Manufacturing Ammonia: Facts, Impacts, and Pathways

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Ammonia is a bulk chemical that shapes the food system, land-use decisions, and the environment we live in. A compound of nitrogen and hydrogen (NH_3), ammonia is used by farmers to fertilize crops and boost yields, which helps keep food affordable and accessible for the entire country. Unfortunately, the benefits of ammonia to our agricultural system can come at a steep cost. Fertilizer runoff can be highly damaging to aquatic ecosystems, exposure to just 300 parts per million of ammonia in the air can cause severe respiratory distress and harm, and the actual production of ammonia, utilizing the Haber-Bosch process, requires a significant amount of energy. Today, most ammonia production is more emissions- and energy-intensive per ton produced than steel and cement.

- **The global production and use of ammonia emits 620 million metric tons of CO_2 annually** (IEA 2021). Of those emissions, U.S. production of ammonia accounts for 57 million metric tons of CO_2.
- **In 2022, 88% of U.S. ammonia production was used for nitrogen-based fertilizer** (U.S. Geological Survey 2023). Ammonia is also used to produce ammonium nitrate for explosives, is an industrial solvent used to manufacture acrylic, nylon, and rayon fibers, and is incorporated into other plastic supply chains.
- **Ammonia production globally is on track to increase a projected 40% by 2050** (IEA 2021). This growth is driven by agriculture sector demands and increasing interest in ammonia as a fuel. Ammonia is one of two major options, with methanol as the other, to use as a low-carbon fuel to power large container ships.
- **When excess fertilizer is added to the soil or washes off into water bodies, nitrous oxide (N_2O) is released into the atmosphere. N_2O's global warming potential is 265 times more potent than CO_2** (Xu et al. 2024). Despite the energy-intensive production of ammonia, an estimated half of ammonia's total life cycle greenhouse gas (GHG) emissions occur following application to agricultural fields and the release of N_2O—essentially wasted energy and investment for farmers.

Ammonia is created by reacting nitrogen pulled from the air with hydrogen using the Haber-Bosch process. Most ammonia producers create the hydrogen they need by steam methane reforming (SMR) natural gas, which can release significant emissions (Figure 1). For that reason, the most promising strategies to reduce ammonia feedstock and manufacturing emissions can be grouped into two main categories: green hydrogen and blue hydrogen (which lead to "green ammonia" and "blue ammonia").

- **Green hydrogen (H2)** relies on clean electricity to power an electrolyzer to create hydrogen from water. This hydrogen can then be converted into ammonia, which results in a near-zero emission production process. In addition to its emissions benefits, this production method is not reliant on existing fossil fuel infrastructure, so it carries the potential to build a more distributed production system built on proximity to end uses (e.g., producing ammonia on or near farms). While green hydrogen relies on mature technologies with many commercial scale demonstrations, the cost remains five to seven times higher than fossil fuel-derived hydrogen (Department of Energy (DOE) 2024).

- **Blue hydrogen** uses carbon capture with either traditional SMR or autothermal reforming (ATR)[1] to reduce emissions compared to traditional production by over 90%. Carbon capture, however, does not always perform to expected efficiency levels, and these methods are sensitive to methane emissions upstream in the natural gas extraction and processing phases. The cost of blue hydrogen is currently more than twice that of traditional fossil fuel-derived hydrogen without carbon capture (DOE 2024).

