

EU Climate Policy for Clean Ammonia: Wishful Thinking or Industrial Strategy?

Addressing the Chicken-and-Egg Dilemma

For over a century, ammonia (NH₃) has been indispensable to fertilizer production, underpinning agricultural productivity and global food security (Quitow, Balmaceda and Goldthau, 2025). The expansion of fertilizer production and use has consequently driven substantial gains in agricultural yields and contributed to a marked reduction in global hunger. As Arthur Miller aptly observed, ‘*All we are is a lot of talking nitrogen*’, capturing the fundamental role of ammonia in sustaining life and, by extension, food production. (Tufail et al., 2024). Yet this achievement comes at a considerable environmental cost: approximately 72% of global ammonia production relies on natural gas, predominantly through the Haber-Bosch process, generating an estimated 2-3 tonnes of CO₂ for every tonne of ammonia produced (Bicer et al., 2017).

Europe is also a net importer of ammonia, leaving it exposed to geopolitical and energy shocks. In 2024, the EU imported 2 million tonnes of ammonia, 5.9 million tonnes of urea, and 6.7 million tonnes of other nitrogen-based fertilisers and mixtures (European Commission, 2026b). As ammonia production is largely concentrated in gas-rich countries, Russia’s invasion of Ukraine exposed Europe’s vulnerability, with European ammonia production capacity utilisation falling to around 50% between 2021 and 2023 (Alsulaiman, Chyong and Schmidt, 2026). The March 2026 blockade of the Strait of Hormuz by Iran further highlighted this dependence on global energy and commodity supply chains, as the Strait carries around one-fifth of global oil consumption, a substantial share of LNG exports, more than one-quarter of internationally traded ammonia, and significant shares of seaborne urea and sulfur trade (Stamm, Bosch and Nan, 2026; North Dakota State University, 2026; Appiah-Kubi, 2026).

Within the European ammonia industry, several major producers play an important role in regional and global markets. **Yara (Norway)** is the world’s second-largest ammonia producer and operates the largest global ammonia trading and logistics network. **Grupa Azoty (Poland)** is the second-largest producer of nitrogen and compound fertilisers in the European Union, while **Agrofert (Czech Republic)** is a major Central European producer and supplier of ammonia and fertilisers (Yara International ASA, 2026; Grupa Azoty, n.d.). The European ammonia market is therefore relatively concentrated among a small number of major producers, as illustrated by their respective market shares in Figure 1.

Figure 1: Market shares of major EU ammonia producers, 2021.

2021	CAN
AGROFERT	[10-20]%
Borealis NITRO	[10-20]%
Combined	[20-30]%
Yara	[20-30]%
OCI	[5-10]%
Eurochem	[5-10]%
Nitrogénművek	[5-10]%
Fertiberia	[5-10]%
Grupa Azoty	[5-10]%
Others	[10-20]%

**Source: European Commission (2023) *Case M.10834 - AGROFERT / BOREALIS NITRO*.
Commission decision of 13 March 2023, EUR_Lex**

Within the scope of the European Green Deal’s objective of achieving deep decarbonisation by 2050, and under the EU Emissions Trading System (ETS), ammonia production is among Europe’s most carbon-intensive industrial activities. It generates approximately 36 million tonnes of CO₂ emissions annually, accounting for around 1% of total EU greenhouse gas emissions and 5% of industrial-sector emissions (Alsulaiman, Chyong and Schmidt, 2026). The possibility of substituting steam methane reforming (SMS) with hydrogen from electrolyzers powered by renewable energy sources has unleashed the possibility to decarbonise the sector (Daniel *et al.*, 2026). This, however, represents only the smaller side of the picture. Green hydrogen could play a key role in decarbonising hard-to-abate industries, while avoiding the intermittency and non-dispatchability challenges associated with solar and wind power (Jayachandran *et al.*, 2024). However, hydrogen remains difficult to transport in both gaseous and liquid forms due to its low density and high volume, energy-intensive transport requirements, potential hydrogen losses, and risks such as hydrogen-induced cracking. Converting hydrogen into ammonia offers a more practical alternative, as ammonia is easier to store, transport, and distribute globally (Kojima and Yamaguchi, 2022).

Since the launch of the EU Hydrogen Strategy in 2020, green ammonia has gained significant attention as a potential hydrogen carrier, maritime fuel, and hydrogen-storage medium, while also supporting established applications in sectors such as chemicals and fertiliser production. In this context, particularly under the Clean Industrial Deal (CID), ammonia has emerged as a potential pathway for decarbonising hard-to-abate sectors without accelerating deindustrialisation, where direct electrification is not feasible. This is especially relevant as European industry faces mounting challenges to its international competitiveness, driven in part by persistently high energy prices (Pastore *et al.*, 2025; Draghi, 2024; Fullonton *et al.*, 2025). According to the European Chemical Industry Council (CEFIC), these pressures are already affecting Europe’s chemical industry, with announced production closures increasing almost sixfold between 2022 and 2025, from 2.9 million to 17.2 million tonnes per year, affecting approximately 20,000 direct jobs (CEFIC, 2026).

This dissertation contrasts the premises underlying the green ammonia hype (MacFarlane et al., 2020) with an industrial reality in which green molecules have yet to achieve large-scale penetration of the energy system (Patonia, 2025). The reasons behind EU policy support for green molecules are not easy to disentangle, nor is it clear whether hydrogen and ammonia could eventually achieve large-scale deployment given sufficient time to mature. Indeed, the EU's decision, formalised through the 2020 EU Hydrogen Strategy, to invest heavily in green hydrogen - and, by extension, ammonia - was driven partly by a lack of viable alternatives and limited technical understanding of the feasibility of different pathways. As put by Karl Falkenberg, former Director-General of DG Environment:

“I think we were basically desperate to come up with innovation, to come up with answers. We had made commitments relatively early on, and more ambitious than others, in decarbonising our economy. That has been criticised a lot by saying this decarbonisation means deindustrialisation. And then some people came here to Brussels and said, we have a solution, it's called hydrogen, and politicians bought it without asking the right questions. And that's how our strategy was kicked out, because it looked like, wow, we have an answer to all those questions”.¹

The aim of this dissertation is therefore to examine the role of ammonia in decarbonising EU industry and supporting climate neutrality, by outlining its key characteristics and the policy expectations surrounding its development, while also identifying its main associated trade-offs and potential solutions. Its added value lies in adopting an interdisciplinary approach, combining insights from academic literature with targeted interviews with key stakeholders from the ammonia industry. This approach provides a more comprehensive understanding of both the opportunities and challenges associated with ammonia's role in Europe's industrial decarbonisation. The ultimate aim is to critically assess the successes and shortcomings of European policies, helping policymakers identify clearer, more robust, and evidence-based pathways for future decision-making. The dissertation therefore addresses three key questions: which technology to support, why green ammonia has become a European policy priority, and how to overcome the barriers to its large-scale deployment.

Chapter 1 – Technology pathways.

The first chapter assesses whether Europe should rely on **electrolytic hydrogen-based ammonia (e-HB)**, benefiting from technological maturity and economies of scale, or support emerging, potentially more efficient alternatives, including electrochemical and plasma-assisted nitrogen reduction and ammonia synthesis from nitrates and NO_x (which are briefly discussed in Annex 1).

Chapter 2 – The origins of the green ammonia hype.

The second chapter examines the emergence of green ammonia as a policy priority, focusing on the **2020 EU Hydrogen Strategy** and ammonia's role as a carrier for hydrogen produced far from its point of use. It maps the EU policy architecture supporting market development through supply creation, demand formation, and the infrastructure and financial frameworks linking the two.

¹ Interview with Karl Falkenberg, President of the Club of Europe EU Chapter and former Director-General, DG Environment, Brussels, 27 April 2026.

Chapter 3 – Overcoming the Chicken-and-egg dilemma.

The third chapter examines the gap between EU policy ambitions and the **chicken-and-egg problem** constraining market development: producers hesitate to invest without demand, while consumers hesitate to commit without sufficient and affordable supply. It explores three (partly competing) pathways: **(i) a “Green Ammonia Ladder”** identifying the sectors most likely to drive early demand; **(ii) imports from regions with abundant, low-cost renewable energy**; and **(iii) opportunity cost of a stronger European industrial policy**, combining carbon pricing with greater coordination and direct support for domestic green-molecule production. Without such complementary measures, the ETS risks encouraging industrial relocation rather than domestic decarbonisation.

Alongside the literature review and interdisciplinary approach, selected interviews capture contrasting perspectives on the EU’s green-molecule strategy. **ICI Caldaie S.p.A.**, a European heat-pump company involved in green hydrogen and ammonia demonstration projects; **NitroVolt ApS**, developing decentralised electrochemical ammonia production for farmers; **Pani Clean**, a US company exploring ammonia recovery from nitrogen-rich wastewater and other contaminated water streams; **Hynfra**, a European enterprise investing in green ammonia production in Mauritania, Jordan, and Oman for export to Europe; **AustriaEnergy**, developing green ammonia projects in Chile for export to Europe and Asia; and **AM Green Group**, an Indian renewable-energy company with 12 GW of renewable assets, pursuing green ammonia exports to Europe. The study also includes **Karl Falkenberg**, former Director-General of DG Environment and a key figure in EU environmental and hydrogen policy, and **Dr Piergiorgio Alotto**, Professor of Electrical Engineering at the University of Padua and former Scientific Attaché at the Italian Embassy in Berlin, with expertise in energy-transition strategies across EU Member States. Beyond providing practical expertise and empirical evidence, the semi-structured interviews revealed a notable consistency in respondents’ answers to key questions, strengthening the robustness of the findings discussed in the following chapters.

