DISCUSSION STARTER

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Decarbonizing nitrogen fertilizer

Push and pull incentives in scaling green ammonia

Nicole Rocque, Senni Alho, Annebelle Rombach, Leanne Zeppenfeldt

Introduction

Nitrogen (N) fertilizers are indispensable to global food production. However, they come with dire environmental costs. Ammonia production, the form of nitrogen fundamental to most synthetic fertilizers, is highly energy and emissions-intensive. While ammonia has various industrial applications, its demand is largely driven by the fertilizer industry, with more than 85% currently attributed to this sector (Van Duc Long et al., 2022). With around 150 million tonnes (t) of ammonia produced annually (2023), production is responsible for around 1.8% of global greenhouse gas (GHG) emissions and 2% of global annual energy consumption (Lee et al., 2022; Smart, 2022; IEA, 2023).

N fertilizers are also a major contributor of non-carbon dioxide GHG emissions, with two-thirds of fertilizer emissions taking place after application on croplands (Gao & Serrenho, 2023); excess nitrate, converted from ammonia, causes soil acidification and leaches into fresh- and groundwater bodies to cause europhication, while nitrous oxide (N_2O) escapes into the atmosphere with a global warming potential 298 times greater than that of carbon dioxide (Ouikhalfan et al., 2022). N_2O has been estimated to account for about one-third of 'farmgate' greenhouse gas emissions (Tubiello et al., 2021).

Expansion of green ammonia technology

As long as agriculture remains dependent on fossil sources of energy, food prices will continue to mirror energy prices and food production will remain a significant contributor to anthropogenic GHG emissions. There is now broad political consensus that global emissions from nitrogen in agriculture should be reduced by about 50%, as stated in high-level policy targets of the EU and of the UN Convention on Biological Diversity. Various approaches ranging from efficient fertilizer management to ending fertilizer use altogether are being explored.

Alongside global decarbonisation targets, ammonia production is becoming a key area for action. This is because ammonia is most conventionally (over 90%) produced using the energy-intensive and fossil-fuel reliant Haber-Bosch (H-B) process, which reacts atmospheric Nitrogen (N_2) with Hydrogen (H_2) from steam methane reforming (SMR) (Osorio-Tejada et al., 2022; Parkinson et al., 2018). Shifting to less intensive carbon production systems and lower energy consuming technologies has the potential to reduce GHG emissions and energy consumption drastically (Ouikhalfan et al., 2022). This can be achieved by integrating renewable energy as well as implementing innovative technologies

Figure 1: Global emissions from ammonia production: Around 30-40% of emissions originate from the production of ammonia, and 60-70% originate from the use of ammonia-based fertilizer.

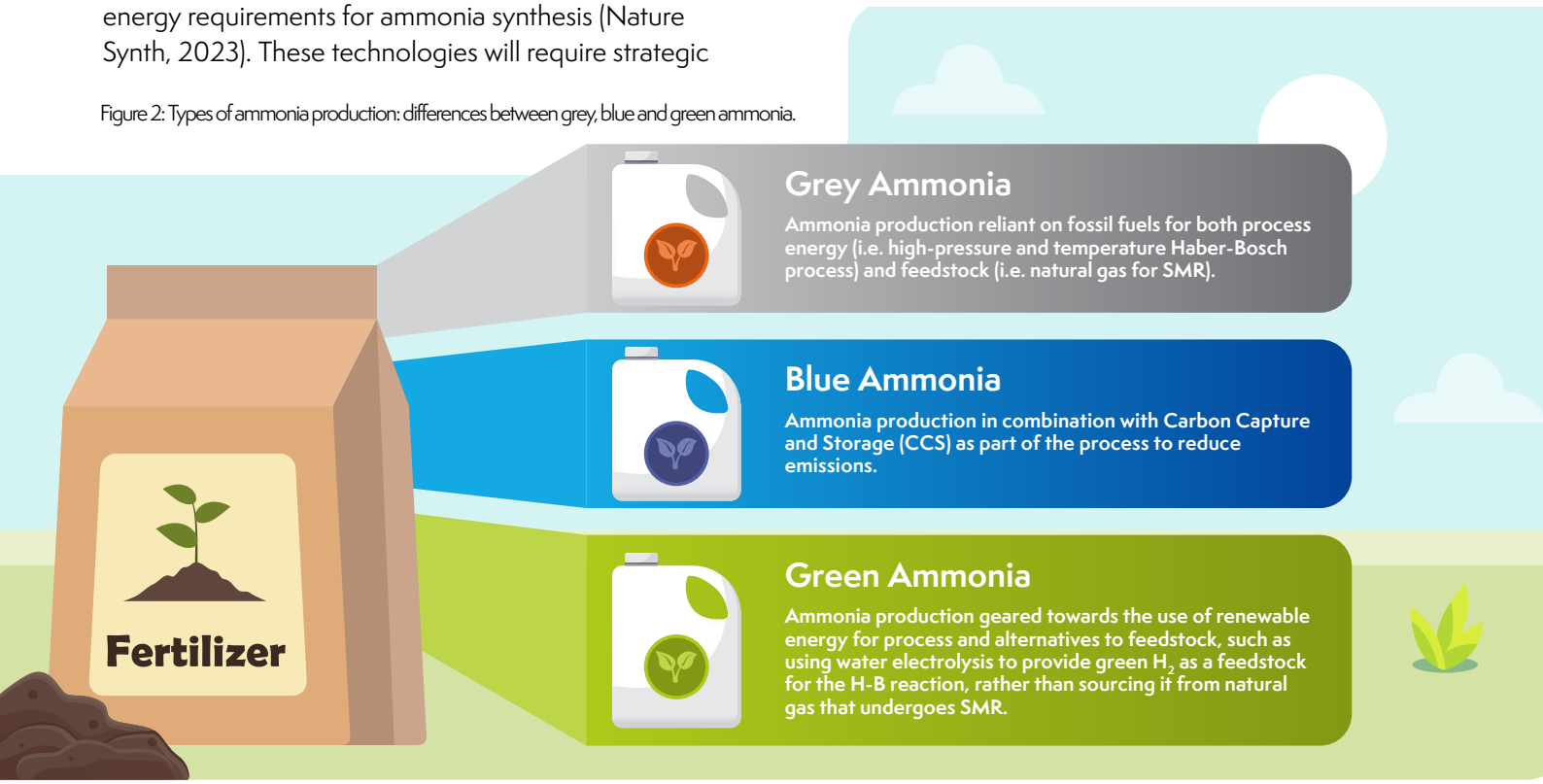
that allow for more sustainable feedstocks and improve energy efficiency.

