QUICK GUIDE

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# Decentralized green ammonia

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# Nitrogen and ammonia

Synthetic nitrogenous fertilizers are indispensable to present and future agricultural production. The production of ammonia, the fundamental material for most nitrogen-containing fertilizers, however, leaves a significant mark on our planet. The Haber-Bosch (H-B) process, the main production process for current ammonia production, is estimated to account for approximately 1-2% of the world's greenhouse gas emissions, and around 2% of global annual energy consumption.

## Current demand and supply

Inorganic fertilizers will have to play a role in meeting future food demand under climate change and population growth, especially in agroecosystems that are inherently nutrient-poor and unproductive. Currently, ammonia production, of which the majority is used by the fertilizer industry, is highly concentrated. Large producing countries and regions include China, the US, the EU, India, Russia and the Middle East.

The current trajectory is unsustainable. Due to the stressors of climate change and population growth on food systems, the demand for ammonia-based fertilizer will continue to rise. If present trends continue, ammonia production will produce approximately 28 Gt of cumulative direct emissions by 2100, equivalent to 6% of the remaining emissions budget to keep global warming under 1.5 °C. However, transitioning to less emissions- and energy-intensive technologies and using renewable feedstocks could significantly cut the impacts of ammonia production.

Figure 1: Emissions from ammonia in production and use phase

## Green ammonia

Enter "green ammonia" (GA): ammonia with a smaller emission- and energy-footprint than current "grey" ammonia. This includes innovative approaches to ammonia production, like the use of renewable materials and energy for feedstock production and process energy, or technologies that provide alternatives to the traditional high pressure and temperature H-B process.* This is a promising avenue for curbing emissions in the agricultural sector. Many of these innovations also offer the opportunity to move away from large-scale centralized ammonia production towards smaller-scale, decentralized plants. In theory, this could improve availability and reduce transportation costs, especially for regions that are import-reliant, like many countries in Africa. At the same time, ammonia facilities have a lifetime of around 50 years, meaning existing plants should be taken into consideration for any green transition.

Despite their theoretical promise, green ammonia technologies are still in the development phase and cannot (yet) compete with average traditional production costs or capacity. For example, in a 1.5°C warming scenario, green ammonia production capacity may need to quadruple to satisfy increasing demand. Still, the potential of a green fertilizer transition is promising and requires analysis as different pilots and companies explore various routes to scale. The purpose of this Quick Guide is to present facts and figures that help explore the feasibility and viability of (decentralized) green ammonia production under different scenarios.

The use of ammonia-based fertilizer also significantly contributes to emissions: around 60-70% of the emissions occur as a result of its application to croplands. This means that while 'greening' the production side of ammonia is important, addressing emissions further down the lifecycle also remains critical.

* See FoodSystems.Tech

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

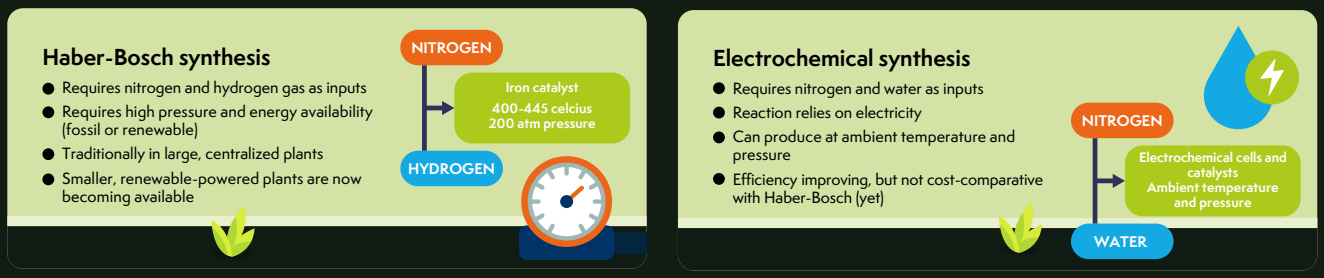



Figure 3: The two currently most developed ammonia synthesis technologies, and the focus of this guide: Haber-Bosch and electrochemical. It is important to note, however, that there are many alternative approaches to nitrogen fertilizer production and use currently under development that lend themselves to decentralized contexts, and this is not an exhaustive list of solutions. Other notable innovations in the field include photochemical ammonia synthesis, plasma ammonia and nitrogen fixation technologies, waste-to-ammonia conversion and enhanced microbial fertilizers, among others. *Read more...*

