline (ALK) electrolysers are the most mature electrolysis technologies (TRL 9), while Solid Oxide Electrolysis Cells (SOECs) offer higher efficiencies but are still in the research and demonstration phase (TRL 6-7).

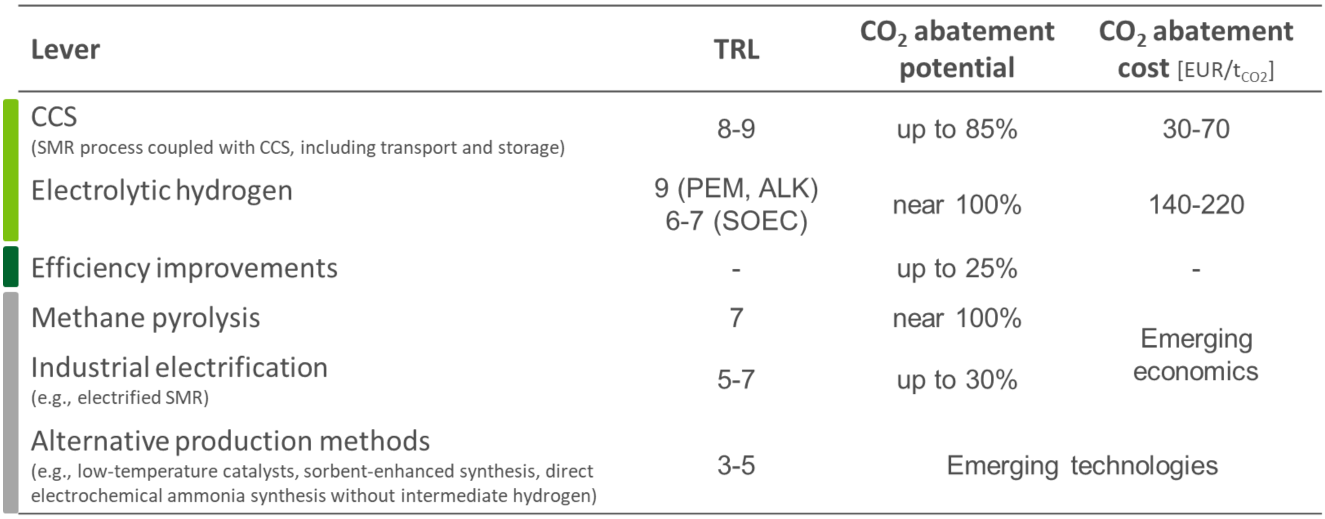
Figure 4 - Schematic overview of steps for renewable ammonia synthesis.



Source: JRC

Another drawback of renewable-based hydrogen production is the intermittency of power supply. However, this challenge can be mitigated through hybridisation configurations, in which renewable hydrogen partially substitutes the hydrogen produced via SMR. In such systems, electrolytic hydrogen is

Figure 5 - Decarbonisation levers CO_2 abatement potential and cost.



Lever	TRL	CO_2 abatement potential	CO_2 abatement cost [EUR/t_{CO2}]
CCS (SMR process coupled with CCS, including transport and storage)	8-9	up to 85%	30-70
Electrolytic hydrogen	9 (PEM, ALK) 6-7 (SOEC)	near 100%	140-220
Efficiency improvements	-	up to 25%	-
Methane pyrolysis	7	near 100%	Emerging economics
Industrial electrification (e.g., electrified SMR)	5-7	up to 30%	
Alternative production methods (e.g., low-temperature catalysts, sorbent-enhanced synthesis, direct electrochemical ammonia synthesis without intermediate hydrogen)	3-5	Emerging technologies	

Source: JRC

integrated into the conventional ammonia synthesis loop alongside SMR-derived hydrogen. Through careful process design, control strategies, and optimisation of the synthesis loop, these hybrid configurations can accommodate the variability of renewable hydrogen while maintaining high overall efficiency [18]. Another emerging hydrogen production route is methane pyrolysis, which decomposes methane into hydrogen and solid carbon instead of CO_2. This process, currently at TRL 7, eliminates CO_2 emissions at the point of production, but its scalability depends on finding sustainable applications for the solid carbon by-product.

Biomass-based hydrogen production is another potentially viable technology, using biomass gasification or anaerobic digestion combined with biogas dry reforming. This could enable ammonia production with CO_2 negative emissions, if paired with CCS. However, biomass supply constraints and higher production costs limit its feasibility in the short term. Similarly, electrified SMR is being explored, where natural gas serves as a feedstock while electricity provides process heat, replacing the current fuel gases. Other novel hydrogen production methods include photocatalytic water splitting, which uses sunlight to directly produce hydrogen, and bioengineered processes leveraging biological enzymes to synthesise ammonia from water and atmospheric nitrogen. These technologies remain at low TRL and require significant research and development before commercialisation.