This current H-B production method, also termed "grey ammonia", is reliant on fossil fuels for both process energy and feedstock, i.e. natural gas for SMR. Various new technologies are emerging in an attempt to decarbonize ammonia production, including "blue ammonia" and "green ammonia". Blue ammonia refers to the implementation of Carbon Capture and Storage (CCS) as part of the process, proving to be a short-term solution to reducing immediate carbon dioxide emissions from grey ammonia production. Green ammonia can be produced with a range of technologies such as electrified and renewable-powered H-B production methods, and using water electrolysis to provide green H_2 as a feedstock rather than sourcing it from natural gas that undergoes SMR. This could significantly decarbonize ammonia production with minimal disruptions to the supply chain, post-hydrogen production, in existing large-scale applications. Projections suggest that this technology could achieve an 80% reduction in direct emissions (Gao Y et al., 2023). Beyond its use in fertilizers, green ammonia is also raising interests for direct applications as maritime fuel and indirect use as a hydrogen carrier.

To achieve full carbon neutrality as well as options for smaller-scale decentralized ammonia production, innovators are looking beyond the conventional Haber-Bosch process, due to its inherent high temperature and pressure requirements. Electro- and photocatalytic reduction of nitrogen into ammonia are gaining traction for their potential to significantly reduce energy requirements for ammonia synthesis (Nature Synth, 2023). These technologies will require strategic investments and purpose-specific R&D grants for further development and testing. In addition to decarbonising production, it is also important to consider farm management practices that improve N-use efficiency. This may, for example, include legume-based systems that allow for biological nitrogen fixation, directly supporting plant growth with lower N_2O emissions in comparison to synthetic N-fertilization. Other cultivation methods that support the capture and storage of carbon dioxide in farmlands will not only help to increase soil organic carbon and thereby raise fertility, but also contribute to a net-zero future.

Higher prices of grey ammonia production and overall lower fertilizer affordability provides a stimulus for low-carbon ammonia production. The optimal locations for green ammonia manufacturing combine access to large renewable energy feedstocks, low capital costs for infrastructure development as well as large centres of demand (and/ or low transportation costs to demand points). In 2021, less than 0.02 million t of green ammonia was produced (IRENA, 2022). Over the next decade several projects announced in Australia, Europe, United States and Saudi Arabia are likely to add between 30-80 million t of green ammonia each year by 2030 (Saygin et al., 2023). In a 1.5°C warming scenario, green ammonia production capacity may need to reach 566 million t to satisfy increasing demand (IRENA, 2022). This is nearly seven times larger than existing project commitments.

Figure 2: Types of ammonia production: differences between grey, blue and green ammonia.

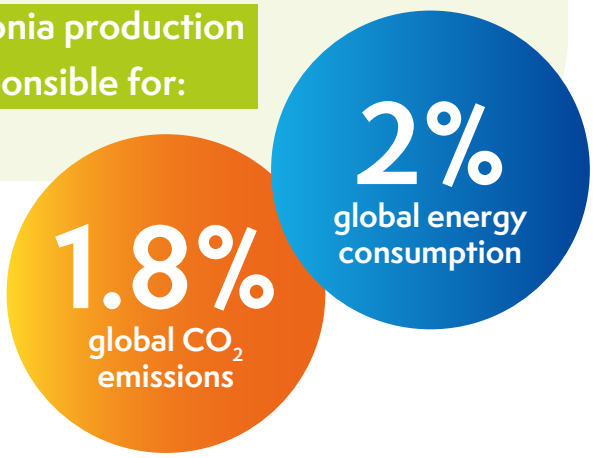


BOX 1: Increasing global demand for ammonia

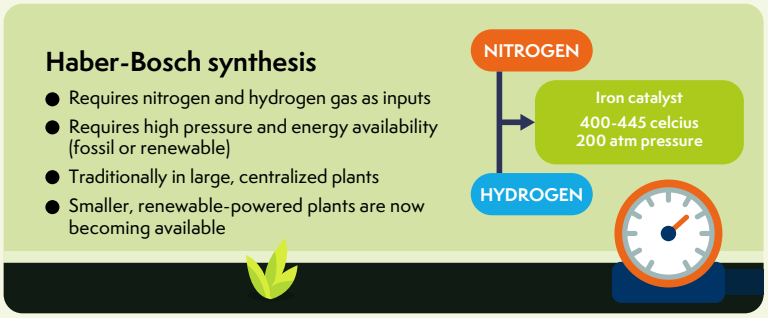
Global nitrogen fertilizer applications have increased almost sixfold over the past 60 years as global populations required higher agricultural production to sustain them (IFIA, 2023). By 2050, ammonia production is slated to increase by 40% driven by economic and population growth (IEA, 2021). Today the Asia-Pacific region is the largest consumer of nitrogenous fertilizer, with China being the largest consumer with 22.55 million t/year followed by India with 19.44 million t/year. North America is the second-largest region for the market, the United States being the third largest consumer with 11.17 million t/year, followed by South America and Europe (IFIA, 2021). Fertilizer applications in Africa are below the levels needed for optimal crop yields, leading to commitments by various actors to boost the production and availability of fertilizers throughout the continent.

