Low-carbon ammonia for fertilizer production

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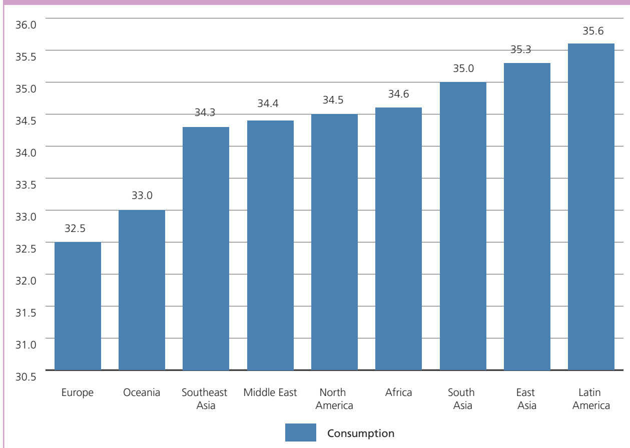
Introduction

Ammonia is one of the most broadly used chemical compounds, with a global annual production volume of over 190 million tonnes (2019–2023 average), out of which approximately 18.5 million tonnes are traded. Ammonia is the basic raw material from which all nitrogen-based fertilizers are derived. Manufacturing ammonia is a highly energy-intensive Haber-Bosch process, whereby atmospheric nitrogen reacts with fossil fuel material (natural gas or coal), also known as feedstock.

Ammonia plants require around 32–36 million British thermal units (mmBtu) of natural gas to produce 1 tonne of ammonia. For this reason, ammonia plants are typically located near a source of natural gas (such as in the Near East, the Russian Federation, Trinidad and Tobago, Algeria, and Egypt), although imported liquefied natural gas (LNG) is increasingly being used in India. China also has some capacity to produce ammonia from coal instead of natural gas.

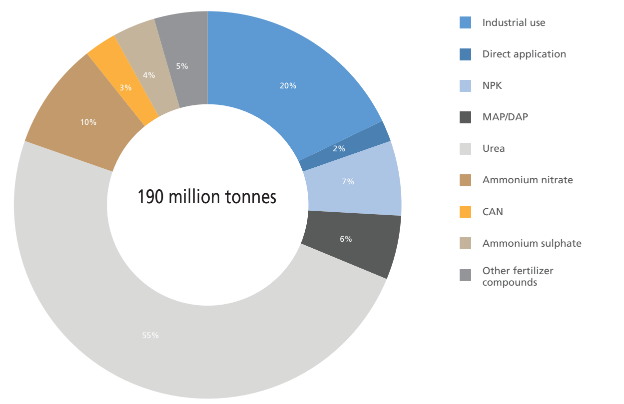
According to the International Energy Agency (IEA), ammonia production accounts for around 2.0 percent of total final energy consumption and 1.3 percent of carbon dioxide (CO_2) emissions from the energy system. Natural gas-based ammonia plants use a steam reforming process, while coal-based plants use partial oxidation or coal gasification.

Figure 2.8. Regional gas consumption for natural gas-based ammonia, production 2022



Source: AEA (Ammonia Energy Association). 2023. The climate and environmental impacts of ammonia: Upstream hydrogen emissions. Atlanta, USA, AEA. https://ammoniaenergy.org/presentations/the-climate-and-environmental-impacts-of-ammonia-upstream-hydrogen-emissions/

Figure 2.9. Global ammonia demand by use

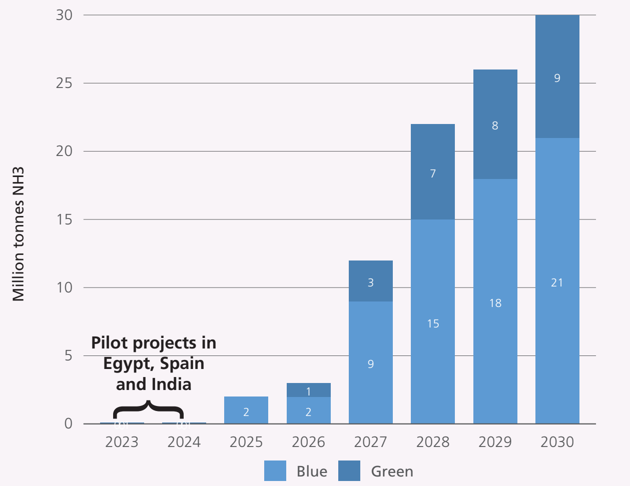


Source: IFA (International Fertilizer Association). 2022. Reducing Emissions from Fertilizer Use. Paris, IFA. https://member.fertilizer.org/Public/Stewardship/Publication_Detail.aspx?SEQN=6203&PUBKEY=E205C2E0-8E5C-477D-8604-6CC16A9D3B98

CO_2 emissions from ammonia production vary by region and are directly linked to the energy efficiency of ammonia plants, which is often determined by the age of the plant. Plants located in Latin America and Asia generate the most emissions, with an average of 35.6 mmBtu, due to their higher energy consumption. Plants located in Europe boast the highest energy efficiency, requiring on average 32.5 mmBtu of natural gas to produce 1 tonne of ammonia.