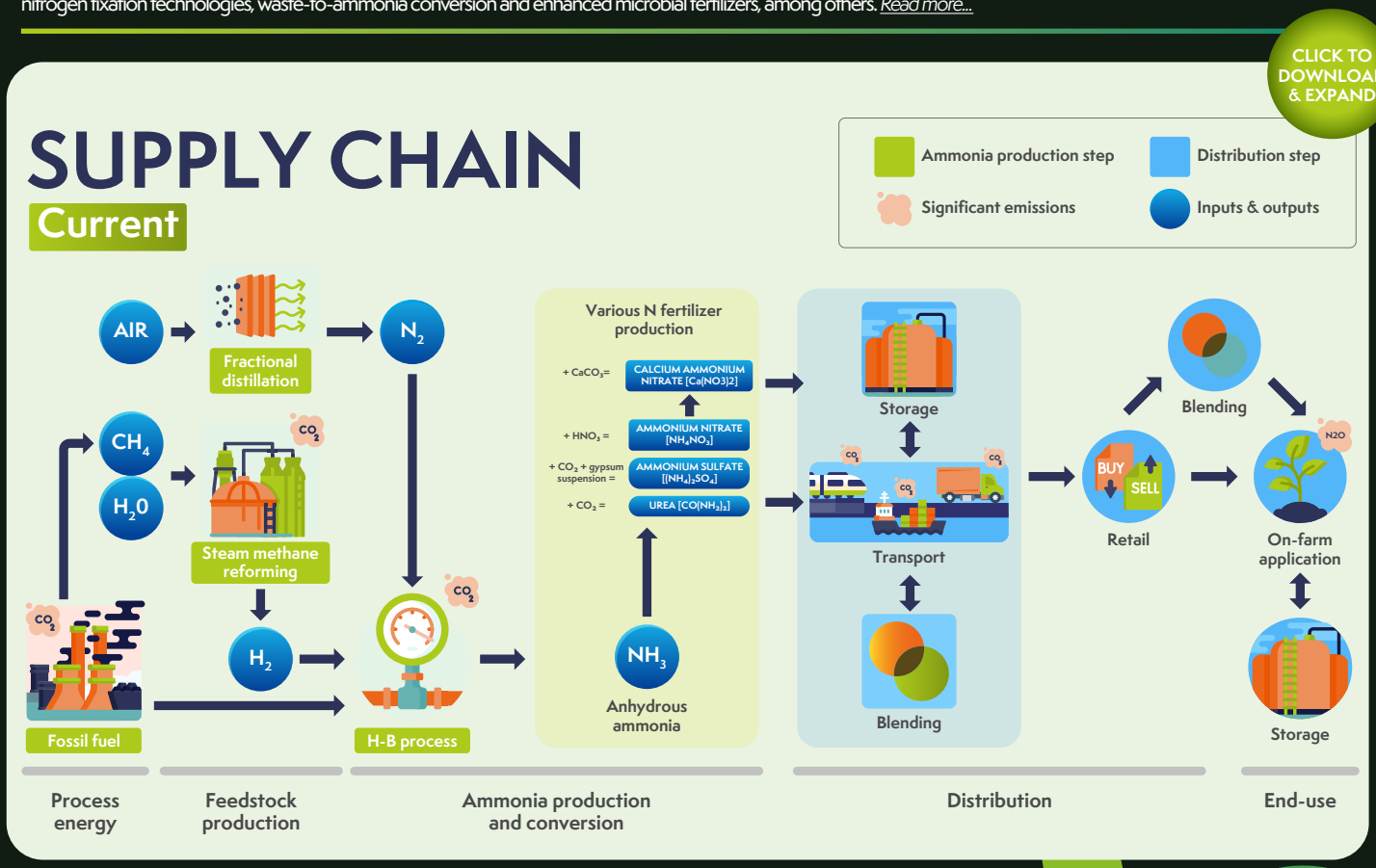



Figure 4: Current supply chain of ammonia production using H-B synthesis.

# Decentralizing green ammonia production

Many of the green ammonia technologies also enable smaller, decentralized production units. Decentralizing the production of green ammonia could, in theory, enhance access and reduce costs for smaller-scale farmers, while reducing emissions from production and transportation. However, there are significant considerations to be addressed to realize this win-win scenario.

## Decentralized, what?

Decentralized green ammonia production can refer to anything from a network of small-scale plants located directly at farms (e.g. 1.4 t/d) to a setup of fewer, medium-sized plants (e.g. 50 t/d) that can cater to regional needs - or a mix of both. Although the capacities of the existing or planned green ammonia plants vary, they are still often considerably smaller in scale than the world-catering and heavily centralized grey ammonia plants (2000-3300 t/d). Figures 4 and 5 illustrate the difference.

## Considerations

There are many factors that need to be considered for decentralized green ammonia production, not least related to the type of green ammonia technology and energy system applied, production plant size and location, farmer demand, transportation costs, as well as the comparative costs to grey ammonia. Figure 6 on the next page illustrates key factors influencing the feasibility, viability, and desirability of a decentralized green ammonia project.

