



Ammonia

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Ammonia

From an agricultural commodity to a key enabler of the global energy transition

For over a century, ammonia has been a cornerstone molecule for global agriculture and industry. Each year, nearly 183 million tonnes of ammonia are produced, underpinning food security for half the world's population through nitrogen fertilizers. Beyond this, it serves as one of the foundational chemicals enabling several industrial processes.

Today, however, ammonia is stepping into a new spotlight, defined by its potential to transform the global energy landscape.

Ammonia production currently contributes to approximately 1% of global greenhouse gas emissions, relying heavily on fossil fuels like natural gas and coal. Decarbonizing this industry is a crucial step to address emissions across the chemical and agricultural sectors.

But ammonia's story doesn't end with challenges. Its unique properties position it as a promising low-carbon energy vector. Unlike hydrogen, which faces hurdles in storage and transport, ammonia offers a scalable solution as a hydrogen carrier.

It is also gaining traction as a clean maritime fuel and a resource for power generation. Since 2020, investments in low-carbon ammonia projects have surged, driven by the global commitment to carbon neutrality by 2050.

At RINA, with our expertise spanning maritime, energy, and industrial sectors, we recognize both the complexities and transformative potential of ammonia. In this white paper, we outline ten key priorities to drive its adoption and upscale, contributing to a cleaner, more secure, and sustainable energy future.

The question is not if ammonia will lead the hydrogen economy, but when.

Andrea Bombardi
Global Market Development Executive Vice President, November 2024



A market in transition



Ammonia has long been a pillar of global industry, particularly in agriculture, where it underpins fertilizer production. As of 2020, global output reached 183 million tonnes (Mt), with fertilizers consuming 85% of this volume. Beyond agriculture, ammonia finds essential applications in plastics, textiles, refrigeration, pharmaceuticals, and water treatment, underscoring its industrial versatility.

Valued at approximately \$75 billion, the ammonia market is geographically dominated by the Asia-Pacific region, which accounts for over half of global production. This dominance is driven by agricultural demand from countries like China and India. Other regions, including North America, Europe, South America, and the Middle East, play vital roles as both producers and consumers. Logistics are equally significant: while most ammonia is consumed on-site, 18–20 Mt are shipped annually, with additional volumes transported via pipelines, trains, and trucks, totaling approximately 25–30 Mt. Ammonia production remains heavily reliant on fossil fuels, with natural gas contributing 72% of the feedstock mix, followed by coal (22%) and naphtha.

This reliance places the industry among the largest industrial CO₂ emitters, accounting for about 0.5 Gt of CO₂ annually. If left unaddressed, rising demand—projected to grow by 40% by 2050 due to population growth—could escalate emissions, posing challenges to global climate targets.

However, the ammonia market is undergoing a profound transformation. Beyond fertilizers, ammonia is emerging as a cornerstone of the energy transition. Its ability to store and transport hydrogen efficiently, coupled with its potential as a carbon-free fuel, positions it as a versatile decarbonization tool. Notably, ammonia is gaining traction as a zero-emission shipping fuel: out of 62 planned green corridors—specific trade routes where public and private actions are catalyzing the feasibility of zero-emission shipping—ammonia features prominently in 15 initiatives.

This highlights its growing role in decarbonizing hard-to-abate sectors like maritime transportation.

The global ammonia market is poised for huge growth, tripling by 2050 under the International Energy Agency's Net Zero Emissions by 2050 (NZE50) scenario. The demand could surge to 688 Mt, driven by both traditional applications and new energy uses. Energy-related demand alone could reach 354 Mt, with maritime fuels (197 Mt), power generation (30 Mt), and hydrogen transport (127 Mt) leading the way.