1. The State of the Art of Ammonia: An Essential Industrial Commodity with a High Carbon Footprint

Global ammonia production stands at approximately **183 Mt per year**, with ammonia synthesis accounting for around **35% of global hydrogen demand** (IEA, 2021; Collado, Herrero and de la Peña O’Shea, 2024). Overall, around 90% of hydrogen is consumed in established industrial applications, primarily oil refining (42%), ammonia production (35%) and methanol production (15%) (Diab *et al.*, 2024). As approximately 70% of hydrogen is produced from natural gas through SMR, with most of the remainder coming from coal, ammonia production remains highly carbon-intensive (IEA, 2021; Ishaq, 2024). In 2020, ammonia production accounted for approximately 1.3% of global GHG emissions, equivalent to 450-500 MtCO_{2e} annually. Including emissions from nitrogen fertilizer use and trade, particularly agricultural N₂O emissions, its overall footprint rises to approximately 1.1-1.3 GtCO_{2e} per year (Carobé, Mingolla and Rosa, 2024). Ammonia production also consumes around 2% of global final energy, highlighting the scale of its decarbonisation challenge.

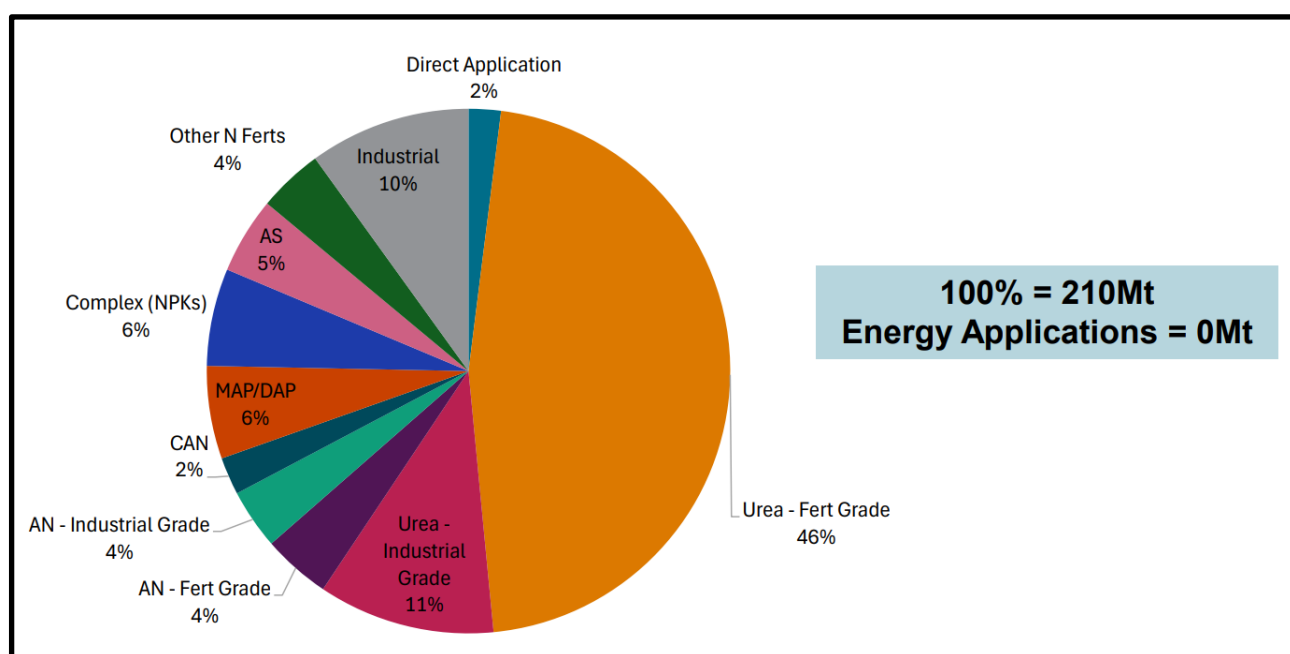
These figures underline a fundamental point: **decarbonising ammonia ultimately depends on decarbonising its hydrogen feedstock**. Reliance on natural gas-based hydrogen has also concentrated ammonia production in countries with abundant and competitive gas resources. China, the United States

and India account for nearly half of global ammonia production capacity, while Brazil remains heavily import-dependent and Russia is the world's leading nitrogen fertilizer exporter (Mingolla and Rosa, 2026). Beyond ammonia, fossil-based hydrogen is essential to several industrial processes, including oil refining, vegetable-oil hydrogenation and steelmaking (Furfari, 2020). Ammonia itself has a broad range of established applications, which can be summarised as follows (Yüzbaşıoğlu, Avşar and Gezerman, 2022):

- **Fertiliser production:** Around 80% of global ammonia is used as a nitrogen source for fertilisers, making agriculture its dominant end-use (Green ammonia synthesis, 2023).
- **Chemical feedstock:** Ammonia is a key input for nitrogen-based chemicals, particularly nitric acid (HNO_3) and ammonium nitrate (NH_4NO_3).
- **Textile industry:** It is used in cotton treatment and synthetic-fibre production.
- **Pharmaceuticals and biotechnology:** Ammonia serves as a precursor for various nitrogen-containing pharmaceutical compounds.
- **General chemical industry:** As one of the world's major bulk chemicals, ammonia supports a wide range of industrial value chains.

The fertiliser sector therefore remains the main source of ammonia demand. Figure 2 illustrates this distribution: in 2026, global ammonia production reached approximately 210 Mt, with more than half allocated to fertilisers and the remainder to industrial applications. No significant share was yet dedicated to the energy sector, underscoring the still emerging nature of ammonia as an energy carrier.

Figure 2: Breakdown of ammonia demand by sector, 2026 (%)



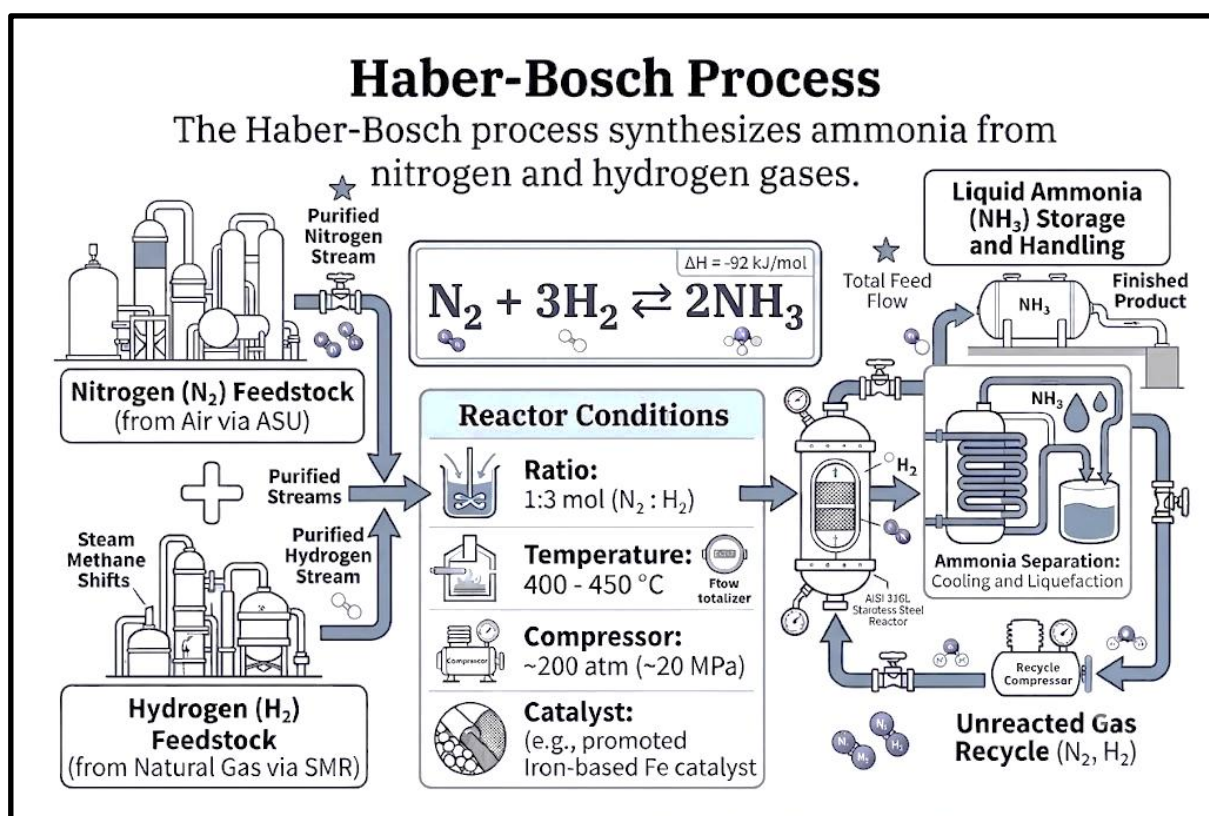
Source: S&P Global Energy (2026)

1.1 The Haber-Bosch (HB) Process: The Conventional Pathway for Ammonia Production

The conventional production of ammonia through the Haber-Bosch (HB) process has been established for over a century and has a technological maturity comparable to that of the petroleum refining and

petrochemical industries (Erfani *et al.*, 2024). Developed by Fritz Haber in 1908 and industrialised by Carl Bosch, it enabled the first large-scale ammonia plant in 1911 and became the foundation of modern nitrogen fertiliser production (Humphreys, Lan and Tao, 2020). The process combines atmospheric nitrogen with hydrogen according to $\text{N}_2 + 3\text{H}_2 \rightarrow 2\text{NH}_3$, using iron-based catalysts at around **500°C and above 100 bar**. While nitrogen is obtained from the air, hydrogen is traditionally produced through SMR, making conventional HB highly energy- and carbon-intensive (Kyriakou *et al.*, 2020).²

Figure 3: Schematic illustration of the Haber-Bosch Pathway



Source: Author's own elaboration.