Lastly, process efficiency improvements offer additional decarbonisation potential. Although there is no significant potential for energy efficiency improvements in the Haber-Bosch process itself, the IFA identifies possible further improvements in the global average: approximately 25% [19] reduction in energy consumption can be achieved by replacing old, inefficient plants with new, efficient ones and by replacing heavy hydrocarbon feed stocks with natural gas. Moreover, companies such as Tsubame BHB (Japan) and Starfire Energy (US) are developing low-temperature catalysts and sorbent-enhanced Haber-Bosch synthesis loops, which would enable lower operating pressures and improve energy efficiency.

STATE OF DEVELOPMENT

Industrial pledges

The European ammonia and fertiliser industry has set ambitious decarbonisation targets, with leading companies committing to significant emissions reductions by 2030 and aiming for net-zero emissions by 2050. Indeed, 91% of large, publicly traded ammonia companies consider climate change in their decision-making processes [20]. For instance, Yara, the biggest ammonia producer in Europe (7.8 Mt/year of a total 17.7 Mt), has pledged a 30% reduction in emissions by 2030, focusing on sustainable ammonia production through renewable hydrogen projects. Other companies, such as BASF, aim for 25% reduction by 2030, to stay on track for net-zero by 2050. Fertiberia (6 Mt/year production), by contrast, aims to achieve zero emissions by 2035, positioning itself as a leader in the European renewable ammonia market. This disparity highlights the challenges in scaling up green hydrogen production and integrating renewable energy sources into existing infrastructure. Indeed, while ammonia produced using renewable hydrogen is a cornerstone of these commitments, largescale adoption remains slow due to high costs, infrastructure challenges, and limited renewable energy availability [15]. In the meantime, many companies are turning to the production of ammonia coupled with CCS to reduce emissions [21]. In response to these challenges, some companies are exploring partnerships to accelerate decarbonisation efforts. Grupa Azoty, for example, is seeking collaborations with U.S. partners to import clean ammonia and engage in joint decarbonisation projects, aiming to enhance its position in the EU fertiliser market and bolster its green strategy.

Recent developments further illustrate the industry's efforts and challenges. In July 2024, German utility company EnBW announced plans to market renewable ammonia from Norway's Skipavika Green Ammonia (SkiGa) project, which utilises local renewable electricity to power a 130 MW electrolyser, significantly reducing CO_2 emissions compared to conventional hydrogen production methods. Additionally, BASF and Evonik have agreed on the first deliveries of biomass-balanced ammonia with a reduced carbon footprint (at least 65% lower than the standard one), demonstrating their commitment to offering products with a lower environmental impact.

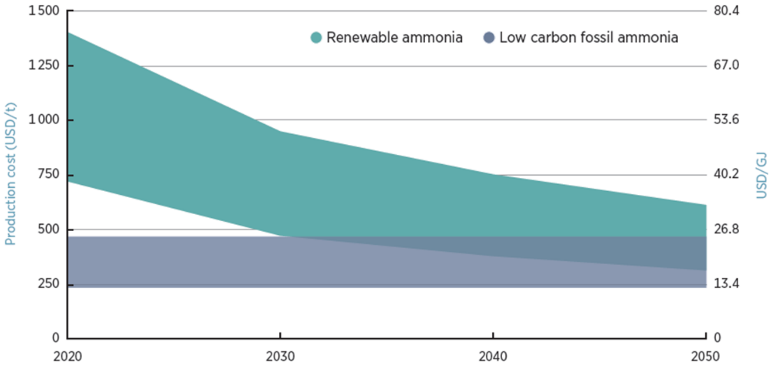
Demonstrators

The demonstrators identified for this study represent cutting-edge initiatives aimed at accelerating industrial decarbonisation through innovative technologies and sustainable practices. For instance, green hydrogen and ammonia projects, such as GAP and MP2X, have the potential to replace fossil fuels in sectors like fertilisers, chemicals and heavy industry. However, their success depends on scaling up electrolysis capacity, reducing production costs, and developing the necessary storage and transport infrastructure. On the other hand, initiatives like CORALIS, INITIATE, and RETROFEED focus on industrial symbiosis and the circular economy, aiming to reduce emissions by optimising resource use, through CCU, and repurposing waste streams, resulting in a GHG emissions reduction of 25-50% across the different integrated plants. Complementing these efforts, projects such as UNIPER's Green Wilhelmshaven and Iberdrola's renewable energy initiatives are essential for providing the clean power backbone necessary for industrial transformation.