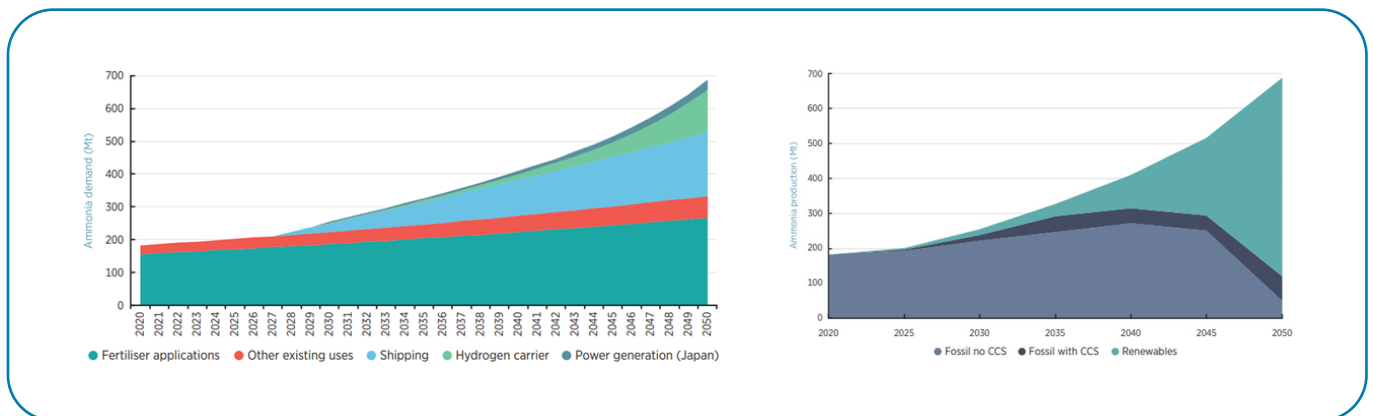


Figure 1: Expected ammonia demand up to 2050 for the NZE50 scenario (left). Expected ammonia production by feedstock up to 2050 for the NZE50 scenario (right). IRENA

Even under the more conservative Stated Policies Scenario (STEPS), reflecting current policies and industrial trends, production is projected to grow to 550 Mt by mid-century. Fertilizers would still dominate (267 Mt), but emerging applications such as hydrogen transport (109 Mt) and maritime fuels (77 Mt) will reshape market dynamics.

The geographic landscape of ammonia production and trading routes are also evolving. While Asia remains the largest consumer, production is increasingly shifting to regions with abundant and cheap renewable energy resources, such as Middle East, Australia, Africa, and Latin America. These areas, leveraging their vast solar and wind potential, are poised to become major hubs for cost-effective green ammonia production. The primary import regions are the energy-hungry markets, such as East Asia and Europe, driven by their decarbonization goals and growing demand for low-carbon energy carriers. To accommodate this shift, significant investments will be required to adapt existing infrastructure, such as receiving ports, and to develop new facilities in exporting regions, enabling efficient transportation and storage of ammonia on a global scale.

The value chain



The ammonia value chain reflects tradition and innovation evolving to meet both existing and emerging market demands while addressing environmental and safety imperatives.

At its core lies the Haber-Bosch process, a technological process that synthesizes ammonia by combining hydrogen and nitrogen at high temperatures and pressures in the presence of a catalyst. Nitrogen, readily extracted from air through separation processes, is paired with hydrogen, whose origin defines the sustainability of the entire chain.

Traditionally, hydrogen has been derived from steam methane reforming (SMR), making ammonia production one of the most carbon-intensive industrial activities.

To decarbonize, two main solutions have emerged: blue ammonia, which integrates SMR with carbon capture and storage (CCS), and green ammonia, produced using renewable electricity to power water electrolysis for hydrogen generation.

Cutting-edge technologies such as solid oxide electrolysis cells (SOECs) further enhance the viability of green ammonia by increasing efficiency and reducing costs.

Ammonia's storage and transport systems are well-established. Liquid ammonia, stored at -33°C under atmospheric pressure or in pressurized tanks for smaller volumes, requires advanced handling to mitigate risks associated with toxicity, flammability, and material corrosion.