The conventional Haber–Bosch process faces three main limitations:

- **High energy intensity:** The strong $\text{N}\equiv\text{N}$ triple bond makes ammonia synthesis kinetically demanding, requiring temperatures of **650–750 K** and pressures of **50–200 bar** even with advanced catalysts (Mohan and Ramanujam, 2024; Vojvodic *et al.*, 2014). This favours large, centralised plants and increases dependence on fossil-based hydrogen (Gu *et al.*, 2026).
- **High carbon intensity:** Around 70% of global ammonia is produced using SMR, emitting approximately 1.6 tCO₂ per tonne of ammonia, increasing to 2.5–3.8 tCO₂/tNH₃ for coal-based production. Overall, ammonia production accounts for around 1.8% of global anthropogenic CO₂ emissions (Fullonton *et al.*, 2025).

² For more than a century, the formulation of Haber-Bosch catalysts has relied on melt synthesis using multiple promoter oxides, including potassium (K), aluminium (Al), calcium (Ca), and silicon (Si), with modern formulations partially replacing the original magnetite precursor with wüstite (Dembélé *et al.*, 2025).

- **Exposure to energy-price volatility:** Natural gas represents more than 60% of the levelised cost of ammonia, making production highly sensitive to energy and geopolitical shocks (Mingolla and Rosa, 2026).

In decarbonisation discussions, ammonia's “colour” largely reflects the hydrogen used as its feedstock, although some frameworks also consider the sources of nitrogen, energy and other inputs (Daniel *et al.*, 2026). Accordingly, **brown ammonia** uses coal-derived hydrogen, **grey ammonia** uses hydrogen from SMR, **blue ammonia** combines SMR with carbon capture and storage (CCS), while **green ammonia** uses renewable hydrogen produced through water electrolysis powered by renewable electricity (Hatzell, 2024; Arnaiz del Pozo and Cloete, 2022).

1.2 Green hydrogen-based Haber-Bosch (e-HB)

The most established route to decarbonised ammonia is to retain the conventional Haber-Bosch (HB) process while replacing fossil-derived hydrogen with electrolytic hydrogen. Rather than reforming methane, hydrogen is produced by splitting water through electrolysis powered by electricity. This approach falls within **Power-to-X (PtX)** and is generally referred to as green or e-hydrogen when renewable electricity is used. Its application to ammonia synthesis is known as e-Haber-Bosch (e-HB) or Power-to-Ammonia (PtA) (Verleysen *et al.*, 2020). With a reported **TRL of 8-9**, e-HB is currently the most technologically mature and commercially credible pathway for large-scale green ammonia production (Bianchi and Bosio, 2024; Palhares, Matos and Okigami, 2025). Its key advantage is that it builds on established HB technology, infrastructure and industrial expertise, replacing only the fossil-based hydrogen feedstock with renewable electrolytic hydrogen.

As Joun Lee, CEO of green-ammonia startup Pani Clean, explains:

*“Renewable H₂-based Haber-Bosch is currently the most credible pathway for large-scale, commodity green ammonia. Haber-Bosch is mature, efficient and capable of producing ammonia at the purity and scale required by the fertilizer and chemical industries”.*³

However, e-HB remains highly energy-intensive, with its economic viability strongly dependent on the availability of low-cost renewable electricity. Its capital-intensive hydrogen production, nitrogen separation and synthesis systems, together with the limited operational flexibility of conventional Haber-Bosch plants, may also constrain its application in small-scale or decentralised systems and complicate integration with variable renewable power, as Lee further notes.

*“Its principal disadvantages are the capital intensity of the hydrogen, nitrogen-separation and synthesis systems; the need for inexpensive renewable electricity; and the difficulty of economically operating very small plants”.*⁴

³ Interview with Joun Lee, CEO of Pani Clean, email correspondence, 1 August 2026.

⁴ Ibid.

Several emerging pathways aim to overcome the high energy intensity of conventional e-HB by enabling more energy-efficient routes to decarbonised ammonia production (See in Annex 1). While these alternatives are worth considering to provide a broader perspective on the sector, most remain at an early stage of development, with an overall TRL of barely above 4 (Pugazhendhi et al., 2025). The key takeaway is that green hydrogen produced through Power-to-X is the critical variable in assessing the scalability of clean ammonia, as it is the main element distinguishing e-HB from conventional Haber–Bosch. The following chapters therefore examine European policies supporting green hydrogen and, by extension, green ammonia. The key takeaway is that green hydrogen produced through PtX is the critical variable in assessing the scalability of clean ammonia, as it is the main element distinguishing e-HB from conventional Haber-Bosch. The following chapters therefore examine European policies supporting green hydrogen and, by extension, clean ammonia.

2. The EU Hydrogen Strategy: Ammonia as a Gateway to Global Hydrogen Trade

In 2019, the European Commission launched the European Green Deal to align EU climate policy with the Paris Agreement and achieve climate neutrality by 2050, making Europe the world’s first climate-neutral continent (Wolf et al., 2021). A central challenge is the decarbonisation of hard-to-abate industries, including steel, ammonia, chemicals, cement, glass and ceramics, where emissions are particularly difficult and costly to reduce. Green hydrogen offers a decarbonisation pathway where direct electrification remains technically or economically unviable (Wyns and Khandekar, 2023). Rather than replacing electrification, hydrogen can bridge the gap between climate objectives and current technological constraints. This rationale underpinned the EU Hydrogen Strategy, adopted in 2020, which placed renewable hydrogen at the centre of the EU’s path to climate neutrality (European Commission, 2020).

The strategy envisaged a gradual expansion of the European hydrogen economy:

- 2020-2024: establish the market and deploy at least 6 GW of renewable electrolyzers.
- 2025-2030: scale up to 40 GW of electrolyzers and up to 10 Mt of renewable hydrogen produced in the EU, with growing use in industry, transport and energy storage.
- By 2050: hydrogen was projected to potentially supply 24% of global energy demand and generate around €630 billion in annual revenues (European Commission, 2020).

These targets illustrate the strategic importance assigned to hydrogen, which the Commission described as essential to achieving climate neutrality and implementing the Paris Agreement (European Commission, 2020). Yet, Europe’s domestic renewable potential may not be sufficient to meet these ambitions. EU production was expected to reach around 10 Mt by 2030, prompting the EU to target an additional 10 Mt of imports from third countries, particularly Africa, where abundant renewable resources and geographical proximity offer attractive production conditions (Van der Zwaan et al., 2021).

This vision is increasingly reflected in emerging hydrogen infrastructure. The proposed SouthH2 Corridor, for instance, would repurpose existing gas pipelines linking Algeria to Central Europe through Tunisia, Italy and Austria (Sarno and Colantoni, 2023). More broadly, Power-to-X (PtX) enables renewable electricity to be converted into transportable molecules, making long-distance energy trade possible

through pipelines or maritime shipping. The potential extends beyond the Mediterranean to resource-rich countries in Sub-Saharan Africa, with Namibia and Tanzania representing particularly promising cases. This is where the hydrogen and ammonia narratives converge. Although hydrogen has a very high gravimetric energy density (120.1 MJ/kg), its volumetric energy density is extremely low- around 0.011 GJ/m³ under standard conditions, compared with 34.5 GJ/m³ for oil (Montignac, Noirot and Chaudourne, 2009). Its transport therefore requires compression or liquefaction:

- **Compressed hydrogen:** relatively simple but still low in density (**42.2 kg-H₂/m³ at 69 MPa**), requiring high-pressure storage and raising concerns over leakage and hydrogen embrittlement.
- **Liquid hydrogen:** substantially denser (**70.8 kg-H₂/m³**) but requires cooling to **−253°C**, resulting in high energy requirements and boil-off losses (Aziz, Wijayanta and Nandiyanto, 2020).

These constraints help explain why ammonia has emerged as a key candidate for transporting renewable hydrogen over long distances.

- **Liquid ammonia:** offers the highest volumetric hydrogen density of the three (**121 kg-H₂/m³**), compared with **42.2 kg-H₂/m³** for compressed hydrogen and **70.8 kg-H₂/m³** for liquid hydrogen. It can also be stored under relatively mild conditions (**25°C at 0.99 MPa**), avoiding the extreme pressures or cryogenic temperatures required for hydrogen. However, recovering the hydrogen requires **catalytic cracking above 400°C**, with a significant energy requirement of around **30.6 kJ/mol-H₂**.

Figure 3: Efficiency Comparison of Different Hydrogen Storage Options

Properties	Unit	Compressed Hydrogen	Liquid Hydrogen	Methanol	Liquid Ammonia
Storage method	-	Compression	Liquefaction	Ambient	Liquefaction
Temperature	°C	25 (room)	−252.9	25 (room)	25 (room)
Storage pressure	MPa	69	0.1	0.1	0.99
Density	kg/m ³	39	70.8	792	600
Explosive limit in air	%vol	4–75	4–75	6.7–36	15–28
Gravimetric energy density (LHV)	MJ/kg	120	120	20.1	18.6
Volumetric energy density (LHV)	MJ/L	4.5	8.49	15.8	12.7
Gravimetric hydrogen content	wt%	100	100	12.5	17.8
Volumetric hydrogen content	kg-H ₂ /m ³	42.2	70.8	99	121
Hydrogen release	-	Pressure release	Evaporation	Catalytic decomposition T > 200 °C	Catalytic decomposition T > 400 °C
Energy to extract hydrogen	kJ/mol-H ₂	-	0.907	16.3	30.6

Source: Elaboration by Aziz et al. 2020.