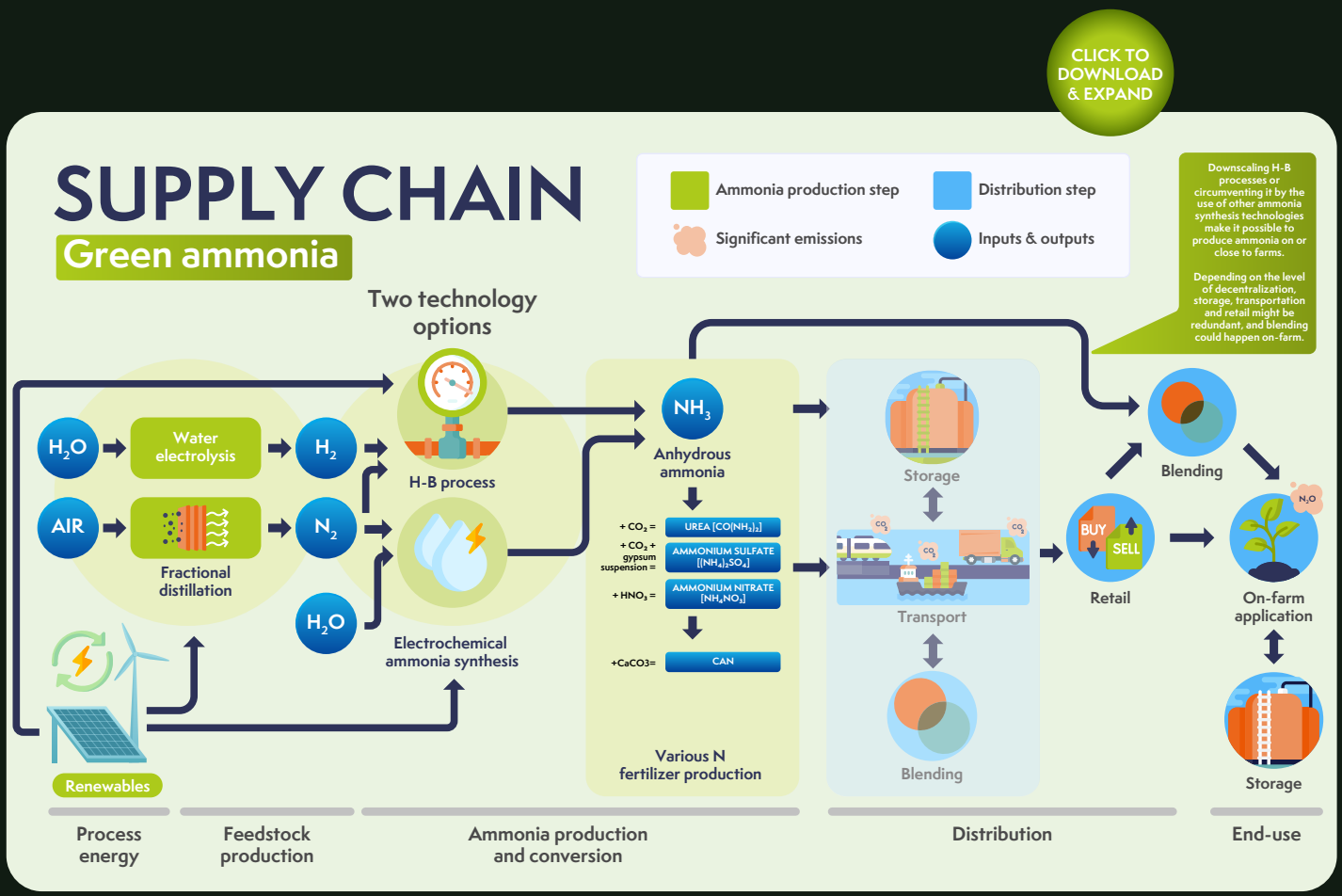



Figure 5: Potential supply chain of decentralized green ammonia production using green-hydrogen based H-B synthesis and electrochemical synthesis.

## Unintended consequences

However, there are also potential unintended consequences of decentralized green ammonia production. These include the possibility of higher fertilizer costs leading to increased food prices, or conversely, lower fertilizer costs and greater availability in certain regions which could result in overuse. There is also the risk that local production may be diverted for exports, creating supply imbalances. Additionally, safety risks associated with production and use, and an increased dependence on inorganic fertilizers, could also have negative consequences, particularly for smallholder farmers.

## Viability factors

The most impactful factors affecting the viability of decentralized green ammonia are highlighted in yellow in Figure 6. Factors which especially improve the business case for green ammonia are high costs of ammonia transportation, volatile costs of grey ammonia production, and demand for green ammonia products. The key hindering factors include green ammonia capital costs, renewable energy costs, and low energy efficiency of green ammonia synthesis.

