

EXECUTIVE SUMMARY

Ammonia Safety and Environmental Impacts in End-Use Applications

Ammonia is a versatile carbon-free fuel that has been widely used as a fertilizer and refrigerant. It can be produced sustainably using low-carbon electricity sources, with air and water as feedstocks. However, as new applications emerge, thorough risk assessments, control measures, rules, and regulations are necessary to minimize health and environmental impacts. This report reviews the safety aspects, existing regulatory landscape, and environmental impacts associated with ammonia as a fuel for industrial process heating and maritime transportation. Information is sourced from peer-reviewed publications, industry reports, white papers, and industry stakeholder websites.

Ammonia is a pungent, colorless gas which can be liquefied via compression and/or refrigeration. Although flammable, its high ignition temperature and low normal flame velocity minimize fire risks. It can be heavier than air in certain conditions, leading to asphyxiation and toxicity risks in confined spaces. Large volumes require adherence to Process Safety Management regulations, community awareness notifications, and emergency response planning. Spills, influenced by weather and atmospheric conditions, can be toxic as well as a fire hazard, with water interaction potentially playing a role either in managing or exacerbating vapor release.

Ammonia is corrosive and toxic, but not carcinogenic, with its odor serving as an early exposure warning. Exposure symptoms range from headaches to severe respiratory issues, and exposure limits have been established for workplace safety. Ammonia hazard mitigation involves engineering controls such as ventilation, administrative measures like training, and personal protective equipment, including National Institute of Occupational Safety and Health (NIOSH)-approved respirators. Emergency responses to ammonia exposure include flushing affected areas with water, seeking medical attention, and using CO₂ for fires (not spraying water directly on flames). For containment breaches, evacuation and isolation are necessary until safety can be assured. Safe storage practices include using double-walled tanks, engineering to avoid corrosion or pressure issues, and routine maintenance to prevent leaks or failures.

Ammonia has well-established applications in agriculture, refrigeration, and food processing and is commonly transported via pipeline and ships. Ammonia incidents largely involve uncontrolled releases due to human error and/or equipment failures. To minimize risks, organizations must implement proper training, establish and adhere to safety procedures, and maintain equipment regularly. Best practices include alarm management, proper communication, configuration management, robust emergency response plans, regular monitoring/maintenance, compliance with regulations, risk assessment, layers of safety controls, promoting a strong organizational safety culture, and collaboration and information sharing.



The use of ammonia as a fuel for process heating or maritime transportation holds promise as a low-carbon solution to reduce greenhouse gas emissions for these difficult-to-decarbonize applications. However, robust safety knowledge for these applications has not yet been established. Safety considerations from established applications can be extrapolated, but formal risk assessments and mitigating strategies are needed for these emerging applications. The potential of ammonia as a carbon-free fuel for industrial process heating faces hurdles due to a lack of codes and standards governing its combustion – a consequence of its limited use in machinery like gas turbines and boilers. The development path of hydrogen as an alternative energy carrier may provide insights for a safety-focused regulatory approach and practical tests to ensure ammonia's safe and efficient use in new applications.

As a maritime fuel, risks to vessel crews and the public at large are exacerbated by the large volume of liquid ammonia that would need to be stored/bunkered as well as the “confined space” nature of onboard fuel dispensing and storage in a maritime platform. On the other hand, safety guidance is more developed for ammonia-fueled maritime transport, largely owing to decades of industry experience handling ammonia as cargo, but the relative lack of real-world experience with ammonia-fueled vessels has limited its applicability to date. Existing regulations for ammonia as a maritime fuel can be organized into five categories: active ammonia-specific guidelines, codes in development, cross-applicable regulations, potential models from other fuel codes, and areas lacking ammonia inclusion. Classification societies have issued detailed rules that comply with International Maritime Organization (IMO) standards for the design, operation, and safety of ammonia-powered ships. These cover material use in cold conditions, training, and operational safety. Cross-applicable and other fuel standards offer a base for new ammonia regulations. However, gaps in current IMO maritime laws highlight the need for updates or new rules to fully embrace ammonia as a maritime fuel, emphasizing the ongoing evolution of safety and regulatory frameworks for its broader adoption.

Reactive nitrogen species, including ammonia and its derivatives, have accumulated in the environment due to human activities, cycling through the ecosystem in a process known as the nitrogen cascade until removal via denitrification. The introduction of reactive nitrogen, partly from ammonia-based fertilizers, into the environment poses ecological challenges, potentially worsened by ammonia's use as a low-carbon fuel without adequate precautions.

Ammonia production varies in carbon emissions, with modern methods emitting considerable CO₂. A large portion of emissions from ammonia production are from synthesis of hydrogen – a feedstock that is combined with atmospheric nitrogen to yield ammonia. Ammonia production decarbonization efforts include hydrogen production through steam methane reforming with carbon capture and storage (CCS) or electrolysis powered by renewable energy. Ammonia combustion produces NO_x, contributing to air pollution and ozone formation. Ammonia emissions degrade air quality by forming secondary particulate matter, which is associated with a number of adverse health outcomes. Green ammonia production can strain water resources and pollute waterways, impacting ecosystems and the nitrogen cycle. The demand for renewable energy for ammonia production could also increase land use. However, emission control and containment strategies can lessen some of these environmental impacts.

One study was identified which highlights the environmental impacts of using ammonia with methane for industrial heating, suggesting that emission controls, renewable energy, and efficient synthesis could mitigate these effects. Further research is needed to refine these conclusions. As a maritime fuel, ammonia offers benefits like easy storage and use in engines and fuel cells, with existing infrastructure supporting its adoption. It can lower pollutant emissions compared to conventional fuels, but issues including NO_x emissions and ammonia leaks from engines or during fuel transfer must be managed through effective combustion controls and safety measures.



In conclusion, ammonia emerges as a promising and versatile alternative energy carrier in the shift towards a low-carbon economy, underpinned by vast existing experience in its synthesis, storage, and transport. However, its safe and effective deployment across new sectors necessitates thorough risk assessments, safety measures, and the establishment and adherence to specific industry standards to mitigate health and environmental hazards. This calls for filling application-specific research gaps, leveraging lessons from existing ammonia applications, and fostering a robust safety culture. Simultaneously, there is a pressing need for developing and adapting codes and standards tailored to ammonia's unique challenges, alongside conducting targeted research, practical trials, and legislative updates to ensure its seamless integration. Additionally, understanding the environmental impacts of novel ammonia uses is crucial to align with global sustainability objectives, requiring meticulous attention to minimizing ecological damage, and addressing concerns like water scarcity, land use, and disruptions to the nitrogen cycle.



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