LCRI LOW-CARBON RESOURCES INITIATIVE

EPRI GTI ENERGY

EXECUTIVE SUMMARY

STATE-OF-THE-TECHNOLOGY REPORT: AMMONIA DELIVERY AND STORAGE

Ammonia is a widely used commodity with over 120 years of knowledge base for production, storage, materials, handling, safety, delivery, and distribution. On a global scale, NH_3 production is estimated at 180 million tonnes for 2021. The current primary use of ammonia, which accounts for about 80% of the global supply, is fertilizer production for the agricultural industry. Other industrial applications are as a refrigerant and feedstock for the manufacture of explosives, plastics, textiles, and other chemicals. In recent years, ammonia has been proposed as an alternative non-carbon energy storage medium, an energy carrier, or a fuel for various applications, including electric power generation. The goal of the current study was to establish an updated knowledge base, identify technical gaps, and suggest necessary research for considering ammonia as an alternative energy carrier. Within this context, this report provides an overview of the current technologies used for delivering and storing ammonia, including large-scale surface storage tanks; refrigerated, semi-refrigerated, and pressurized systems; and underground caverns. Novel technologies, such as solid storage media, are also discussed. For delivery methods, the report provides an overview of the state of rail, pipeline, marine transport, and road vehicles. Potential technology gap areas are brought forth, as ammonia is considered a part of a decarbonization strategy.

Key findings highlighted from the full report include:

- **Storage materials**: NH_3-induced stress corrosion cracking (SCC) is a concern for carbon and low alloy steels used in ammonia storage and delivery applications. Although preventive measures for mitigating the effects of SCC are known, the mechanisms for its occurrence need further definition.
- **Cavern storage**: Hard rock caverns have been successfully used for large-scale NH_3 storage, albeit only at a few sites. A complete mapping and identification of geologic storage sites are needed, near proposed ammonia production facilities, to determine the potential capacity for underground storage.
- **Solid-state storage**: Storage of NH_3 in solid materials via sorption and desorption mechanisms is an active research area. Novel materials, such as metal halide amines, enable the attachment of NH_3 to metal ions through thermal changes. These and other engineered compounds can be compacted into a dense material with very close volumetric content as that of liquid NH_3. Some safety advantages may be realized by this approach when compared to liquified ammonia storage. Further developments in material design and chemical composition of the sorbents are needed to advance this storage method.
- **Pipelines**: Major challenges include right-of-way attainment, location of the NH_3 production sites with respect to distribution hubs, and implementation time from design to operation. A better understanding of regional pipeline economics and lessons learned is needed.
- **Maritime fuel**: Adoption of NH_3 as a maritime fuel is under way. In its latest session, the International Maritime Organization adopted new regulations with a goal of 40% carbon intensity reductions from 2008 levels by the year 2030. The regulatory framework to allow ammonia as a maritime fuel is a complex area that is monitored by multiple agencies actively working toward a consensus for implementation.
- **Barge transport**: NH_3 transport by barge in the United States is limited and would require renewal of the existing aging fleet and expansion with more transport capacity. After decades of idle barge constructions, the newest NH_3 tanker barge was placed into service in 2017. An assessment is needed of the current barge fleet and potential for growth along existing and new potential waterways.

- **Hybrid LNG/NH_3 infrastructure**: Another area of interest is the repurposing or redesign of existing liquified natural gas (LNG) infrastructure, which includes large storage tanks and importing liquefaction terminals, for NH_3 utilization. Modifications and retrofits to facilitate a hybrid system for LNG and NH_3 storage and distribution could provide a short-term pathway to integrate wider NH_3 deployment.
- **Larger import/export terminals**: These sites will need to be modified to accommodate larger gas vessel classes than those currently in use. These modifications include loading and unloading tank storage capacity along with corresponding economic pump flow rates.
- **Rail transport**: The adoption of alternative locomotive designs, such as electric-powered locomotives and new NH_3 fueled locomotives, is slowly increasing. Electric locomotive engines are in service in some parts of the world and are being investigated in the United States to serve specific areas. However, the adoption of electric locomotives also has some barriers derived from private rail ownership. With respect to direct fuel replacement, efforts are under way to demonstrate new NH_3-fueled locomotives.
- **Public perception**: Because NH_3 is a toxic chemical, safety, environmental, and economic factors will need to be considered in the development of any expanded delivery and storage network. Therefore, an effective plan for wide scalability of an ammonia-based economy should include public education, safety training, and risk-based policymaking.
- **Accidental release countermeasures**: Development of countermeasures to mitigate the risk of permanent injury or death from an NH_3 exposure event is needed. Existing countermeasures, including water curtain systems, have been implemented as part of risk-mitigation plans at NH_3 sites. However, these systems have limited containment efficiency. A more robust hazard analysis study needs to be conducted for the development of containment measures if NH_3 is used on a wider scale.

From a regulatory perspective, occupational safety, public security, transportation, and environmental protection codes and standards (C&S) are in place for current NH_3 applications. However, there is a need for consistency across these C&S and for adoption to new applications. Further coordination and research should be conducted to clarify existing exposure limits to avoid long-lasting health effects.

The Low-Carbon Resources Initiative

This report was published under the Low-Carbon Resources Initiative (LCRI), a joint effort of EPRI and GTI Energy addressing the need to accelerate development and deployment of low- and zero-carbon energy technologies. The LCRI is targeting advances in the production, distribution, and application of low-carbon energy carriers and the cross-cutting technologies that enable their integration at scale. These energy carriers, which include hydrogen, ammonia, synthetic fuels, and biofuels, are needed to enable affordable pathways to economy-wide decarbonization by mid-century. For more information, visit www.LowCarbonLCRI.com.

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