Earlier initiatives such as **DESERTEC and SolarMed** sought to export renewable electricity from North Africa to Europe through HVDC infrastructure, making geographical proximity essential. Green hydrogen and ammonia, by contrast, enable renewable energy to be converted into **transportable molecules**, extending potential production to resource-rich regions such as Namibia while maintaining Europe as a major demand centre. Transmission costs depend on distance and volume: pipelines are generally most competitive over shorter distances, HVDC over medium distances, and tankers over longer routes (Dinh *et al.*, 2024). For maritime transport, **ammonia and e-methanol** emerge as the main alternatives to liquid hydrogen (Cui and Aziz, 2023).

Ammonia is particularly attractive as a hydrogen carrier due to its **high volumetric hydrogen density, established global infrastructure and potential for near-zero emissions** (AlZohbi *et al.*, 2025). However, it is not necessarily the dominant future carrier. Different molecules may suit different applications, including **ammonia, methanol, hydrogen and e-SAF**, particularly across hard-to-abate transport and industrial sectors (Aziz, Wijayanta and Nandiyanto, 2020).

This diversity is reflected in industry perspectives. All five operators interviewed identified **green methanol** as a relevant alternative. AustriaEnergy, for instance, favours ammonia for its Chilean projects partly because of the limited availability of biogenic CO₂ and the current constraints of industrial-scale direct-air capture. As one representative put it, “*the future will be [...] a number of different flowers: one will be methanol, the other one will be hydrogen, the third one will be ammonia*”.⁵

Among the range of potential energy carriers, ammonia retains several advantages, particularly its established market and infrastructure. As AustriaEnergy explains, e-methanol is less attractive in regions where the CO₂ required for its production is not readily available. The company notes that biogenic CO₂ is scarce in the region, while direct-air capture remains insufficiently mature for large-scale industrial deployment, making ammonia a more practical option.⁶ Ammonia benefits from an **established market and extensive infrastructure**, facilitating its deployment as a hydrogen carrier. Unlike e-methanol, it does not inherently require CO₂, while nitrogen can ultimately be returned to the atmosphere; it also contains around **40% more hydrogen by mass than methanol** (Rodrigues *et al.*, 2026). Compared with **liquid organic hydrogen carriers (LOHCs)**, ammonia may also reduce logistical complexity by avoiding the energy and transport requirements associated with carrier regeneration, including the return of the spent carrier to the production site.⁷ Ammonia offers a logistical advantage over LOHCs and other carriers requiring regeneration, as it does not require the return transport of a spent carrier: nitrogen can be sourced from and ultimately returned to the atmosphere. Combined with its established market and infrastructure, this supports its potential for transporting renewable energy from resource-rich regions to Europe (Agyekum *et al.*, 2023).

Ammonia can also be used directly without reconversion to hydrogen, including for **iron-ore reduction in the DRI-EAF pathway** (still at R&D stage) and as a potential fuel for **maritime transport** (Ma *et al.*,

⁵ Interview with Helmut Kantner, CEO of AustriaEnergy, online, 30 July 2026.

⁶ Ibid.

⁷ Interview with Carlo Tregambe, R&D Manager at the Hydrogen Lab, ICI Caldaie S.p.A., phone call, 17 July 2026.

2023; Luu *et al.*, 2025; Liu *et al.*, 2025; Al-Aboosi *et al.*, 2021). However, toxicity, corrosiveness, NO_x emissions, ammonia slip and N₂O formation remain important challenges, requiring appropriate standards and emission-control technologies such as SCR (Rodrigues *et al.*, 2026; Wang *et al.*, 2025). These should nevertheless be weighed against the CO₂, SO_x, NO_x and particulate emissions of conventional marine fuels (Roy and Chakraborty, 2025). Infrastructure is also expanding: **Rotterdam** is preparing to handle up to 2.5 million tonnes of green ammonia annually, while Antwerp-Bruges supports hydrogen derivatives through initiatives such as **2Enhance** (Balci *et al.*, 2024; Notteboom and Haralambides, 2023). Ammonia may also support **energy storage and grid stabilisation**, with conversion losses comparable to those associated with hydrogen liquefaction or compression (Tawalbeh *et al.*, 2022; Kojima and Yamaguchi, 2022).

Taken together, the rationale for the green ammonia hype extends well beyond fertiliser decarbonisation. Under the EU Green Deal and Hydrogen Strategy, ammonia could become a key enabler of long-distance hydrogen trade. As Helmut Kantner of AustriaEnergy puts it: “*Why do we go for ammonia? Because you can ship it easier than hydrogen.*”⁸

2.1 European Policy Instruments for Ammonia Decarbonisation: Carbon Pricing, Demonstration Funding and Regulation for lead market creation

The European Union has developed a **multidimensional policy framework** to support low-carbon ammonia through four main pillars: **regulation, carbon pricing, public funding, and international climate policy**. Regulatory instruments such as RED III, AFIR, the Hydrogen and Decarbonised Gas Market Package, and the Net-Zero Industry Act (NZIA) establish the framework for renewable energy, hydrogen and derivatives, and related infrastructure. The EU ETS increases the cost of carbon-intensive production, while instruments such as the Innovation Fund, European Hydrogen Bank and proposed EU Decarbonisation Bank aim to mobilise investment. International measures, including CTIP and CBAM, extend these efforts through trade and carbon-leakage policies.

Against this backdrop, green ammonia is better understood as an **emerging lead market** than an established one. Following Quitzow *et al.* (2014), a lead market is a geographical market where favourable environmental, economic and social conditions create early demand for an innovation and support a design that may later diffuse internationally. The EU could therefore shape not only domestic demand for green ammonia but also the conditions for its global diffusion. Lead-market formation requires coordinated **demand and supply development**. Long-term targets, regulation and incentives can create demand, while investment, R&D, skills and supplier ecosystems support supply. Mechanisms such as long-term offtake agreements, take-or-pay contracts, tax incentives and production premiums can further reduce investment risk and narrow the cost gap with conventional ammonia (Zhao, 2024). Accordingly, the analysis that follows examines EU policies according to three core functions of lead-market formation: **(i) supply creation; (ii) demand creation; and (iii) the infrastructure and financial conditions required to scale the emerging green-ammonia market**, as summarised in Figure 4.

⁸ Interview with Helmut Kantner, CEO of AustriaEnergy, online, 30 July 2026.

EU POLICY INSTRUMENTS FOR GREEN AMMONIA DECARBONISATION

Overview of key policies across the value chain

1. GREEN SUPPLY CREATION		2. GREEN DEMAND CREATION		3. BRIDGING INFRASTRUCTURE & MARKET ENABLERS	
RED III (Dir. 2023/2413)	Binding targets for renewable energy and renewable hydrogen (RFNBOs).	RED III – Industrial provisions (Dir. 2023/2413)	Targets for renewable hydrogen/ RFNBO consumption in industry, creating a regulated market for low-carbon hydrogen.	H₂ & Gas Package (Dir. 2024/1788 & Reg. 2024/1789)	Comprehensive regulatory framework for hydrogen and decarbonised gas markets, including rules for networks, storage, transport and certification.
RFNBO Delegated Acts (Regs. 2023/1184 & 1185)	Define renewable hydrogen criteria, including additionality, temporal/geographical correlation and GHG methodology.	FuelEU Maritime (Reg. 2023/1805)	Gradually reduces the GHG intensity of energy used by ships, creating demand for renewable ammonia as a marine fuel.	TEN-E (Reg. 2022/869)	Supports cross-border energy infrastructure and Projects of Common Interest (PCIs), including hydrogen corridors.
REPowerEU Plan (2022)	Accelerates domestic renewable hydrogen production and imports.	RefuelEU Aviation (Reg. 2023/2405)	Establishes increasing requirements for sustainable aviation fuels (SAFs), including a share of RFNBOs.	Connecting Europe Facility (CEF) (EU funding instrument)	Provides financial support for cross-border energy and transport infrastructure, connecting production and demand centres.
Net-Zero Industry Act (NZIA) (Reg. 2024/1735)	Supports deployment and manufacturing of net-zero technologies and streamlines permitting (e.g., electrolyzers).	CARBON PRICING INSTRUMENTS		AFIR (Reg. 2023/1804)	Supports deployment of alternative fuels infrastructure, including hydrogen refuelling and related facilities along the TEN-T network.
EU Taxonomy (Reg. 2020/852)	Establishes a framework for sustainable activities, facilitating access to finance for green hydrogen and ammonia projects.	EU ETS (Dir. 2003/87/EC)	Puts a price on industrial GHG emissions, increasing the cost of fossil-based ammonia and improving the competitiveness of low-carbon alternatives.		
		CBAM (Reg. 2023/956)	Applies a carbon adjustment to imports (ammonia included), reducing carbon leakage and ensuring a level playing field.		
4. FINANCIAL & MARKET-BRIDGING INSTRUMENTS					
European Hydrogen Bank (EU funding mechanism)	Uses competitive auctions and support mechanisms to close the cost gap between renewable hydrogen production and market prices, de-risking demand for suppliers.	Innovation Fund (EU funding mechanism)	IPCEIs (Important Projects of Common European Interest) (State aid instrument) Enable Member States to jointly support large, cross-border projects in strategic value chains (e.g., hydrogen and derivatives such as ammonia) where market failures justify public intervention.	CISAF (Clean Industrial State Aid Framework) (EU State aid framework) Provides a legal basis for Member States to support the decarbonisation of industry, including the production of renewable hydrogen and its derivatives (e.g., ammonia), through investment aid, operating aid, and auction schemes, while ensuring proportionality and EU-wide level playing field.	