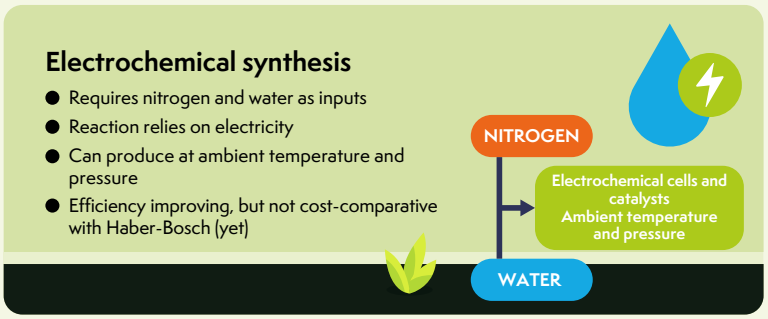
Ammonia production is highly centralized, with a majority of ammonia coming from around 500 facilities (Tonelli et al., 2024), in large part due to its heavy reliance on natural gas as a feedstock. Countries and regions like Russia and the Middle East, with abundant natural gas reserves, are thus able to produce ammonia at relatively low cost for export. In Europe, ammonia production is also mainly based on natural gas as a raw material (Fertilizers Europe). Following increases in natural gas prices in 2022, the operational capacity of European ammonia production decreased by up to 32%, which is likely to continue to challenge producers as they continue to pay higher prices for feedstocks. The situation is particularly severe in Africa, where countries are highly dependent on imported fertilizers for agricultural production. Changes to energy prices have a direct effect on production costs of fertilizers, and thus on global food prices, with poor and vulnerable populations most affected.

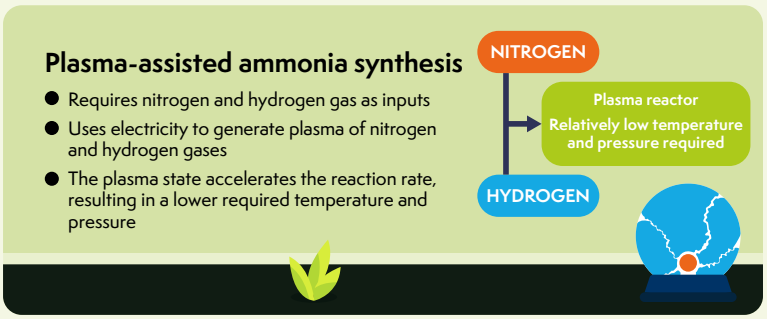
Ammonia production is responsible for:

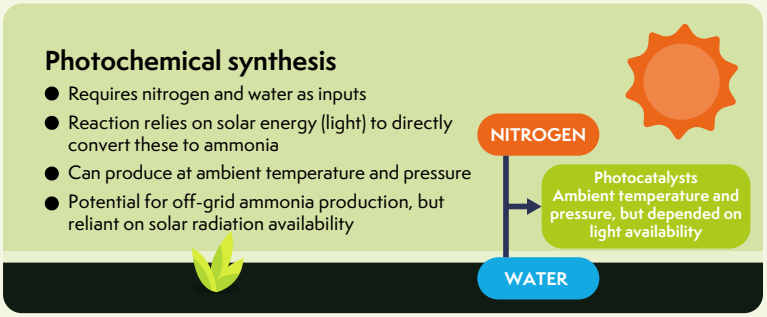


BOX 2: Ammonia synthesis technologies









! It is important to note that there are many alternative approaches to nitrogen fertilizer production and use currently under development, and this is not an exhaustive list of solutions. Other notable innovations in the field include waste-to-ammonia conversion, non-thermal plasma nitrogen fixation and enhanced microbial fertilizers, among others. Read more...

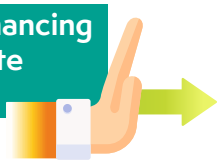
Barriers to accessing finance

Like other impactful technologies such as renewables and electric vehicles, green ammonia technologies face barriers to scaling up:

- Need to achieve cost and quality parity with mature incumbent industry in commoditized markets
- Require long-term, low-cost financing for manufacturing infrastructure
- High fixed-costs and uncertainty about future demand can result in under-investment
- Real or perceived risks around projects lead to prohibitively high interest rates on project debt financing

Yet, infrastructure will need to be built either way to meet growing demand for food, and public investors can accept the investment risk that private-sector markets cannot. There are several incentives that could be applied to green ammonia to promote uptake. These include incentives that "push" technological advances by tweaking the financial environment with direct funding of green N, and those that "pull" the development of green N by increasing return-on-investment. "Push funding" includes grants, research and development tax credits, and public funding for national laboratories and basic science, while "pull funding" encompasses volume guarantees, and other "pay for results methods". Depending on the state of technology development, these incentives can be employed to support technology development and/ or scale-up efforts. These investments could take several forms, depending on the Technology Readiness Level (TRL), regulatory environment, industrial policies, prevailing market incentives and access to capital. This is further explored within the "accelerators of change" framework of Herrero et al. (2020), which describes the elements that need to be in place if technologies are to be taken up at scale.