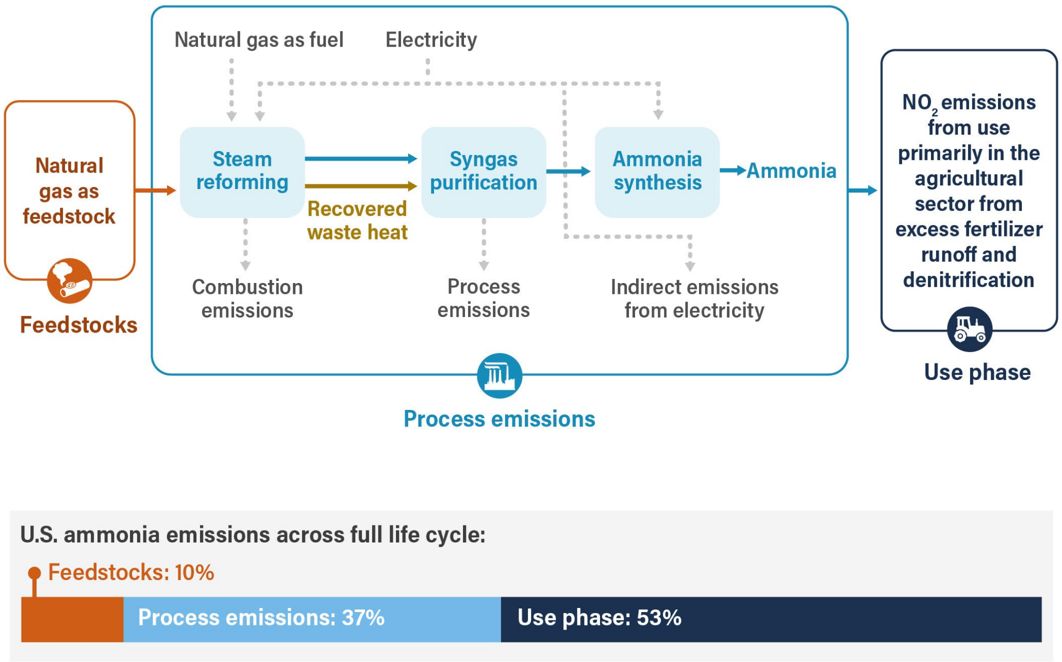

Figure adapted from: Banafsheh Jabarivelisdeh, Enze Jin, Phillip Christopher, Eric Masanet. July 2024. "Achieving net-zero U.S. ammonia: Technology and policy options and their emissions, investment, and cost tradeoffs". https://www.sciencedirect.com/science/article/abs/pii/S0959652624025939?via%3Dihub

Figure 1. U.S. ammonia emissions across feedstock, process, and use phases.

Geography of Ammonia Production

Four states produce two-thirds of all domestic ammonia. Louisiana is the leading producer, followed by Iowa, Oklahoma, and Texas. The location of these ammonia facilities is driven in large part by access to low-cost natural gas to produce the required hydrogen. The largest ammonia producer in the U.S. is CF Industries Holdings, Inc., with facilities in Louisiana, Mississippi, Iowa, and Oklahoma. The company is working to cut production energy emissions intensity by 25% by 2030, and reduce Scope III emissions 10% by 2030, by reducing natural gas processing emissions. For that reason, CF Industries is piloting a green ammonia[2] unit in their Donaldson, LA facility, which can produce 20,000 tons of green ammonia per year (<1% of annual ammonia production capacity at this location) in addition to several announced blue hydrogen projects, including one at their Blue Point Complex facility in Ascension Parish, LA.

[1] Autothermal reforming is potentially more energy efficient than SMR but also a more complex technology.
[2] Green ammonia is a lower-carbon ammonia production strategy reliant on green hydrogen.

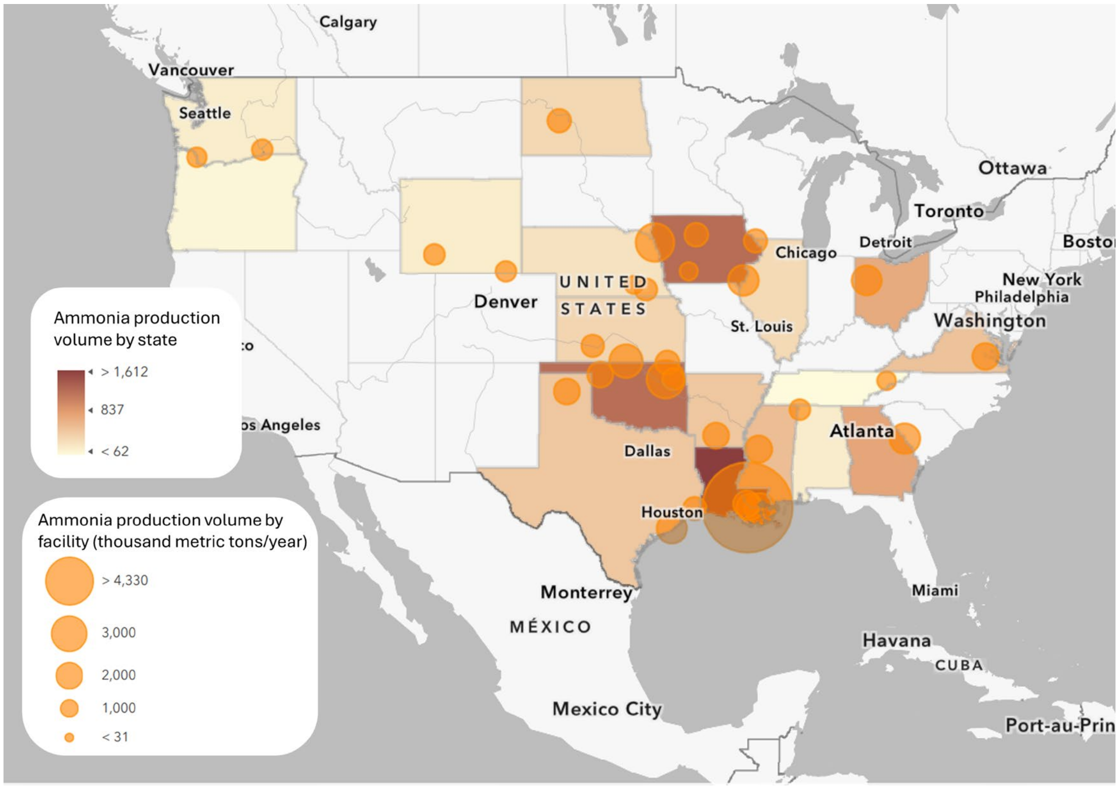

Figure 2. Map of ammonia production in the U.S. Production volume units in thousand metric tons/year. Data Source: USGS 2022.