CLICK TO DOWNLOAD & EXPAND

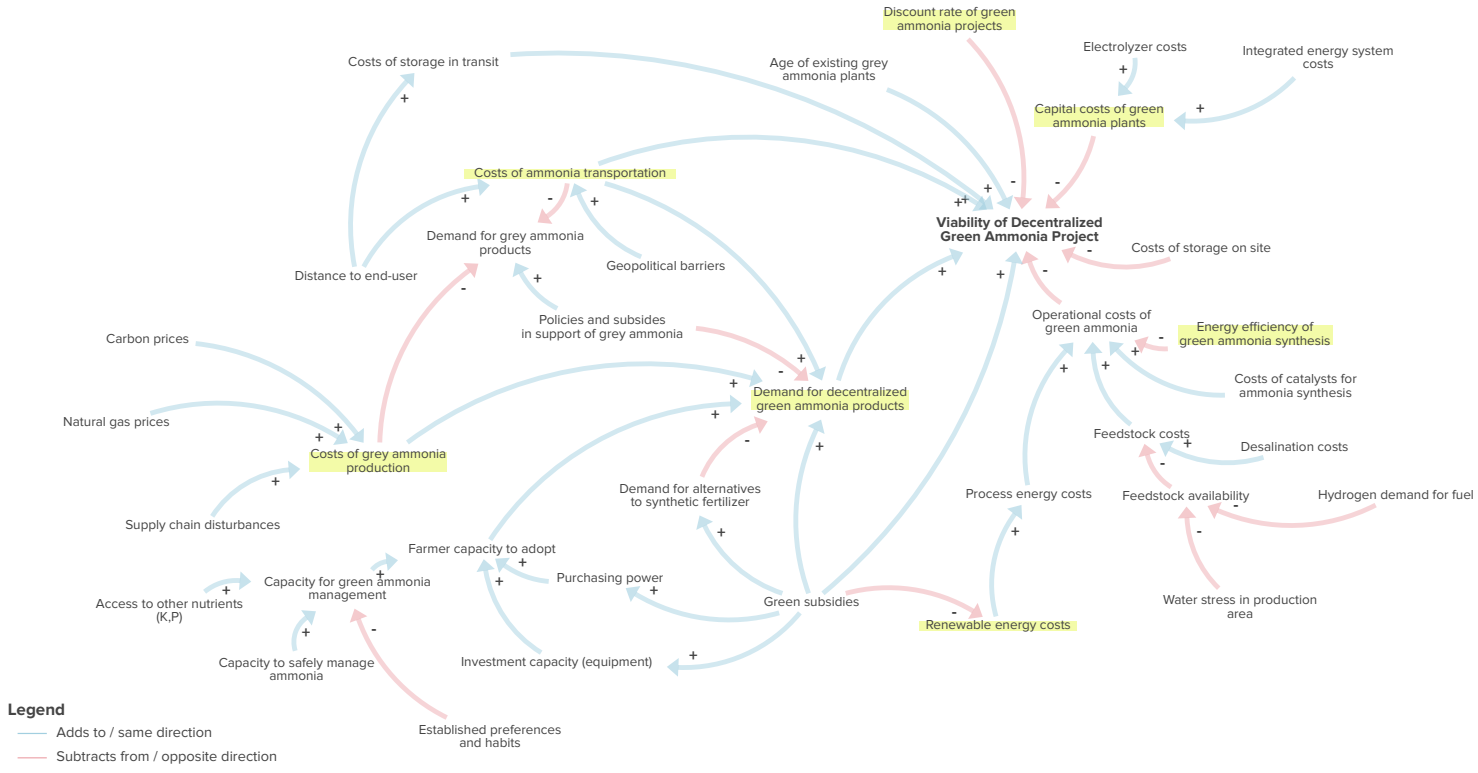



Figure 6: Diagram of viability factors of decentralized green ammonia projects

# Viability scenarios

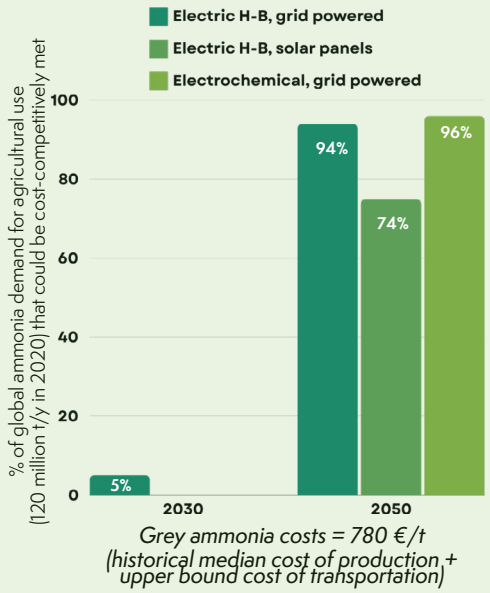
The viability scenarios on the subsequent pages shed more light to how some of these key levers, namely grey ammonia prices, capital costs (CAPEX), and energy efficiencies, affect the speculated future competitiveness of green ammonia on a global level. Rather than offering an all encompassing financial forecast, they are illustrating the interconnectedness of each factor as well as the differences in viability between green ammonia technologies.