Push-incentives to support project financing of infrastructure through Public Private Partnerships (PPPs)



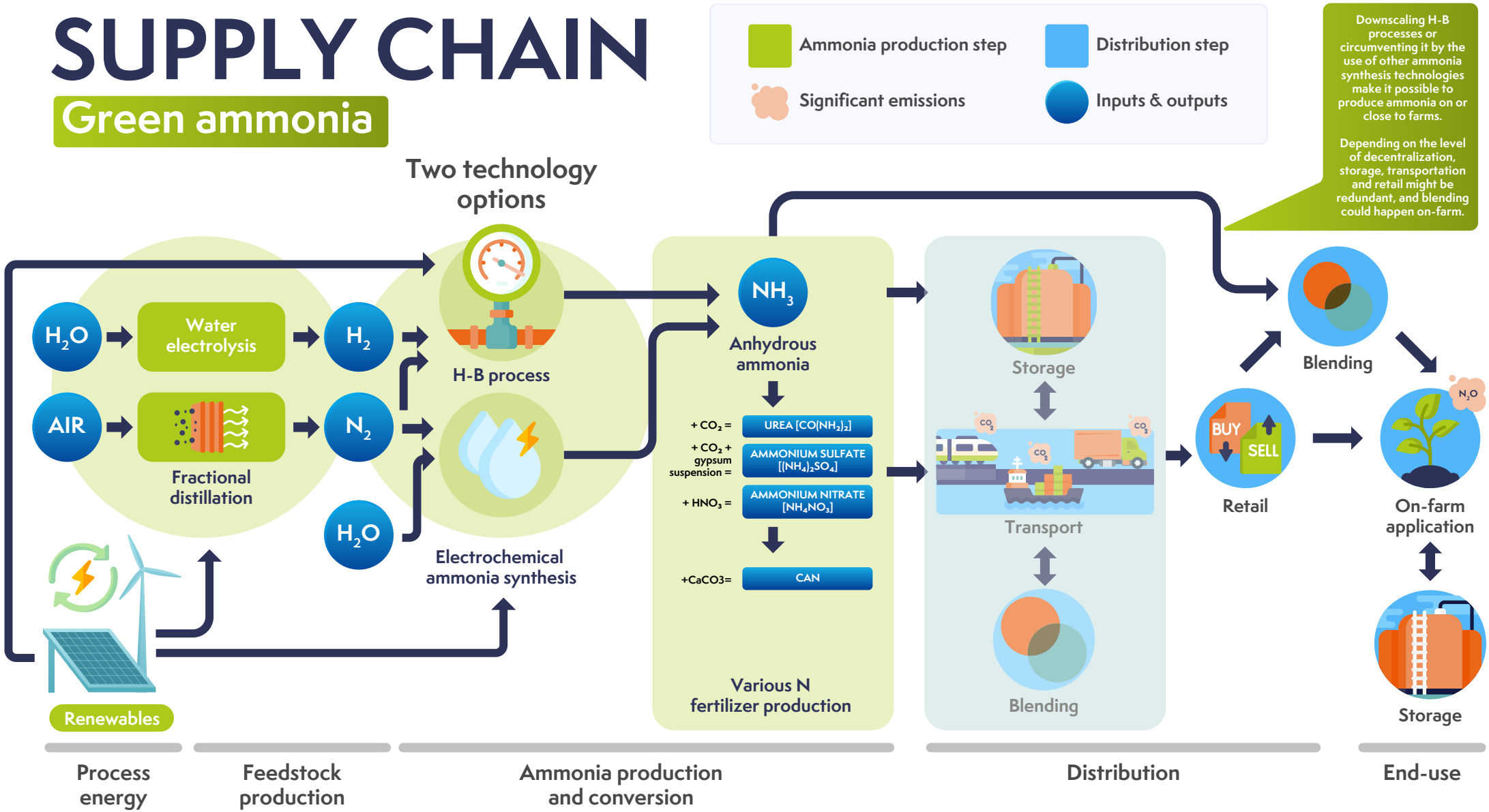
Green ammonia production will require new infrastructure and investment. High capital costs and access to renewable energy sources are two key factors hindering cost-competitiveness with grey ammonia production. Considering the highly strategic nature of fertilizer production for food production worldwide, partnerships involving state-owned entities and public institutions in private-sector led initiatives, backed by public funds, will enable project developers to access capital for infrastructure development. These investments could take several forms, including:

1. **Strategic alliances and partnerships between different players along the supply chain.** Developers predominantly opt for strategic alliances and partnerships across the ammonia supply chain, integrating captive solar energy production, electrolyser industrialization, carbon finance, dedicated hydrogen pipelines and demand aggregation, thereby enhancing market validation, offtake alignment and risk mitigation for financiers. This approach involves the creation of partnerships between buyers and suppliers to lower the total systems cost of doing business. This in turn allows for lower prices while preserving the profits necessary for reinvestment in new product development.

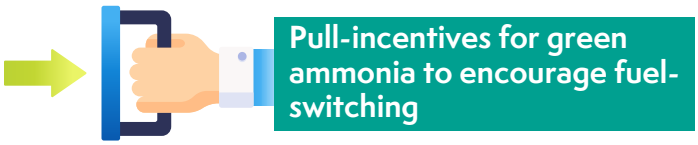
2. **Co-production of green hydrogen and other value-added products.** Depending on the process used to generate green ammonia, value addition may be possible via co-production of other materials such as oxygen gas in the hydrogen production process (Zhao et al., 2020). In line with renewable energy targets, individual countries have drawn up roadmaps for the development of green hydrogen projects where the role of ammonia may need to be re-assessed. To lower offtake risk, business models are based on hydrogen derivatives, including low-carbon ammonia for fertilizers, low-carbon steel, or cement.