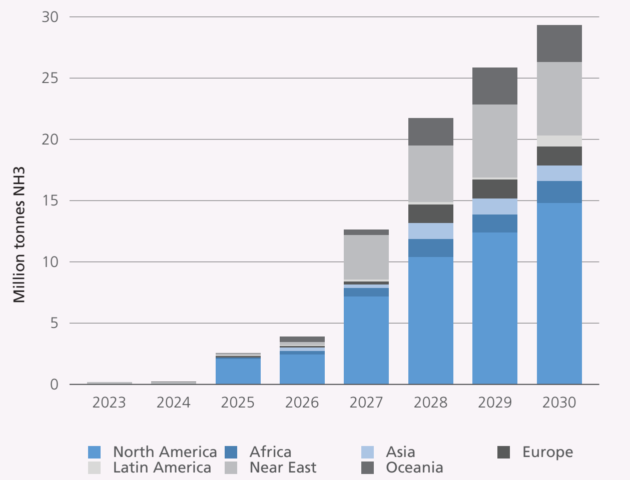
Some 80.0 percent of the world's ammonia supply, or 152 million tonnes, is further processed into fertilizers. Additionally, ammonia can be used directly as a nitrogen fertilizer, and this type of use accounts for 2.0 percent of total global demand. In this case, ammonia is directly injected into soils, a practice most used in the United States of America and Mexico for cereal production. Australia also uses ammonia for direct application but at a much smaller scale, limited to just 25 000 tonnes per year. This use of ammonia is limited to these countries because they have existing infrastructure to cool and store ammonia and because they more often use mechanized and precision agriculture with tractor-drawn knives and shanks to place ammonia in the correct location 10–20 cm underground.

Figure 2.10. Low-carbon supply outlook by CO_2 footprint



Source: Author's own elaboration based on project announcements to 2030

Figure 2.11. Low-carbon amnonia capacity outlook by region



Source: Author's own elaboration based on project announcements to 2030

Low-carbon ammonia

When produced using renewable energy such as solar, wind, or hydro, ammonia is a carbon-free product, enabling decarbonization of various sectors, including agriculture.

Decarbonizing ammonia means reducing the carbon intensity of the hydrogen used in the ammonia-synthesis process. In the framework of decarbonization policies, ammonia is classified according to its carbon intensity as follows:

- Grey ammonia is the conventional ammonia produced from hydrocarbons (natural gas or coal) with CO_2 emissions generated without carbon capture.
- Blue ammonia is identical to grey ammonia, but the CO_2 emissions generated are captured or stored. Blue ammonia is already being produced with carbon-capture storage, mostly in the United States and some countries in the Near East.
- Green ammonia is produced via electrolysis/hydrolysis using renewable electricity and water, without CO_2 emissions since it is essentially a zero-carbon compound. Green ammonia is being trialed as a carbon-neutral source of nitrogen and can be used in the downstream production of fertilizer.

By 2030, production of 21 million tonnes of blue ammonia and of up to 9 million tonnes of green ammonia could come on-stream, provided the announced projects materialize on-time. These capacities would add approximately 30 million tonnes of low-carbon ammonia to the already existing conventional grey ammonia supply of 190 million tonnes. However, the International Fertilizer Association forecasts the capacity of green ammonia to be only 3.4 million tonnes by 2028. Much larger volumes of green ammonia capacity are expected to be commissioned beyond the next five years, as projects develop through final investment decisions.

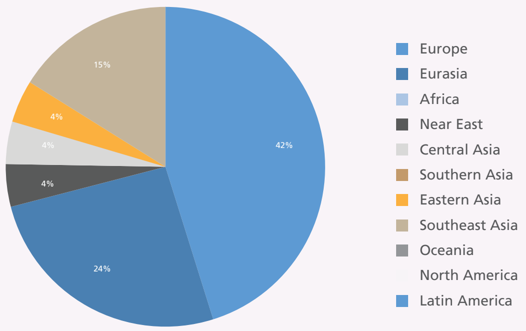
A constraint to producing low-carbon ammonia includes the high investment costs of converting from the conventional production of grey ammonia to green ammonia. Regulatory frameworks and government incentives can play an essential role.

The United States is expected to dominate blue ammonia supply within this decade, primarily due to the provision of carbon sequestration credits under the Inflation Reduction Act and favourable natural gas endowments. Europe also has a high potential for expanding production of both blue and green ammonia due to a supportive regulatory environment and an established and mature emissions trading scheme. For green ammonia, European projects are limited in location to Southern Europe (solar), the North Sea (wind) or countries with renewable grid power (Norway).