Note: Legal bases refer to the main act. Delegated and implementing acts complement these instruments.

Source: Author's own elaboration.

Among these instruments, the **EU Emissions Trading System (ETS)** is particularly significant. Described by DG CLIMA officials as the EU's "main instrument" for climate policy (Meadows, Quinn and Yordi, 2024, p. 59), the ETS is the world's largest carbon market, covering more than 11,500 installations across energy-intensive sectors responsible for around 40% of EU GHG emissions (Venmans, 2012). As a cap-and-trade system, it places a direct cost on emissions and has included ammonia production since Phase 3, requiring covered installations to monitor, report and surrender allowances for their CO₂ emissions (Directive 2003/87/EC, 2003). By increasing the cost of fossil-based ammonia, the ETS strengthens the relative competitiveness of low-carbon alternatives and provides an important market signal for green ammonia, increasingly complemented by **CBAM**.

Carbon pricing can materially improve the economics of green ammonia: higher carbon prices have been estimated to increase its NPV by around **36%**, while combining carbon pricing with hydrogen subsidies further narrows the cost gap (Alsulaiman and Chyong, 2025). However, important gaps remain, notably the limited coverage of international shipping under the ETS and its exclusion from CBAM (Alsulaiman and Chyong, 2025).

The **Renewable Energy Directive III (RED III)** complements carbon pricing by creating demand for renewable hydrogen and its derivatives through the **RFNBO framework**, with certification based on criteria including additionality, geographical correlation and temporal correlation (European Commission, 2025). Yet, the central obstacle remains the **green premium**. Green ammonia is estimated to cost around USD 696 –1,024/t, compared with approximately USD 297/t for grey ammonia, leaving a gap of around USD 600/t (Tjahjono *et al.*, 2023). Stronger carbon pricing could narrow this differential, but risks undermining industrial competitiveness and encouraging relocation; direct support for CAPEX and OPEX therefore remains important (Mayer *et al.*, 2016).

To address these investment and cost barriers, the EU has developed a broader financial architecture. The Innovation Fund supports first-of-a-kind net-zero projects beyond the research stage, including the planned 300 MW green ammonia plant in Brunsbüttel based on solid oxide electrolysis (Rajabloo, 2022). The European Hydrogen Bank supports renewable hydrogen production and its derivatives, while the EIC, EIB and Horizon Europe provide additional support for innovation, investment and R&D. Further instruments, including the Modernisation Fund, InvestEU and the Connecting Europe Facility (CEF), address infrastructure and financing constraints across the hydrogen value chain (Metzger and Kusch, 2024; Zabanova, 2024). Taken together, these instruments combine carbon pricing, regulation, financial support and infrastructure investment, targeting the main barriers to the emergence of a European green-ammonia market.

The experience of ICE Caldaie S.p.A., as reported by its representative, illustrates both the value and limitations of EU funding for industrial innovation. The company's laboratory reportedly develops "*a couple of million euros of projects financed by Horizon*" each year, enabling technological experimentation and prototype development in emerging fields such as hydrogen. Yet the interview also highlights a critical gap: although a green-hydrogen demonstration prototype was "*possible thanks to European projects, [...] in reality there is no market*".⁹ This points to a disconnect between supporting technological development

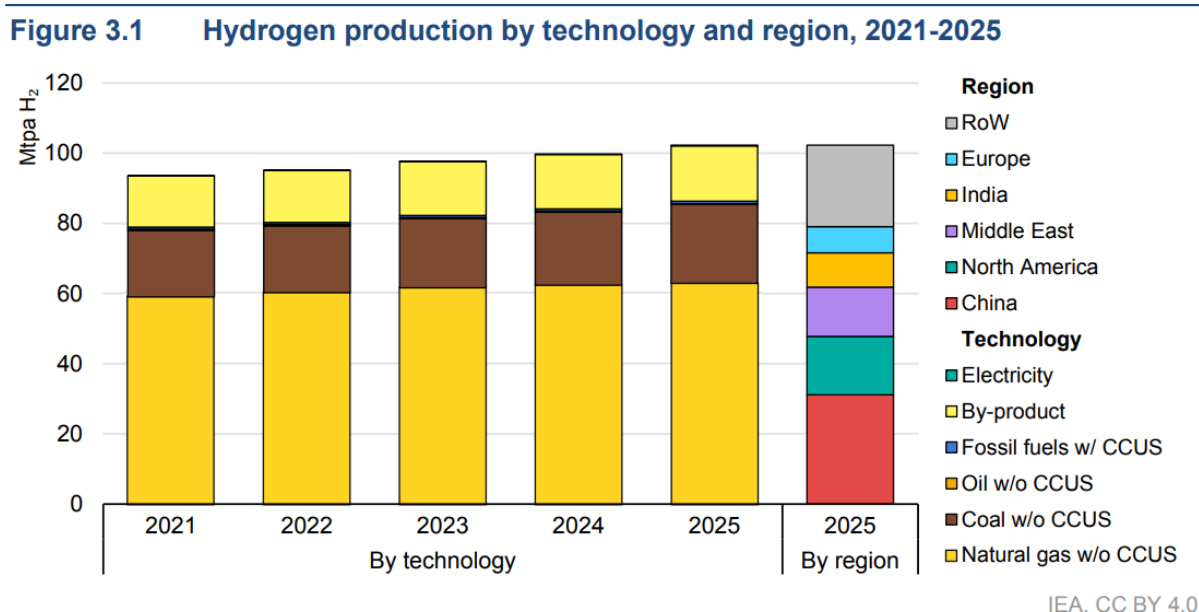
⁹ Interview with Alberto Zerbinato, Vice-President and CEO, ANIMA Confindustria and ICI Caldaie S.p.A., phone call, 28 April 2026.

and creating the market conditions required for commercialisation. Despite instruments ranging from the EU ETS to the European Hydrogen Bank, EU support has not yet, from some industry perspectives, generated sufficiently strong and predictable demand for hydrogen and its derivatives. The key question is therefore not only whether Europe provides adequate financial support, but whether its policy framework generates the demand, price signals and investment certainty needed for market formation. This persistent gap helps explain the growing “hydrogen scepticism” identified by Furfari (2020) and raises broader questions about the EU’s ability to establish hydrogen lead markets.

3. Time for a Reality Check: Assessing EU Policies Against Market Realities

For six years, the EU has invested in green hydrogen under the EU Hydrogen Strategy. Yet, by 2026, these efforts have yielded limited results: the IEA’s *Global Hydrogen Review 2026* shows that **low-emissions hydrogen still accounts for less than 1% of global hydrogen production**, as illustrated in Figure X (IEA, 2026).

Figure 5



Notes: CCUS = carbon capture, utilisation and storage; RoW = Rest of World. By-product hydrogen includes hydrogen production in catalytic naphtha crackers and steam crackers which is subsequently used in refining.

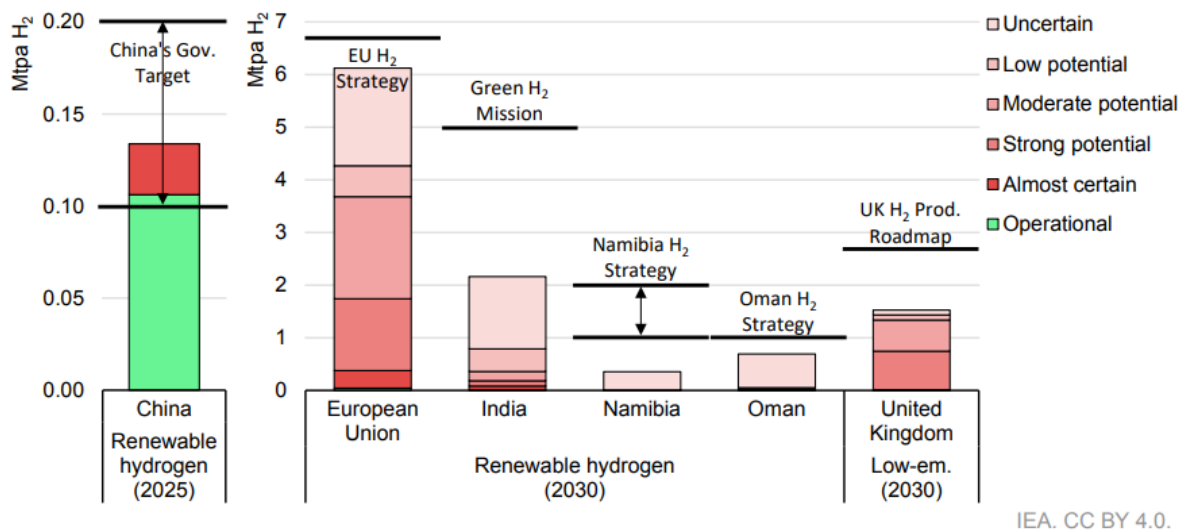
Hydrogen production remains dominated by unabated fossil fuels, leading to emissions of around 1 000 Mt of CO₂ in 2025.