3. **Access to green and transitional finance.** Current technologies, such as the use of green hydrogen as a partial feedstock in fossil-based ammonia plants, the use of carbon capture and utilisation (CCU) or source hydrogen from by-product or waste streams, can be deployed at scale in the medium-term by retrofitting existing plants with these technologies commercialised across other manufacturing industries. Deployment will require access to green and transitional capital at low discount rates for building up, or retrofitting, production infrastructure. Governments can help de-risk part of the capital expenditure-side (CAPEX) of investments through favourable interest-rates for loans, and loan guarantees; and additionally, on the operational-side (OPEX), through public procurement, contracts and off-take guarantees.

Figure 3: Green nitrogen fertilizer supply chain under the two most developed technologies: Green H-B production and electrochemical ammonia synthesis



4. **Public funding for "bundles" of technology.** Concessional funding and blended finance attract investors in riskier markets, using pilot projects as proofs-of-concept. Aligning interests between equity holders and offtakers, and involving key stakeholders, proves effective in lowering project risks and gaining investor confidence. This could be an appropriate mechanism for high-risk pilots—for instance, combining small-scale ammonia production with novel renewable energy storage solutions in rural areas relatively far from markets. Such solutions would include sand batteries and high-efficiency solar-power batteries, for example. Small-scale distributed ammonia production could be used locally (e.g. generated on a farm and used on the land) or collected and transported by tanker to a regional storage.



Pull-incentives for green ammonia to encourage fuel-switching

In order for green ammonia to be price competitive with "grey" alternatives, production processes will require significant technological advances to increase efficiencies and lower costs. At current premiums there is a lack of credible offtakers and a developed marketplace for low-carbon alternatives. In order to make green ammonia market-competitive, long-term offtake agreements with defined volumes and prices are one of the effective ways to tackle market risks—a significant consideration for ensuring investor confidence in the sector. The following mechanisms can be employed to ensure a viable initial market and increase early competitiveness:

1. **Production tax credits.** While natural gas prices and carbon taxes remain low, steam methane reforming with carbon capture and storage is likely to be the lowest cost option for reducing the carbon footprint of ammonia production (IEA, 2021). Increasing the carbon price can have a large influence on the returns from investment in green ammonia and the transition from grey to green ammonia (Zhao et al., 2022). Currently, a carbon price of around USD 150 per t CO_2 is required for renewable ammonia to be competitive with existing fossil-based ammonia production (IRENA, 2022). Carbon prices averaged around USD 76 in 2023, with estimates reaching around USD 160 by the end of the decade as looming net zero targets push regulators in key markets to tighten supply and include more industrial sectors.

2. **Auctions and contract-for-differences (CfD).** Companies bid for funding based on how much they would save in carbon emissions by switching to a new technology and how much funding they would need per tonne of saved carbon emissions, versus the cost of using cheaper fossil-fuel equivalents. Winning bidders, selected on their commitment to save the most carbon at the lowest price, are guaranteed a "strike price" for using the lower-carbon option, which would come in the form of a government "top up" payment based on the prevailing cost of the higher-carbon option. By encouraging competitive bidding processes, where companies bid for what they need rather than what they want, "top up" payments are likely to be much lower than traditional subsidy payments (as seen in the EU's European Hydrogen Bank (EHB) auction). While countries are developing early proof-of-concepts, it is likely that this would need to be complemented with other incentives such as subsidies or concessional financing to incentivise green manufacturing.

3. **Advance Market Commitments (AMC).** This approach involves the creation of partnerships between buyers and suppliers, whereby a funder commits to purchasing a guaranteed volume of green N at a guaranteed price, for distribution or subsidized resale to target beneficiaries such as small-scale rural farmers. This in turn allows for lower prices while preserving the profits necessary for reinvestment in new product development. Long-term offtake agreements with defined volumes and prices are an effective way to tackle market risks, and can help secure debt-financing for infrastructure development, similar to the power sector.

4. **'Renewables pull' for making green ammonia cost competitive.** The 'renewables pull' hypothesis for energy-intensive manufacturing industries (Verpoort et al., 2024), suggests that a transition to carbon neutral technologies might result in the relocation of industry depending on the availability of renewable energy. Current costs of green ammonia production vary across regions due to variations in renewable energy availability and prices. To encourage green ammonia competitiveness, international co-operation must be fostered between highly competitive producing and consuming regions. Country-level partnerships to support technology deployment and trade may support global decarbonisation targets and minimise political risk.