Government-to-government partnerships for low-carbon ammonia projects also exists; Australia, Japan, and the Republic of Korea are taking the lead in advancing bilateral agreements, mostly focused on power generation and marine fuels. Countries with significant regulatory support for low-carbon ammonia projects also include Brazil, Canada, Chile, the European Union and the United States.

Blue ammonia capacity growth is dependent on the available carbon sequestration solutions. These solutions

Figure 2.12. AN/CAN yearly production share by region, 2019–2023



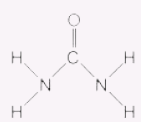
IHS (IHS Markit). 2021. Green and Blue Ammonia: Outlook for Carbon-Free Ammonia Market. London, IHS.https://cdn.ihsmarkit.com/www/pdf/0921/IHS-Markit-Green-Ammonia-Strategic-Study-Brochure-June-2021.pdf

can be nature-based, such as reforestation and soil-carbon sequestration, or technology-based, such as carbon-capture utilization and storage. Carbon-capture storage includes injection underground, and utilization includes conversion into solid carbon or production of nanofibers. Blue ammonia, as a steppingstone in the transition to green ammonia, is unlikely to have a significant impact on agriculture. Green ammonia, on the other hand, has a higher propensity to impact agriculture and food production.

The cost of manufacturing low-carbon ammonia is significantly more elevated than conventional ammonia, and this higher cost will be reflected in the pricing of low-carbon ammonia. Preliminary contractual discussions suggest premiums of up to USD 300 for blue ammonia, and a first official government agreement[1] in July 2024 prices green ammonia at EUR 1 000/tonne.

Fertilizers

Low-carbon ammonia creates the opportunity of producing low-carbon nitrogenous fertilizers and subsequently reducing CO_2 emissions in the agricultural sector. Green ammonia itself could be directly applied as nitrogen fertilizer in those regions where direct application of conventional ammonia is customary. However, ammonia carries substantial handling and storage costs in addition to the already higher costs of producing green ammonia, and therefore it is difficult



to believe that farmers will opt to use this product over conventional readily available grey ammonia.

Urea is the most commoditized and widespread nitrogenous fertilizer with a globally traded market of 55 million tonnes/year. It is not a readily suitable candidate for decarbonization via low-carbon ammonia feedstock. Urea poses a different challenge, as it inherently contains carbon at a molecular level, due to its manufacturing process that requires ammonia to react with CO_2 at 200°°C. As such, while producing urea with low-carbon ammonia would lower the product's carbon intensity, it could never be zero due to the inherent molecular carbon that then reacts and emits CO_2 when applied to soils.

Nitrates, namely ammonium nitrate (AN) and calcium ammonium nitrate (CAN), are suitable for producing low-carbon fertilizer. Ammonium nitrate and calcium ammonium nitrate production is often integrated with ammonia production, occurring in-situ in the same industrial complexes, meaning that the nitric acid and nitrates units could be based on green ammonia and the same renewable power source used to produce it.

Global production of AN and CAN amounts to 45 million tonnes/year and uses 13.0 percent of the global ammonia supply. Production is heavily concentrated in Europe, the Russian Federation and Central Asia, where 66.0 percent of production happens. Therefore, the production and consumption of low-carbon nitrates would be most prevalent in Europe and Eurasia, making low-carbon ammonia a regional rather than global solution to decarbonizing fertilizer use in agriculture. Trials of nitrates produced with green ammonia have already taken place in Spain and the Kingdom of the Netherlands in 2022–2023.

Ammoniated phosphates, namely DAP and MAP, are also viable candidates for decarbonization via the use of green ammonia in production streams. Morocco and Saudi Arabia are both top phosphates producers, accounting for 11.9 million tonnes of global DAP and MAP supply and 6.0 percent of the world's ammonia use. These two countries have announced green ammonia projects totaling 2.4 million tonnes by 2030, making possible the prospect of DAP and MAP produced with lower carbon intensity ammonia.

In conclusion, there is scope for decarbonization of fertilizers by means of green ammonia as feedstock, with up to 3.4 million tonnes of directly applied ammonia, 45 million tonnes of nitrates and 11.9 million tonnes of phosphates viable to switch to production by means of green ammonia. However, while existing data and project announcements paint a picture on a

[1] The German Government entered an agreement to purchase 259 000 tonnes of green ammonia between 2027 and 2030 from a United Arab Emirates supplier at a price of EUR 1 000 per tonne (Alkousaa, 2024).

prospective supply of green ammonia through 2030 and beyond, the demand prospects are unclear and are likely to lag behind supply. Actors along the agricultural supply chain (farmers, food processors, retailers) need to be willing to bear the cost and pay the premium pricing needed to make green nitrogenous fertilizers economically viable and profitable.

Beyond the use as feedstock for fertilizer production, another role of low-carbon ammonia in agrifood systems would be decarbonizing supply chains by facilitating low CO_2 emissions in transportation, as marine fuel. To date, favourable governmental policies target production of low-carbon ammonia with a focus on marine fuels and power generation, with no known regulatory framework focused specifically on agricultural applications.

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