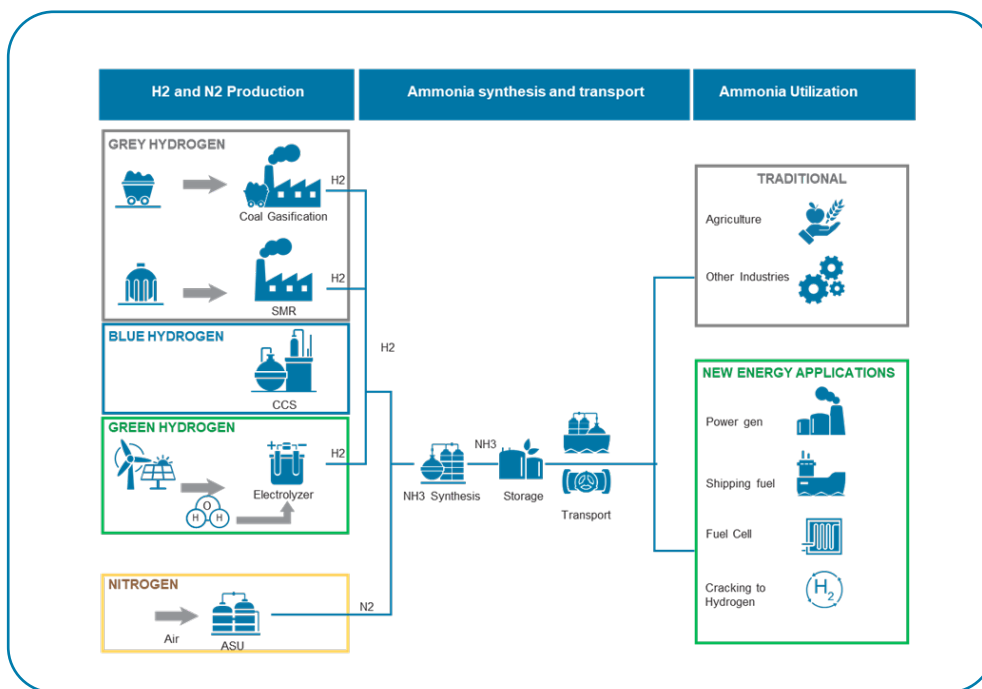


Figure 2: Ammonia value chain

The ammonia transportation network spans pipelines, ships, rail, and road systems. Pipelines provide efficient regional distribution, exemplified by infrastructures such as the 2,424-km Tolyatti-Odessa pipeline and the U.S. pipeline network spanning over 3,200 km, capable of moving millions of tonnes annually. For international trade, maritime transport dominates, with specialized refrigerated ships handling around 20 million tonnes per year. Rail and road networks complement these systems, ensuring connectivity between production hubs and end markets, from fertilizers to energy applications.

In its role as a hydrogen carrier, ammonia can be “cracked” back into hydrogen through thermal decomposition. While cracking technology is still maturing, advancements in efficiency and scalability will be critical for its broader application in hydrogen economies.

Across the chain, proactive risk management and advanced monitoring systems are critical to address potential hazards. Integrating safety expertise at every stage of the value chain ensures ammonia's viability in supporting the global energy transition.

Blue ammonia

A Transitional Solution for decarbonization

Blue ammonia, derived by combining nitrogen with blue hydrogen, is a promising transitional solution for achieving decarbonization goals. It integrates CCS technologies, cutting emissions to 0.1–0.2 tonnes of CO₂ per tonne of ammonia—significantly lower than traditional methods, which emit 1.8–3.2 tonnes per tonne. Approximately two-thirds of these emissions originate from hydrogen production, while the remainder is from heating processes. Despite its reduced carbon footprint, blue ammonia faces challenges. The adoption of CCS requires extensive infrastructure, including CO₂ transport and storage networks, and significant capital investment. Current CCS systems capture 80–95% of emissions, leaving a residual footprint. Nonetheless, momentum is growing, with over 4 million tonnes of low-carbon ammonia capacity installed globally.

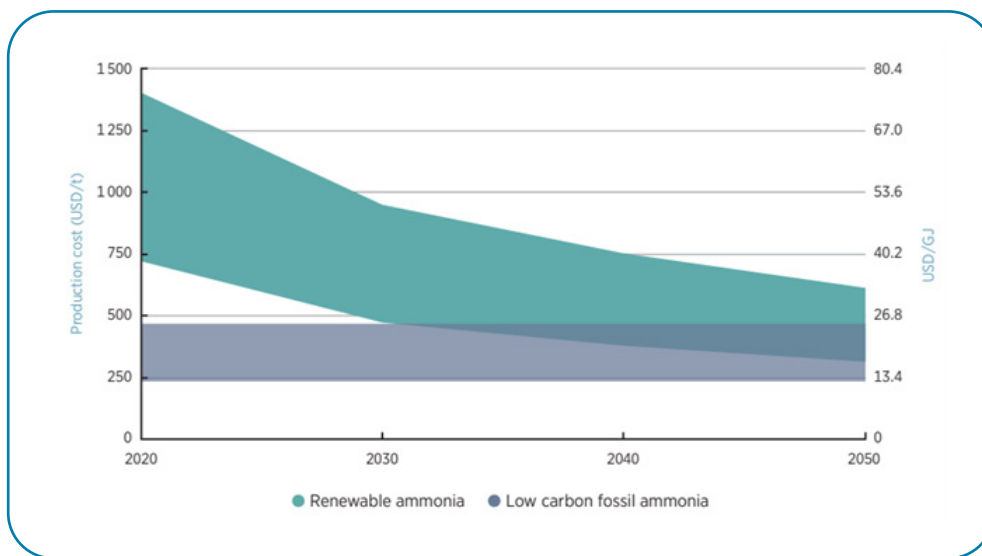


Figure 3: Current and future production costs of renewable ammonia, compared with production cost range for low carbon fossil ammonia (2–10 USD/GJ). IRENA