Source: IEA’s *Global Hydrogen Review 2026*

According to the IEA (2025), most announced hydrogen projects in the EU are **unlikely to become operational by 2030 or remain subject to significant uncertainty**. As a result, projected capacity for 2030 amounts to only **0.04% of the REPowerEU target of 10 Mtpa of renewable hydrogen production**, highlighting the substantial gap between EU ambition and expected delivery (Figure 6).

Figure 6

Figure 3.6 Low-emissions hydrogen production from announced projects compared with government targets for 2025 and 2030



Notes: Low-em. = low-emissions hydrogen. The EU Hydrogen strategy target is based on modelling results for the Fit-for-55 package. For the United Kingdom, the targets reflect low-emissions hydrogen, which includes both hydrogen produced from low-emissions electricity, from biomass, and from fossil fuels with CCUS..

Sources: [IEA Hydrogen Production Projects Database](#) (September 2025); [Hydrogen Industry Development Plan \(2021-2035\)](#); [EU Hydrogen Strategy](#); [India's Green Hydrogen Mission](#); [Oman Green Hydrogen Strategy](#); [Namibia Green Hydrogen and Derivatives Strategy](#); [UK Hydrogen Production Delivery Roadmap](#).

The status of the project pipeline suggests that government targets for low-emissions hydrogen production by 2030 are unlikely to be met.

Across Europe, numerous hydrogen pilot projects have stalled or been cancelled, with around one in five initiatives abandoned in 2024 alone (Lardizabal, 2025). Ammonia use as a shipping fuel also remains virtually non-existent (Fullonton *et al.*, 2025). This highlights the widening gap between policy ambition and market reality. Under REPowerEU, the EU targeted 10 Mt of renewable hydrogen production and 10 Mt of imports annually by 2030, yet the definition of the import target remains contested, particularly regarding the treatment of ammonia as either a direct import or hydrogen equivalent (Oxford Institute for Energy Studies, 2026).

At the core of this gap lies a structural **“chicken-and-egg” dilemma**: high production costs suppress demand, while weak demand discourages investment in production capacity and infrastructure (Sperling and Cannon, 2004). Furfari (2020) argues that this challenge is reinforced by hydrogen’s unfavourable energy economics: electrolysis requires around 282.8 kJ per mole of H₂, compared with 41.2 kJ for hydrogen derived from methane. He therefore questions whether technological progress alone can overcome these structural constraints, concluding that **“molecules are not bits”** (Furfari, 2020). Historical experience supports this caution. The **Euro-Québec Hydro-Hydrogen Pilot Project (EQHPP)** demonstrated the technical feasibility of producing low-carbon hydrogen in Québec and transporting it to Europe, but suffered energy losses of approximately 54% and was ultimately abandoned after around €38 million of investment (Drolet *et al.*, 1996). Green ammonia could now fulfil a similar carrier role, but may face comparable difficulties despite far stronger policy support. The key question is therefore whether existing EU instruments can finally break this supply-demand deadlock.

An alternative perspective comes from the Senior General Manager of **AM Green Group**, who argues that regulation should come first: “*there is no chicken and egg. First regulation, then demand will come, then supply will follow*”. In this view, binding regulatory mandates and secured offtake contracts, rather than subsidies alone, are what can ultimately unlock investment.¹⁰ This reflects their direct experience: EU regulations such as FuelEU Maritime and the EU ETS have already provided sufficient signals for Greenko, AM Green’s parent company and a major Indian renewable-energy producer with around 12 GW of capacity, to initiate large-scale green ammonia projects targeting the European market.

The challenge arises when decarbonization policies impose costs that energy-intensive industries struggle to absorb, potentially shifting rather than sharing the burden and increasing the risks of carbon leakage and industrial relocation. This tension partly underpins the shift from the European Green Deal to the Clean Industrial Deal, with greater emphasis on reconciling decarbonisation with industrial competitiveness - “decarbonisation without deindustrialisation”. Recent developments suggest that overly ambitious targets may otherwise become politically unsustainable, potentially weakening instruments such as the ETS. Against this backdrop, the Clean Industrial Deal moves away from an exclusive focus on large-scale hydrogen production in third countries for import into Europe, towards strategic hard-to-abate sectors and regional hydrogen valleys, while placing greater emphasis on preserving European technological capabilities and strengthening strategic autonomy.

Neither AustriaEnergy nor AM Green, both interviewed for this dissertation and developing export-oriented green ammonia projects in Chile and India respectively, currently receives EU funding. Instead, the EU is considering instruments such as Clean Trade and Investment Partnerships (CTIPs) to support international green value chains and industrial decarbonisation (Wolf, 2025). Their practical relevance to green ammonia remains uncertain, however, as only one CTIP - between the EU and South Africa - has so far been concluded, with details yet to be published. Hydrogen policy has therefore moved from “hype to realism”, shifting towards a more pragmatic assessment of commercial viability and scalability. Yet clean hydrogen remains one of the few credible options for decarbonising sectors where direct electrification remains technically difficult, including steel, chemicals, refining, fertilisers, shipping, aviation and heavy-duty transport (Patonia, 2025).

3.1 Breaking the Chicken-and-Egg Dilemma: The “Green Ammonia Ladder”

This final section develops a critical reflection and proposes policy directions for the EU to foster green ammonia as a commercially viable commodity. The analysis starts from a shift from *hydrogen enthusiasm* to *hydrogen realism*: rather than promoting hydrogen indiscriminately, policy should prioritise applications where direct electrification or other alternatives are technically or economically constrained. Michael Liebreich’s “**Hydrogen Ladder**” provides a useful framework for ranking hydrogen applications according to their decarbonisation value and the availability of competing technologies.

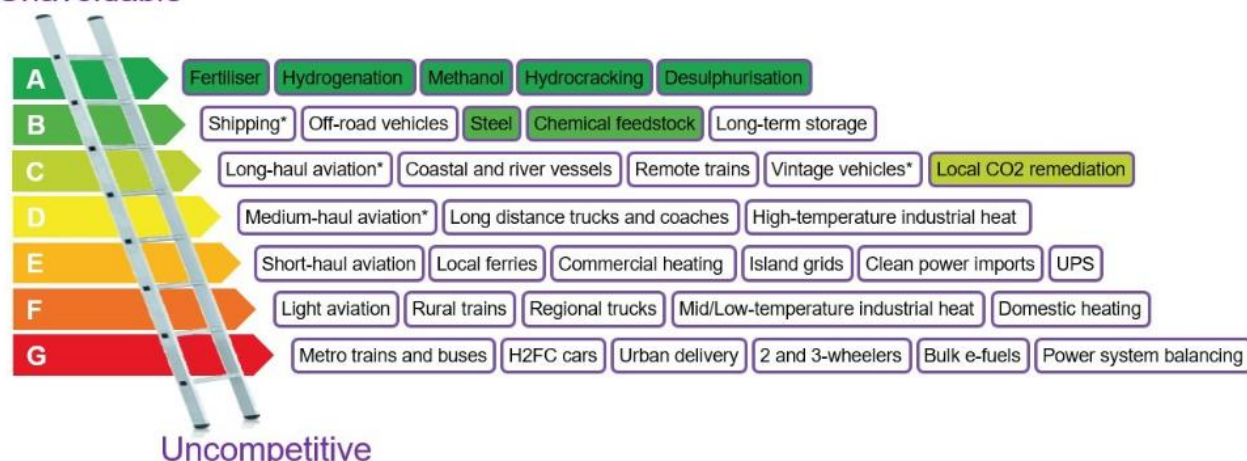
¹⁰ Interview with Cyril Vanderheyden, Senior General Manager and Europe Business Developer, AM Green Group (Greenko), Brussels, 11 August 2026.

Figure 7: Clean Hydrogen Ladder: Chemicals & processes

Clean Hydrogen Ladder: Chemicals & processes

Liebreich
Associates

Unavoidable



* Via ammonia or e-fuel rather than H2 gas or liquid

Source: Liebreich Associates (concept credit: Adrian Hiel/Energy Cities)

The underlying principle is that green hydrogen should bear its relatively high production and transport costs primarily where substitution is difficult or impossible. Liebreich's Hydrogen Ladder ranks applications according to their hydrogen dependence and the availability of alternatives, placing established uses such as **oil refining, fertiliser production and methanol**, alongside emerging applications such as **green steel and ammonia-fuelled shipping**, among the stronger candidates (Johnson *et al.*, 2025). Applied to **green ammonia**, however, the framework requires some adaptation: methanol falls outside its scope, while green steel remains uncertain due to technological and cost barriers. **Shipping** is particularly relevant because ammonia can be used directly as a maritime fuel. Other applications, such as long-duration energy storage and grid balancing, may develop over time, but **fertilisers, refining and shipping** appear the strongest near-term candidates. The key question is therefore how to adapt the Hydrogen Ladder to ammonia to assess the **techno-economic opportunity cost of different applications** and identify where EU policy can deliver the greatest decarbonisation impact.

Drawing on evidence from **Vanderheyden, Business Developer for Europe at AM Green Group**, these applications can be assessed across three dimensions: **(i) market readiness, (ii) energy efficiency, and (iii) technological readiness**. Based on these criteria, the main potential applications of green ammonia can be ranked as follows:¹¹

(1) Refineries: Refineries represent **one of the most immediately viable markets**, as hydrogen is already extensively integrated into existing processes. Switching from grey to green hydrogen would therefore require limited infrastructural changes, while the cost premium could translate into only a low-single-digit increase in fuel costs. When ammonia is used as a hydrogen carrier, however, it must first be cracked back into hydrogen, causing additional energy losses. Although ammonia-cracking

¹¹ Interview with Cyril Vanderheyden, Senior General Manager and Europe Business Developer at AM Green Group (Greenko), Brussels, 11 August 2026.

technology is not yet fully mature, large-scale demonstrations are under way and wider commercial deployment is expected towards 2030. Its competitiveness will ultimately depend on the relative cost of domestic hydrogen production versus importing hydrogen as ammonia and subsequently reconverting it.