Leverage points for taking green ammonia to scale

In order for green ammonia technology to be widely taken up, and for its benefits to be realised at scale, fundamental changes are required at the systems level. The "accelerators of change" framework of Herrero et al. (2020) describe eight of these elements, six of which were identified as being of particular relevance to the scaling-up of green ammonia (Thornton, 2023):

- **Enabling social licence and stakeholder dialogue:** given the direct dependency on renewable energy for green ammonia production, engagement with actors across the supply chain, where there is competition for renewable-fuelled energy and existing competitiveness from fossil-fuelled incumbents, will be essential to support decarbonising efforts.
- **Stable finance:** a mix of green and socially responsible public and private financing to spur investment in green ammonia production and utilisation, in ways that do not reinforce existing inequalities across countries or supply chain stakeholders.
- **Market incentives** to help spread the costs and risks associated with the innovation, via mechanisms that can ensure a viable initial market and increase its early competitiveness.
- **Changing policies and regulations**, to ensure appropriate supervision of the technology and appropriate environmental regulations and health and safety standards, as well as reducing economic and bureaucratic constraints that can sometimes blight adoption and diffusion of new technology.
- **Safeguarding against undesirable effects:** innovation often results in winners and losers, and safeguarding is needed to protect those who may miss out on the benefits in the short term. This is likely to revolve around monitoring the impacts of green ammonia on the livelihoods of various value chain actors, from vulnerable small-scale farmers to decarbonised manufacturers, as well as on sustainable development goal reporting.
- **Developing and implementing transition pathways** that decarbonize ammonia production at scale, in ways that are economically viable and socially just. Such transition plans need to go into the details of what needs to happen, where and by whom, and would likely be needed at both national and international levels to be effective.

Possible leverage points are listed in Table 1 for each of these accelerators for higher-income countries and for lower-income countries separately, given that these leverage points are likely to differ based on national context. Also included is information on the type of organization that could be responsible. For the leverage points that are not the responsibility of governments, highly conjectural estimates of cost (order of magnitude, on a scale of very low to high) and time to measurable impact or completion are included. Also included are tentative suggestions as to target geographies.

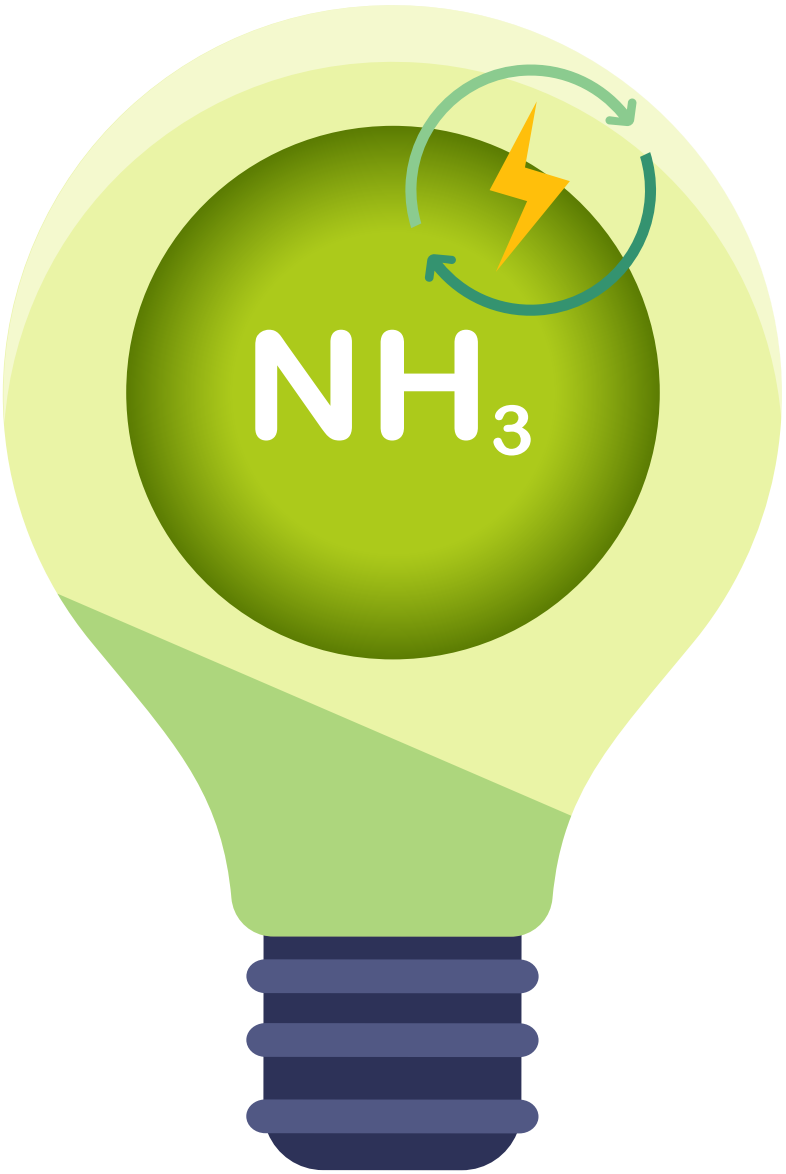


TABLE 1. Leverage points for taking green ammonia to scale, linked to the "accelerators of change" framework of Herrero et al. (2020).

A. Higher-income countries

ACCELERATOR	POSSIBLE LEVERAGE POINTS	WHO IS PRIMARILY RESPONSIBLE	POSSIBLE TARGET GEOGRAPHY	HIGHLY INDICATIVE COSTS [A]	TIME HORIZON [B]
Enabling social licence and stakeholder dialogue to build engagement with supply chain actors	• Deployment of existing technologies • Reassessment of the role of ammonia in green-H strategy	• Public & private funders • Government	• Selected countries	• High • -	• 2-3 year • 3-5 years
Ensuring stable finance to promote innovation	• Short-term green energy subsidies • Emissions trading systems for carbon and green hydrogen credits	• Government • Government	• EU	• - • -	• 2-3 years
Designing market incentives to spread costs and risk	• Put in place AMCs • Contracts for Differences (CfD) • Value addition and new applications	• Public & private funders • Government • Public & private tech developers, then funders	• To be decided • Selected countries and global	• High • Medium	• 3-5 years • 3-5 years
Changing policies and regulations that support innovation over the medium term	• Retarget subsidies while moving towards true cost accounting for the food system • Temporary tax exemptions	• Government • Government	• - • -	• - • -	• 2-3 years • 1-3 years
Safeguarding against undesirable effects by monitoring / correcting at local & national scales	• MRV systems and certifications for low-carbon ammonia	• -	• Global standards and certifications	• -	• -
Developing transition pathways for implementation at scale that are viable and equitable	• Evaluation of green ammonia contributions to national NDCs, poverty rates and food security globally • Focused R&D to increase the energy efficiency of water electrolysis and electrochemical technology • Further expansion and reductions in the cost of renewable power generation	• Public funders and research organizations • Public & private research organizations • Government	• Selected countries and global • Locations of "best-bet"[C] R&D teams • Areas with competitive renewable energy resources	• Low • Medium • -	• 2 years • 5 years • -