Green ammonia

Pioneering a carbon-free future

Green ammonia represents a paradigm shift in sustainable energy and industrial production. Produced through the Haber-Bosch process using nitrogen and green hydrogen, it eliminates carbon emissions by relying on water electrolysis powered by renewable electricity. While chemically identical to conventional ammonia, green ammonia is distinct in its environmental profile, offering a carbon-free alternative.

Though the concept of green ammonia dates back to the 1920s, with hydropower-driven electrolyzers, green ammonia remained niche due to inexpensive fossil fuels. Today, green ammonia accounts for less than 0.01% of global production, with an annual output of just 0.02 million tonnes. This is set to change, with over 250 green ammonia projects anticipated by 2030, driven by renewable-rich regions like Australia, Chile, and Africa.

However, green ammonia faces hurdles. Renewable electricity and electrolyzers are costly, driving up production expenses. The process is energy-intensive, requiring approximately 30 GJ per tonne of ammonia. Intermittent power sources like solar and wind necessitate advancements in energy storage and grid reliability. High-temperature electrolysis technologies, such as SOECs, hold promise for improving efficiency and cost-effectiveness. As global demand surges, scaling green ammonia production will depend on infrastructure investments and policy support. These efforts will cement its role as a cornerstone of sustainable industrial and energy systems.

Ammonia is today a cornerstone commodity within the industrial sector, supported by a well-established value chain. However, as industry shifts toward greener pathways, it faces substantial challenges. Governments, producers, and other stakeholders have already taken some steps to reduce emissions of ammonia production but they remain high, calling for greater ambition and coordinated action.

Achieving a low-carbon ammonia market demands an integrated strategy combining policy, regulation, financing, and technology.

Drawing from decades of expertise, RINA has pinpointed ten key priorities that pave the way for a sustainable, economically viable future for ammonia.



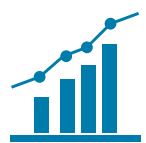
1. Driving investment through a Comprehensive Policy Portfolio

Low-carbon ammonia production requires significant capital and operational investments, often considered high-risk by private sector stakeholders. Governments play a critical role in creating favorable conditions through robust policy measures. These can include production tax credits, grants and green premiums, all of which play a critical role in de-risking early-stage projects. Demand-side incentives, such as subsidies for low-carbon fertilizers and ammonia-fueled vessels can drive market adoption, while achieving economies of scale. Incorporating low-carbon ammonia into national energy strategies, transparent certification systems and carbon pricing mechanisms, will further strengthen investor confidence and accelerate market growth.



2. Decarbonizing Existing Ammonia Production

Retrofitting existing ammonia plants offers the quickest path to emission reductions. Technologies like carbon capture and storage (CCS) and electrified steam methane reforming (eSMR) can transform existing facilities, leveraging their established infrastructure. Transitioning to renewable hydrogen as feedstock represents a direct route to sustainability.



3. Reducing Costs and Scaling Up

Ammonia's future hinges on the scalability of green hydrogen and CCS value chains. Blue ammonia depends on affordable CO₂ capture, transport and storage. Priorities include advancing cost-effective capture technologies, creating integrated CO₂ hubs, and ensuring a safe and permanent destination for the captured CO₂. Green ammonia needs to reduce hydrogen production costs by scaling up electrolyzer manufacturing and investing in new renewable energy infrastructure. Coordinated planning across stakeholders, regulatory clarity, and public-private partnerships will be key to building resilient supply chains capable of delivering ammonia at scale.



4. Supporting Innovation through R&D&I

A robust R&D&I ecosystem is vital to unlocking low-carbon ammonia's potential. This involves enhancing technologies like electrolytic hydrogen powered by variable renewable energy, methane pyrolysis, advanced CCUS methods, and ammonia cracking for hydrogen recovery. Key focus areas include improving the cost, efficiency, and durability of electrolyzers. Similarly, for CCUS technologies, reducing costs in CO₂ capture, and exploring innovative approaches and energy-efficient capture methods, developing affordable reuse technologies, are the priorities. Large-scale demonstration projects play a pivotal role in validating these innovations and achieving economies of scale. Public and private sectors must collaborate to fund and scale promising technologies, advancing and tailoring solutions to regional needs.