(2) Maritime transport: Ammonia-fuelled shipping is also progressing technologically, with early vessels already entering operation. **Market readiness, however, remains the main constraint**, as large-scale adoption requires both ammonia-fuelled fleets and substantial port infrastructure for storage and bunkering. While FuelEU Maritime provides an important regulatory signal, it may not yet generate sufficient demand to establish a large-scale ammonia-fuel market. A stronger international framework through the IMO could therefore provide greater demand certainty and support investment.

(3) Fertilizers: Fertilizer production combines **high technological readiness with significant market (or political) constraints**. Ammonia is already the core feedstock, meaning that replacing fossil-based hydrogen with renewable hydrogen would require relatively limited process changes and avoid additional conversion losses. However, fertilisers operate in highly competitive global markets, while farmers have limited capacity to absorb green premiums. The EU Fertilizers Action Plan recognises that rising fertiliser costs may reduce farmers' use of inputs, potentially lowering yields, cultivated areas, and soil fertility in the long term (European Commission, 2026a). Political resistance to agricultural decarbonisation has further constrained policy ambition, as illustrated by the 2024 farmers' protests and the subsequent withdrawal of the **Sustainable Use of Pesticides (SUR)** proposal and relaxation of certain **CAP** environmental requirements. Urea production also presents an additional challenge because it requires a reliable CO₂ supply, currently largely provided as a by-product of conventional ammonia production.

Figure 8: The Green Ammonia Ladder

GREEN AMMONIA DEPLOYMENT PRIORITIES: A CROSS-SECTORAL ANALYSIS.

Comparative evaluation of market, technological, and energy efficiency readiness.

[Deployment Priority]	[Sector/Rank]	[Market Readiness Score]	[Technological Maturity Score]	[Energy Efficiency Score]	[Key Factors & Critical Path]
Highest / Immediate Viable	1. REFINERIES	High ●●●●●	Medium ●●●○○	Medium ●●●○○	Uses existing H ₂ infrastructure; limited process adaptation; requires significant capital for ammonia cracking (if imported).
Intermediate / Emerging	2. MARITIME TRANSPORT	3 ●●●○○	3 ●●●○○	3 ●●●○○	Early-stage vessels are operational; critical gaps in port bunkering facilities; requires extensive fleet technology validation.
Lower / Politically Sensitive	3. FERTILIZERS	Low ○○○●●	High ●●●●●	High ●●●●●	Highly mature, tech-ready process with highest end-to-end efficiency (no cracking required); constrained by low market willingness to pay for green premium; substantial CO ₂ management is required.

*Comparative Sectoral Assessment based on multiple parameters. Scale: High (●●●●●), Medium (●●●○○), Low (●●○○○).

*Deployment priority is a composite assessment based on market, technological maturity, and energy efficiency.

For detailed methodology, see text.

Source: Author's elaboration based on an interview with Vanderheyden, AM Green Group (2026).

Once these three priority sectors are identified, a key policy trade-off emerges between producing green ammonia domestically and importing it from abroad. The ranking of applications may differ accordingly: if ammonia is produced in Europe, decarbonising fertiliser production may take priority over maritime transport, given the need to preserve existing industrial capacity. The Clean Industrial Deal combines international partnerships, including Clean Trade and Investment Partnerships and improvements to CBAM, with a stronger emphasis on decarbonising European industry without triggering carbon leakage or relocation (European Hydrogen Observatory, 2026). This is particularly important for the domestic ammonia and fertiliser industries, which face competition from lower-cost imports. Di Bella *et al.* (2025) therefore argue that industrial policy should strategically support sectors such as ammonia to preserve existing production capacity and prevent further industrial decline.

3.2 The Future of Green Ammonia in Europe: Import or Domestic Production?

According to Neumann, a regulatory expert at Hynfra, a Polish industrial company with a substantial portfolio of overseas ammonia projects aimed at supplying the European market, Europe's fertiliser sector is dominated by three major producers: **Yara (Norway), Agrofert (Czech Republic), and Grupa Azoty (Poland)**. As he notes, "it is not some secret information; it is publicly available that all those three

companies want to switch to imports, just to cut their fixed costs and be only exposed to high prices of ammonia”.¹²

All three companies are therefore moving towards **greater reliance on ammonia imports** to reduce fixed production costs and limit exposure to Europe’s relatively high-cost production environment. Yara has already pursued this strategy, Agrofert is expanding import capacity through Rotterdam, and Grupa Azoty has incorporated imports into its corporate strategy. This trend suggests that **imported ammonia may become increasingly important to Europe’s fertilizer supply**, potentially including green ammonia as import infrastructure expands across Central and Eastern Europe. As Neumann notes:

“Ammonia trade is something that exists already; 20–30% of the volume globally is being traded, primarily through maritime transport; there are almost 1,000 ammonia terminals globally.”¹³

Moreover, production costs are potentially lower in regions with abundant renewable resources:

“better conditions for the production exist not only in the Middle East, but in the entire, we call it the equator belt [...] If you have an energy-intensive process, and the EU says we want this hydrogen to be made from electrolysis and later on ammonia, the cheapest electrolytic hydrogen on the planet you can get from those locations [...] This is a fun consequence of the EU climate policy, that they wanted to make it resilient, but the business sees that the economics is somewhere else than in Europe.”¹⁴

The emerging picture therefore points towards a **geographically diversified model of green ammonia supply**, in which Europe may increasingly rely on imports from renewable-rich regions while retaining selected domestic production capacities. This approach is also supported at the political level. In the Fertilizers Action Plan, the EU intends to diversify fertiliser supply chains while preserving a resilient domestic production base. To this end, it will leverage Global Gateway and Team Europe partnerships to support fertiliser and ammonia production in partner countries, including green ammonia linked to renewable hydrogen projects, while strengthening the infrastructure and supply corridors needed to serve EU, regional, and local markets (European Commission 2026,a).

At the other end of the spectrum, the EU is also promoting domestic green molecule production through initiatives such as the European Hydrogen Bank and the forthcoming European Decarbonisation Bank. This raises the question of whether such policies can offset the economic incentives favouring imports and, ultimately, influence the future geography of green hydrogen and ammonia production in Europe.

¹² Interview with Aleksander Naumann, Technology and Regulatory Expert at Hynfra, online, 22 July 2026.

¹³ Ibid.

¹⁴ Ibid.

3.3 Breaking the Chicken-and-Egg Dilemma: EU Industrial Champions and a Common Industrial Policy

The main limitation of relying on carbon pricing without a coordinated industrial policy is that its price signal may simply encourage European firms to import green ammonia rather than absorb the higher cost of domestic production. While CBAM preserves the relative advantage of lower-carbon alternatives, it does not eliminate the green premium and may therefore remain insufficient to prevent carbon leakage or industrial relocation (Evans *et al.*, 2021). EU industrial policy currently relies largely on public funding for green hydrogen and ammonia projects and industrial consortia, but two structural challenges remain. First, the emphasis on SMEs may limit the investment capacity needed for large-scale industrial deployment. Second, the absence of a coherent industrial policy aligned with EU climate and carbon-pricing frameworks risks creating a disconnect between decarbonisation and the preservation of European industrial capacity.

On the first issue, former Director-General of DG Environment Karl Falkenberg notes that European industrial policy has traditionally prioritised SMEs, while the Commission is increasingly considering adjustments to competition rules to strengthen European industrial champions.¹⁵ This shift would be consistent with the structure of the European ammonia industry.

This is particularly significant because green ammonia production exhibits features associated with natural-monopoly-like structures, notably substantial economies of scale and scope (Train, 2009). As confirmed by a green ammonia industry CEO, larger facilities can lower unit costs through more efficient electrolyzers and balance-of-plant systems, optimised nitrogen separation and ammonia synthesis, shared engineering and infrastructure, and access to cheaper renewable electricity. Further economies of scope arise when renewable generation, hydrogen and ammonia production, storage, fertiliser manufacturing, and export infrastructure are integrated within a single system.¹⁶ As envisaged by Draghi (2024), the creation of **European industrial champions inspired by the Airbus model** could help address Europe's competitiveness challenge by enabling strategic industries to mobilise the scale and financial resources required for long-term investment.

This approach should also inform the design of **EU funding for industrial consortia**. However, as the Scientific Attaché at the Italian Embassy in Germany cautions, public support for pilot projects does not necessarily translate into commercial deployment. As he observes:

“Pilot projects are often confused: they may be interesting from a scientific point of view, may break records, and may have real merits. [...] I know how companies operate, and also how many research centres within private companies use public funds to run pilot projects that they

¹⁵ Interview with Karl Falkenberg, President of the Club of Europe EU Chapter and former Director-General, DG Environment, Brussels, 27 April 2026.

¹⁶ Interview with Joun Lee, CEO of Pani Clean, email correspondence, 1 August 2026.

know will not lead anywhere. However, with this money they pay salaries to people who, in practice, do work that is useful for the company.”¹⁷

This highlights a critical distinction between supporting technological innovation and building commercially viable industrial capacity. Overcoming the innovation “Valley of Death”, which reinforces the EU’s chicken-and-egg dilemma, therefore requires funding that bridges the gap from demonstration to large-scale deployment and market uptake (Muscio, Simonelli and Vu, 2023). Without support covering both CAPEX and OPEX, stringent ETS targets may widen the green premium, suppress demand and weaken the competitiveness of producers and offtakers. Rising carbon costs could consequently become increasingly politically contentious, undermining long-term support for carbon pricing (Markard and Rosenbloom, 2020; López Hernández, 2026).