Evaluation of progress and alignment with policy and industry targets

Coupling SMR with CCS is one of the most developed and mature solutions, with a TRL of 8-9. In ammonia production, it can capture up to 85% of CO_2 emissions. It is economically viable at carbon prices of EUR 30-70 [10] [21] per tonne of CO_2, and CCS-based solutions are relatively straightforward to integrate into existing ammonia plants. The drawback is the extensive pipeline networks required for CO_2 transport and long-term geological storage solutions, which are not universally available. Indeed, the CETO report on CCUS [14] highlights the need for an enhanced CO_2 transport infrastructure and regulatory frameworks to accelerate CCS adoption. Additionally, CCS applications require continuous monitoring to mitigate the risks associated with storage sites and long-term financial liabilities. Electrolysis-based ammonia provides the most significant long-term benefit, offering near-zero emissions if powered entirely by renewable energy [22]. One concern is the possible use of PFAS in PEM electrolysers, which raises environmental and health issues due to their persistence and potential toxicity. This has prompted ongoing efforts to identify and develop suitable alternative materials [23]. Additionally, the process is water-intensive, requiring around 9 litres of purified water per kilogram of hydrogen, which could strain water resources, especially in arid regions. Moreover, the large-scale adoption of electrolysis depends on access to cheap renewable electricity, hydrogen pipelines and storage facilities. The economic feasibility of green ammonia improves when renewable electricity costs drop below EUR 20/MWh [24], a threshold achievable through largescale deployment of wind and solar. Overall, electrolysis-based ammonia production currently costs 10-100% [6] more than fossil-based alternatives, requiring consistent investments for EU-wide adoption by 2050.

Figure 6 - Current and future production costs of renewable ammonia, compared with production cost range for low-carbon fossil ammonia and cost.



Source: IRENA [10]

Efficient ammonia production and distribution require coordinated investments in hydrogen liquefaction, compression, and storage. Projects such as Grupa Azoty's U.S. partnerships illustrate the growing importance of international supply chains in ensuring hydrogen availability at industrial scales. At the same time, increasing attention is being given to decentralised production models based on modular ammonia plants (typically 50 000–100 000 t/year), located closer to end-use demand and designed to leverage local renewable energy and CO_2 resources. While such configurations can reduce transport needs and improve system flexibility, they generally come at the expense of economies of scale. Demonstrator projects are actively validating electrolysis-based ammonia production, aligning with the European Union's research & innovation (R&I) phase, projected to take place between 2025 and 2030. Current projections indicate that, for widespread deployment, electrolyser capacity must scale from today's gigawatt-scale to several terawatts by 2050, requiring substantial investment and supply chain expansion. Additionally, effective integration with intermittent renewable sources necessitates advancements in energy storage and grid-balancing technologies.

The evolution of these trajectories is expected to unfold in distinct phases, with research and innovation progressing until 2030, followed by largescale demonstration projects in the 2030s and full-scale deployment anticipated by 2040-2050. Demonstrator projects are already testing electrolysis-based ammonia production, aligning with EU policy targets [25]. In the near term, CCS-based solutions may dominate due to their compatibility with existing ammonia plants, while electrolysis and biomass-based hydrogen gain momentum. In the IRENA Innovation Outlook (Figure 6), it is projected that the cost for CCS-based ammonia will be competitive after 2030. Industrial clusters with shared hydrogen and CO_2 transport networks could improve scalability by optimising infrastructure use and reducing individual plant costs. Additionally, market mechanisms such as carbon pricing, the Carbon Border Adjustment Mechanism (CBAM), the EU Emissions Trading System (ETS), and direct subsidies will play a crucial role in determining the financial viability of these paths forward.

CONCLUSIONS

The decarbonisation of the ammonia sector presents both significant challenges and opportunities. Progress has been made through CCS and efficiency improvements, but achieving net-zero by 2050 requires a shift to renewable electrolysis-based production, supported by innovation, infrastructure investment, and policy-driven financial support. While demonstrator projects are essential for proving technological feasibility, largescale adoption depends on cost reduction, regulatory certainty, and a resilient hydrogen supply chain. To address these barriers, key policies should enhance funding for demonstrators, improve CO_2 storage and methane monitoring, support renewable infrastructure, and incentivise low-carbon ammonia. If these trajectories fail to deliver, the EU risks missing critical climate targets, such as REPowerEU's hydrogen production goals. Increased collaboration between industry and policymakers is essential to align investments, and research needs to focus on efficiency improvements, alternative feedstocks, and scalable hydrogen storage solutions for achieving net-zero ammonia production by 2050. The next few decades will be pivotal in determining the chemical sector's progress toward sustainability, with cooperation among stakeholders playing a central role in driving forward decarbonisation.

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CONTACT INFORMATION

European Commission, Joint Research Centre (JRC)
E-mail: Chiara.Coffano@ec.europa.eu,
Jose.Moya@ec.europa.eu, RTD-E3-ASSIST@ec.europa.eu

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