5. Building Ammonia Transport and Storage Infrastructure



Developing effective ammonia transport and storage infrastructure is a critical enabler for its widespread deployment. The challenge lies in coordinating extensive systems that support ammonia but also hydrogen and carbon dioxide. Existing systems, such as receiving ports, pipelines, and storage facilities, must be upgraded to handle ammonia's unique properties safely and efficiently. In exporter countries, building new facilities-ranging from large-scale ammonia production hubs to dedicated shipping terminals-is essential to meet growing global demand. These new installations should be strategically located to align with expected trade routes and equipped with advanced safety systems to ensure reliable operation. Public-private partnerships and streamlined permitting processes will be essential to infrastructure development.

6. Expanding Ammonia Shipping and Terminal Infrastructure



With ammonia set to play a pivotal role in the transition to a net-zero energy system, new opportunities for the maritime sector are emerging. Maritime transport emerges as the ideal solution for connecting exporter countries and countries with high energy demand, according to new expected trade routes, particularly over long distances. As demand for ammonia shipping grows, investment in specialized vessels and terminal facilities becomes essential to support the large-scale movement of liquefied ammonia. Shipping ammonia requires a fleet of dedicated vessels equipped with advanced refrigeration and safety systems to handle its unique properties, including its toxicity and flammability. Beyond ships, the development of ammonia terminals at key ports is equally critical. These facilities must be capable of safely managing large volumes of ammonia, including storage, loading, and unloading operations, while adhering to stringent environmental and safety standards.

7. Ensuring a holistic approach



Deploying low-carbon ammonia at scale demands an integrated, end-to-end strategy that aligns policies, technologies, and collaborations across the value chain. The international nature of green ammonia market underscores the need for this cohesive planning and partnerships between governments, industries, research institutions, and civil society. A synchronized development of production capacity and demand, together with the infrastructure connecting them, is vital to prevent supply chain bottlenecks and create a stable market. Policies should encompass the full lifecycle of ammonia, addressing production, transportation, storage, and end-use applications. International cooperation can facilitate infrastructure development, such as pipelines, shipping terminals, and storage facilities, ensuring seamless global trade. Life-cycle thinking and safety considerations must guide every decision to create a sustainable, efficient, and resilient ammonia economy.

8. Facilitating a Global Market for Low-Carbon Ammonia



Green ammonia has an inherently international nature: ammonia will often be produced in regions with abundant and cheap low-carbon energy and exported to areas with high energy demand. Building a global market for low-carbon ammonia hinges on fostering international trade and cooperation. Harmonized standards for carbon intensity, safety, and quality are critical to ensure seamless trade and build trust among stakeholders. Governments can support this by integrating low-carbon ammonia into trade agreements, removing barriers, and establishing mechanisms like carbon border adjustment measures (CBAMs) to level the playing field. Collaborative efforts, such as bilateral agreements and regional partnerships, can accelerate investments in essential infrastructure-from export-import terminals to storage and distribution networks. Transparency is equally important. Developing digital platforms to track production, certification, and trade flows will foster accountability and enable data-driven market strategies. Financial incentives, such as export credits and risk guarantees, can encourage participation, reduce uncertainties, and drive growth.

9. Establishing standards and global Certification Framework for Low-Carbon Ammonia



The development of universally recognized certification standards for ammonia is crucial to building trust across the value chain. Transparent methodologies for assessing and reporting greenhouse gas emissions throughout ammonia's lifecycle can foster market alignment and comparability. This harmonization not only facilitates international trade but also attracts investments by providing certainty about environmental credentials. In addition to carbon intensity, robust technical and safety standards must be established to ensure safe handling, storage, transport and use of ammonia. Developing detailed protocols for equipment design, operational procedures, and emergency response mechanisms is critical, especially in those applications where adoption of ammonia is new. These standards should align with international frameworks, such as ISO and other regulatory bodies, to avoid fragmentation and support global adoption.

10. Enhancing Public Awareness and Engagement



Public perception can make or break the low-carbon ammonia economy. Despite its potential, ammonia's storage and use as a fuel raises concerns about toxicity, particularly in densely populated areas. Addressing these safety issues through transparent regulatory frameworks and robust safety protocols is paramount to building public trust. Effective communication strategies are needed to inform communities about ammonia's role in a sustainable energy future. Governments and industry stakeholders must collaborate to promote awareness and dialogue, addressing misconceptions and emphasizing safety measures.

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