A more ambitious approach would establish a European Public Enterprise for industrial decarbonisation, allowing the EU to take equity stakes in consortia linking energy companies with strategically important hard-to-abate industries (Perrino, 2026). Such an instrument could finance part of the green premium and support shared CO₂ infrastructure, combining industrial decarbonisation with reindustrialisation and strategic autonomy. Its rationale would nevertheless need to be weighed against the opportunity cost of importing cheaper green ammonia from renewable-rich regions, highlighting the fundamental trade-off between industrial sovereignty and cost-efficient energy resilience.

4. CONCLUSION

Ammonia has been a strategically important commodity for over a century and remains essential today, primarily as the basis of nitrogen fertilisers supporting food production for around 3.8 billion people (Rosa et al., 2025). This importance comes with substantial environmental costs, however, as both its carbon-intensive Haber–Bosch production, traditionally reliant on natural gas or coal, and agricultural use generate significant emissions (Backes et al., 2016). Ammonia also benefits from economies of scope, serving as a key intermediate across several nitrogen-fertiliser products (Akridge and Hertel, 1986), contributing to a relatively concentrated European market. In 2021, Agrofert, Yara and Borealis each accounted for up to 20% of EEA-wide CAN sales, while OCI, EuroChem, Nitrogénművek, Fertiberia and Grupa Azoty each held around 5–10% (European Commission, 2023). Beyond fertilisers, renewable ammonia is increasingly viewed as a carbon-free energy carrier, particularly for maritime transport and energy storage (Bora et al., 2024; Alsulaiman, Chyong and Schmidt, 2026; Kookos, 2026). The EU has promoted this transition through the 2020 Hydrogen Strategy, RED III, the EU ETS and CBAM, targeting renewable hydrogen deployment, sustainability requirements and lower-carbon production (Magnino et al., 2026). Yet, six years after the Hydrogen Strategy, the gap between policy ambition and industrial reality remains substantial: despite extensive project announcements, EU production of green hydrogen and green ammonia remains negligible (IEA, 2026).

This dissertation examines the role of ammonia in industrial decarbonisation, shedding light on its potential as a low-carbon commodity and assessing under what conditions European policy can turn a technologically promising concept into a commercially viable solution. More specifically, it asks whether

¹⁷ Interview with Dr. Piergiorgio Alotto, Scientific Attaché at the Embassy of Italy to Germany, online, 17 April 2026.

the EU's clean-ammonia policy framework is moving beyond technological ambition towards a credible industrial strategy.

The analysis suggests that the answer is neither a straightforward yes nor no. The EU has developed a sophisticated policy mix combining regulation, carbon pricing, financial support and industrial policy, yet ambitious targets have not translated into a mature, self-sustaining market. Uncertainty remains over technologies, end uses, and the balance between domestic production and imports. Ultimately, ammonia policy reflects a broader European challenge: reconciling decarbonisation with competitiveness, industrial resilience and strategic autonomy.

Establishing a viable lead market therefore requires three conditions: (i) sufficient demand for low-carbon ammonia, (ii) competitive supply, and (iii) the infrastructure and financial mechanisms needed to connect the two. Since the European Green Deal and the EU Hydrogen Strategy, the EU has pursued these objectives through four broad policy pillars: regulation and standards (RED III, NZIA), carbon pricing and trade measures (EU ETS, CBAM), funding and investment (Innovation Fund, European Hydrogen Bank), and market-creation measures such as mandates, targets and premiums. This dissertation assesses their effectiveness against actual market developments and evidence from industry stakeholders.

Yet, with many European green-hydrogen projects postponed or cancelled and virtually no green hydrogen or ammonia produced at scale, these instruments have not yet bridged the supply–demand gap. This reflects a classic “chicken-and-egg” dilemma: high production and conversion costs constrain demand, while weak demand discourages investment in new capacity and infrastructure. Without sufficient scale, the green premium remains high, further limiting demand and increasing investment risk. Current EU policies have therefore not yet demonstrated an ability to break this self-reinforcing cycle, as illustrated by industry experience. As the CEO of ICI Caldaie S.p.A. noted regarding EU-funded demonstration projects:

“Let's say that it was possible thanks to European projects, but in reality there is no market. So, the question you asked me, is there an interest in green hydrogen? In the newspaper articles there is an interest, but then...”¹⁸

This highlights the persistent gap between policy-supported technological development and the emergence of a commercially viable market for green hydrogen and ammonia.

Interviews across the sector indicate that electrolytic Haber–Bosch (e-HB) is currently the only technically credible pathway for green ammonia production at commercially relevant scale in the short to medium term. Alternative routes remain largely at the R&D stage and are not yet mature enough for large-scale deployment. Given the broader challenges of scaling a hydrogen economy, identifying the applications where green ammonia offers the greatest decarbonisation potential is therefore essential. Drawing on an adapted Hydrogen Ladder and three criteria identified through an interview with an AM Green Group manager - (i) market readiness, (ii) energy efficiency, and (iii) technological readiness - three priority applications emerge:

¹⁸ Interview with Alberto Zerbinato, Vice-President and CEO of ANIMA Confindustria and ICI Caldaie S.p.A., phone call, 28 April 2026.

1. **Refineries:** the most immediately viable market, combining established demand with high technological readiness. Although ammonia must be cracked back into hydrogen, the resulting energy losses and cost increase are expected to remain relatively limited.
2. **Maritime fuel:** increasingly mature technologically and highly efficient, as ammonia can be used directly as a fuel. Market readiness, however, remains the main constraint, given limited vessel deployment and bunkering infrastructure.
3. **Fertilisers:** technologically mature and energy-efficient, as ammonia can be used directly. The main constraint is market competitiveness, particularly given the political sensitivity of higher fertiliser costs for European farmers.

A further question is whether Europe should produce green ammonia domestically or import it from renewable-rich countries. For most industry interviewees, the economic rationale lies in producing green molecules where renewable energy is cheapest and transporting them to demand centres, except in EU regions with particularly favourable renewable resources, such as Spain and Scandinavia. As one industry representative interviewed for this dissertation explains:

“The purpose of your green molecule is to be able to store and to get it from wherever it's cheaper. That's true. To harness the sun of India or the sun of Africa or wherever, get it and be able to get it as a source of cheap energy or less expensive energy in Europe.”¹⁹

While the Clean Industrial Deal promotes international green value chains through instruments such as Clean Trade and Investment Partnerships (CTIPs), the externalisation of hydrogen and ammonia production may sit uneasily with its objectives of shorter energy value chains, greater energy security and lower energy costs. The design of EU support for demonstration and scale-up therefore remains critical. Given the thermodynamic and Power-to-X costs of electrolysis compared with SMR, green ammonia is likely to remain more expensive than fossil-based alternatives. Beyond demonstration funding, EU policy may therefore need to provide longer-term CAPEX and OPEX support, potentially favouring larger projects able to capture economies of scale. A European public enterprise or public-private consortium with European participation could provide an alternative model for scaling green molecules and CCS through a more direct industrial-policy approach.

This dissertation has sought to test the key techno-economic and policy assumptions underpinning the European scale-up of green ammonia. A critical test is now approaching: in the first half of 2026, only eight electrolytic hydrogen projects, totalling 480 MW, reached Final Investment Decision (FID) in Europe (Hydrogen Europe, 2026). Their progression towards commercial operation will therefore provide an important indication of whether green molecules are moving from policy ambition to industrial deployment. Should deployment remain limited, a stronger European industrial role may be required to move beyond policy signalling, while guarding against the risks of greenwashing and excessive lobbying and ensuring that public support translates into genuine decarbonisation without deindustrialisation. Ultimately, the challenge is to reconcile industrial competitiveness with the transition towards a carbon-neutral economy,

¹⁹ Interview with Cyril Vanderheyden, Senior General Manager and Europe Business Developer at AM Green Group (Greenko), Brussels, 11 August 2026.

not only to safeguard Europe's economic prosperity today, but also to ensure a sustainable future for generations to come, both in Europe and all over the world.

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INTERVIEWS

Interview with Dr. Piergiorgio Alotto, Scientific Attaché at the Embassy of Italy to Germany, online, 17 April 2026.

Interview with Karl Falkenberg, President of the Club of Europe EU Chapter and former Director-General, DG Environment, Brussels, 27 April 2026.

Interview with Alberto Zerbinato, Vice-President and CEO of ANIMA Confindustria and ICI Caldaie S.p.A., phone call, 28 April 2026.

Interview with Mattia Saccoccio, CTO and Co-founder of NitroVolt ApS, online, 8 July 2026.

Interview with Mattia Saccoccio, CTO and Co-founder of NitroVolt ApS, email correspondence, 8 July 2026.

Interview with Carlo Tregambe, R&D Manager at the Hydrogen Lab at ICI Caldaie S.p.A., phone call, 17 July 2026.

Interview with Aleksander Naumann, Technology and Regulatory Expert at Hynfra, online, 22 July 2026.

Interview with Helmut Kantner, CEO of AustriaEnergy, online, 30 July 2026.

Interview with Joun Lee, CEO of Pani Clean, email correspondence, 1 August 2026.

Interview with Cyril Vanderheyden, Senior General Manager and Europe Business Developer at AM Green Group (Greenko), Brussels, 11 August 2026.