Equity and Environmental Justice Impacts of Ammonia Production

Ammonia production today contributes to equity and environmental justice burdens. Production facilities emit air pollution and release nitrogen-contaminated wastewater into local waterways (Xu et al. 2024). Over-application of ammonia-based fertilizer to agricultural fields leads to excess nitrogen run-off into ground or surface-water, reducing drinking water quality and damaging aquatic ecosystems. Global price instability of fertilizer also contributes to farmer economic stress; in 2022, fertilizer was close to 25% of total costs for corn production in the U.S. (U.S. Department of Agriculture (USDA) Economic Research Service 2024).

- Ammonia production facilities contributed 7.7 million pounds of nitrogen pollution to U.S. waterways in 2021 and thousands of pounds of smog-contributing air pollutants (Gibbons et al. 2023). Many of these facilities are located in communities with a legacy of elevated environmental pollution burdens, and community residents have been resistant to expanding facility footprints (Brook 2024).
- Green ammonia can be produced at smaller scale and without the need for combusting fossil fuels, helping to distribute economic benefits to smaller businesses, including farms (Kirk et al. 2024). For example, a state granting program is being developed in Minnesota to support

agricultural or electrical cooperatives in setting up green ammonia producing facilities in the state (MDA 2025).

Technological Pathways: Challenges and Opportunities

Challenge: Low-carbon hydrogen is essential to reduce embodied carbon within ammonia production but is not yet at cost-parity with legacy hydrogen.

The majority of carbon emitted during ammonia production is from the steam reforming of natural gas to create hydrogen. Strategies to support alternative and lower-emission production methods are needed to narrow the cost gap between these newer technologies and legacy steam reforming production. In addition, developing non-fossil-based supply chains to produce ammonia can help buffer the price of fertilizer against variability in fossil fuel prices and global supply chain disruptions, reducing economic stress for U.S. farmers (USDA 2023).

- There is a continued need to support the high capital expenditures of first movers ready to invest in low-carbon ammonia production at scale. Federal programs, like the DOE's Loan Program Office funds, are supporting an innovative new methane pyrolysis facility in Nebraska to produce ammonia for fertilizers (Iaconangelo 2022). Additional appropriations through the USDA and DOE to make similar investments, particularly in major crop-producing states, could accelerate the deployment of these new, lower-emission technologies.
- Market and tax policy tools can help to close price gaps between legacy and low-carbon products, which can be set up at a national or state/regional level. For example, clean contracts for differences (CCfDs), indexed to the price of green hydrogen, can help to address the price disparity between conventionally produced ammonia and low-carbon ammonia, for use in the agricultural sector and as a fuel for long-distance shipping. This financial tool is being deployed to support growing clean energy markets internationally (IEA 2023), but it is a new tool in the context of U.S. state and federal policy that could be explored as an alternative to other support mechanisms like tax credits.
- Targeted grant programs can help to de-risk and incentivize the buildout of a more distributed green fertilizer industry, with the added benefit of helping smaller farmers buffer themselves against fertilizer price uncertainties (Tonelli et al. 2024). Existing programs, like the USDA's Fertilizer Production Expansion Program should also be evaluated for how they can better target fertilizer producers that use low-carbon ammonia.

Challenge: Inefficient fertilizer application is responsible for significant GHG emissions from ammonia but will require a wide range of strategies to mitigate effectively.

The majority of emissions from ammonia occur within the agricultural sector, when ammonia-based fertilizers are applied to fields. Optimizing application techniques and quantities can maintain crop yield while reducing the total demand for ammonia and reducing nitrogen lost to the atmosphere in the form of N_2O.

- Precision agriculture techniques such as GPS-enabled soil and yield mapping, variable rate application technologies, or automated equipment guidance systems can all enable more efficient application of fertilizer without a decrease in crop yields. For example, variable rate application technologies, which use sensors or maps to vary the rate of fertilizer inputs across fields dependent on crop and soil conditions, have been able to cut ammonia-based fertilizer use by over a third (Cilento 2022).

- Alternative non-ammonia-based fertilizers like PivotBio's microbial nitrogen, for example, can replace some portion of the demand for ammonia-based fertilizers. Microbial nitrogen fertilizers are a biological alternative to ammonia-based fertilizers and use nitrogen-fixing microbes to enhance plant uptake of available soil nitrogen; this strategy can reduce ammonia-based fertilizer application needs by up to 25% (Temple 2024).
- New smart agriculture approaches seek to limit nitrification (the formation of the potent GHG, N_2O, when excess nitrogen-based fertilizer is added to agricultural systems) by timing fertilizer application to better coincide with crop needs, changing crop rotation or tilling patterns, directly modifying nitrifier microbial communities in soils, and deploying other organic practices that avoid the use of synthetic fertilizers. The effectiveness of these techniques will vary dramatically based on substrate, climate, microbial community, and crop (Gao and Serrenho 2023), and localized technical assistance will be key to developing optimal strategies.

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