A - Costs: very low (< USD 100,000); low (several USD 100,000s); medium (several USD 1 millions); high (several USD 10 millions)

B - Time horizon: time to measurable impact or to completion

C - Best-bet: R&D teams most likely to succeed

TABLE 1. Leverage points for taking green ammonia to scale, linked to the "accelerators of change" framework of Herrero et al. (2020).

B. Lower-income countries

ACCELERATOR	POSSIBLE LEVERAGE POINTS	WHO IS PRIMARILY RESPONSIBLE	POSSIBLE TARGET GEOGRAPHY	HIGHLY INDICATIVE COSTS [A]	TIME HORIZON [B]
Enabling social licence and stakeholder dialogue to build engagement with supply chain actors	• Facilitating global collaboration for technology transfer	• Government	• Linked to renewable energy production	• -	• -
Ensuring stable finance to promote innovation	• Establish a network of small-scale pilots	• Public & private funders	• One region of sub-Saharan Africa (e.g. 2 countries in East Africa)	• High (e.g. 5 pilots to reach 100,000 total small-scale farmers)	• 3-5 years
Designing market incentives to spread costs and risk	• Put in place AMCs • Prizes for technology development • Establish workable technology bundles that add value, such as renewable energy provision	• Public & private funders • Public funders and research organizations • Public & private tech developers	• Linked to the pilot locations	• High • Medium	• 3-5 years • 1-2 years
Changing policies and regulations that support innovation over the medium term	• Retarget fertilizer subsidies	• Government	• -	• -	• 2-3 years
Safeguarding against undesirable effects by monitoring / correcting at local & national scales	• Ex ante impact assessments and monitoring of pilots	• Public funders and research organizations	• Linked to the pilot locations	• Low	• 1-5 years
Developing transition pathways for implementation at scale that are viable and equitable	• Evaluation of contributions to national NDCs in pilot countries • R&D on cost-effective small-scale production methods	• Public funders and research organizations • Public funders and research organizations	• Linked to the pilot & other countries • Locations of "best-bet"[C] R&D teams	• Very low • Low to medium	• 2 years • 3 years

A - Costs: very low (< USD 100,000); low (several USD 100,000s); medium (several USD 1 millions); high (several USD 10 millions)
B - Time horizon: time to measurable impact or to completion
C - Best-bet: R&D teams most likely to succeed

Regional differences (higher-income vs lower-income countries)

The scale up of green ammonia technologies will require major expansion in renewable energy infrastructure, scientific advancements around electrolyser technology and optimised energy efficiency, and markets for low-carbon products. Timelines for deployment will also depend to a large extent on the state of existing production infrastructure. Ammonia production facilities have long lifetimes of up to 50 years. The current average age of installed capacity is around 25 years since first installation, but varies significantly by region. Plants in Europe are around 40 years old on average, compared with 12 years in China, which is home to around 30% of global capacity (IEA).

For higher-income countries, where the development of the green ammonia sector is already well underway, the leverage points included focus on market incentives to encourage fuel switching through the use of AMCs and access to marketplaces for low-carbon hydrogen to help secure feedstocks for green ammonia products. As examples, Japan is exploring a contract for differences scheme to fill the gap in price between green and SMR-derived hydrogen, and Germany is developing a similar marketplace in order to reduce short-term hurdles until the market is fully developed.

Regions with well-developed, or high potential for, renewable energy resources have a greater advantage in producing affordable green ammonia in the medium-term. For example, Europe's advantage in renewable energy deployment coupled with increasingly stringent emissions regulations could help position the region as market leaders in deploying carbon-free agriculture and industrial production. Leverage points here include access to stable finance to provide greater incentives for innovation. Countries with national hydrogen strategies must also re-assess the role of ammonia, including providing access to short-term green energy subsidies to support production scale-up. Where emissions trading systems are well developed, like the Emissions Trading System (ETS) and the upcoming Carbon Border Adjustment Mechanism (CBAM) in the EU, emission trading can play a key role in decarbonising industries by adding a new revenue stream for producers, adjusting the price competitiveness of low-emission goods, and levelling the industrial playing field to incentivise final investment decisions for decarbonisation projects. In April 2024, EU ETS rules explicitly granted producers of renewable hydrogen and its derivatives the same free allowance eligibility as those granted to producers of hydrogen and ammonia made with fossil fuels.

Another leverage point is to increase understanding of the associated environmental and social costs and benefits through industrial policy and regulation. Existing regulations around industrial decarbonisation have prompted corporations to assess their Scope 3 GHG emissions targets, which make up an estimated 85% of the emissions attributable to companies in the downstream food chain. Large players like Nestlé, Danone and Kraft Heinz, have set targets to reduce 50% of their Scope 3 emissions by 2030 and to attain net zero by 2050. Companies are able to reduce fossil energy consumption as well as direct GHG emissions through green ammonia production (Gao Y et al., 2023). While individual farmers may be reluctant or unable to switch to products and services with a "green premium," large companies can play an important role in expanding demand for green ammonia.

Some R&D leverage points are also included, specifically to increase the energy efficiency of water electrolysis and electrochemical technology. Novel mechanisms around IP transfer can also incentivise private companies in higher-income countries to invest capital into solving context-specific issues afflicting mostly lower-income countries. For example, public purchase of production patents by a group of countries looking to develop domestic production could encourage the development of context-specific plant-nutrition technologies. More novel approaches like 'Benevolent Patent Extensions' (Barrett, 2023), where companies are incentivised to fund local R&D for the development of a global, non-exclusive novel technology in exchange for an extension on a luxury, non-essential patent, could be used to partially offset private R&D expenditures.

Middle-income countries currently emit a substantial amount of emissions from food production, including fertilizer production. Green ammonia could play an important role in mitigating the global energy and climate crises by reducing reliance on fossil fuels to manufacture fertilizers. However, the price gap between fossil- and renewable-based hydrogen will continue to be a challenge to scale up green ammonia production in these countries. To overcome market barriers and support technology development, pull-funding mechanisms like prizes, volume guarantees, and other "pay for results methods," can promote the development of context-specific technological approaches by increasing the return from innovation. Countries like Argentina and India,

with high potential for renewable energy development, are also calling for the facilitation of global collaboration for technology transfer, with higher-income countries and global financial institutions providing financial and technical support to increase adoption of low-emission technologies and capacity building to effectively use these new technologies. Monitoring and verification systems will need to be developed to calculate and verify the carbon and ecological footprint of differently produced ammonia. Currently the Ammonia Energy Association, a global trade association, is looking to set up a global Ammonia Certification System to verify and support the development of green ammonia (AEA, 2021).

For lower-income countries, potential for decentralised, distributed ammonia production offers an opportunity to meet countries' growing demand for fertilizers, while reducing reliance on fertilizer imports and improving food security. Various regions in Africa, Asia, and Southern America have growing demand for nitrogen fertilizers and are dependent mostly on imports. Establishing working pilots for decentralised facilities will require the establishment of a stable financing environment made up of public and private funders. Catalytic funding from public financiers or philanthropic funders in the form of grant funding or through access to low-cost capital can support the establishment of a network of small-pilots at the crop-land level. Philanthropic loan guarantees and other credit enhancements eliminate risk and help to unlock necessary commercial investments.

Decentralised facilities, with an average production capacity of lower than 50 t/d of ammonia per day in comparison to centralised facilities with capacities over 2000t of ammonia per day, powered by electricity and operating at low temperatures and pressures could support in building food security across regions (Tonelli et al., 2024). While Africa is slated to triple fertilizer use across the continent over the next decade, setting up pilot facilities for decentralised fertilizer production could help reduce African dependence on imports while freeing up and redirecting foreign currency in the process. The Africa Fertiliser Financing Mechanism, housed at the African Development Bank, is currently financing production facilities through credit guarantees by international development banks, grants and blended finance mechanisms that leverage private investment capital. Other private funding models are being tested, including an ammonia-as-a-service business model, where companies (e.g. Talus) are setting up decentralised facilities at the crop-level, with the aim of shortening supply chains and easing access to local farmers.

Way forward

In order to test the applicability of the leverage points identified to accelerate the development of green ammonia solutions, some next steps that should follow include:

- **Identify 'best-bet' R&D teams:** Given that a large determinant of the successful scale-up of green ammonia technology lies in improving the energy efficiency of electrolysis technology, it would be advantageous to identify focused R&D teams most likely to succeed where funding can be efficiently funneled. R&D funding mechanisms can take the form of prizes, patent buyouts, grant funding, etc depending on the national context as identified above.
- **Establish a network of pilot projects for decentralised production:** Decentralised ammonia production presents an opportunity for lower-income countries, currently dependent on fertilizer imports, to establish in-country production and processing facilities. In order to test their feasibility, it is necessary to identify one region and a set of countries to establish pilot facilities. These pilots can be hubs for development of cost-effective small-scale production methods and business models supporting supply of green ammonia while minimizing and monitoring unintended consequences that arise from new value chains.
- **Develop implementation pathways:** Scaling green ammonia solutions in the short- to medium-term will depend largely on existing capacity of renewable power generation and public policy support to enhance cost-competitiveness. Regions with high potential uptake need to be monitored for associated environmental and social costs and benefits and how these may contribute to national NDCs to ensure equitable scaling pathways.
- **Build a demand-side case for green ammonia:** Currently global fertilizer subsidies account for more than $635 billion a year (Daminia et al., 2023). Working together with target regions to establish a needs assessment of potential users of green ammonia, specifically highlighting in-country capacities required, to ensure the development and implementation of transition pathways that work to lower the total systems cost of doing business. Demand-side feasibility studies can be used to support the re-targeting of fertilizer subsidies to support a demand shift towards low-carbon fertilizers, thereby unlocking a major lever for financing.

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About the authors

Nicole Rocque is a German Chancellor Fellow (2023-24) supported by the Alexander von Humboldt Foundation.

Senni Alho is the Innovations Officer at Clim-Eat.

Annebelle Rombach is the Innovations Researcher at Clim-Eat.

Leanne Zeppenfeldt is the Collaboration and Learning Architect at Clim-Eat.

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