## Grey ammonia cost scenarios

Tonelli et al. (2024) assess the cost-competitiveness of decentralized green ammonia production by comparing the costs of different technologies and energy systems against historical grey ammonia costs. Scenarios 1 and 2 illustrate the share of global ammonia demand, for agricultural use, that could be cost-competitively supplied by different decentralized green ammonia technologies and energy systems in 2030 and 2050. The scenarios highlight the significance of grey ammonia costs in determining the competitiveness of green ammonia.

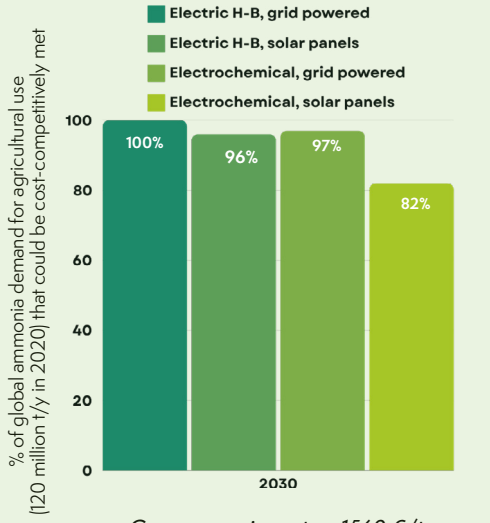
Scenario 1 sets grey ammonia cost to 780 €/t - the historical median cost of production with high cost of transportation. Under this scenario, electric H-B powered with grid electricity is expected to cost-competitively supply 5% of global ammonia demand by 2030 due to its technological maturity. Improvements in technological performance and lowered CAPEX are anticipated to increase the competitive supply of ammonia with other decentralized systems too by 2050. Scenario 2, with grey ammonia cost at 1560 €/t, is based on the 95th percentile of historical production costs and extreme transportation costs. With grey ammonia production under severe supply chain disruptions, all decentralized green ammonia technologies and energy systems could reach high levels of cost-competitive supply by 2030.

**Scenario 1: Median grey ammonia production costs with high transportation costs**




*Grey ammonia costs = 780 €/t (historical median cost of production + upper bound cost of transportation)*

**Scenario 2: High grey ammonia production costs with extermely high transportation costs**




*Grey ammonia costs = 1560 €/t (95th percentile cost of production + extreme transportation costs)*

Figure 7: Potential % global ammonia demand met under different scenarios. Based on Tonelli et al. (2024).

**Cost-competitiveness globally**
Viability of decentralized green ammonia differs largely depending on the geographical scope applied. On a global level, decentralized green ammonia doesn't reach cost-competitiveness with centralized grey ammonia, unless 1) upper bound costs of transportation are included, or 2) grey ammonia production is under severe supply chain shocks, or 3) carbon pricing of ~135 €/t* is introduced, or 4) natural gas prices are high.

**Cost-competitiveness regionally**
Green ammonia can achieve viability earlier in certain locations. Decentralized green ammonia production with grid powered H-B technology could supply cost-competitively in small regions in South Africa and North America already by 2030 under Scenario 1.



* Converted from USD (see Annex)

## Capital-cost scenarios

Fernandez et al. (2024) assessed how different capital cost (CAPEX) scenarios for green ammonia technologies affect the projected production costs and the degree of decentralization. They approached this by modeling what an optimized global production setup could look like for H-B and electrochemical technologies with integrated wind and solar systems under low and high CAPEX scenarios in 2050.

The scenarios are based on the cost predictions for electrolysis, photovoltaics, and wind technologies in 2050, the main factors influencing CAPEX for green ammonia projects. Since electrochemical technologies still face challenges with limited energy efficiencies, an optimal green ammonia production setup is modeled for both low (20%) and high (60%) energy efficiency systems addressing both ends of the spectrum.

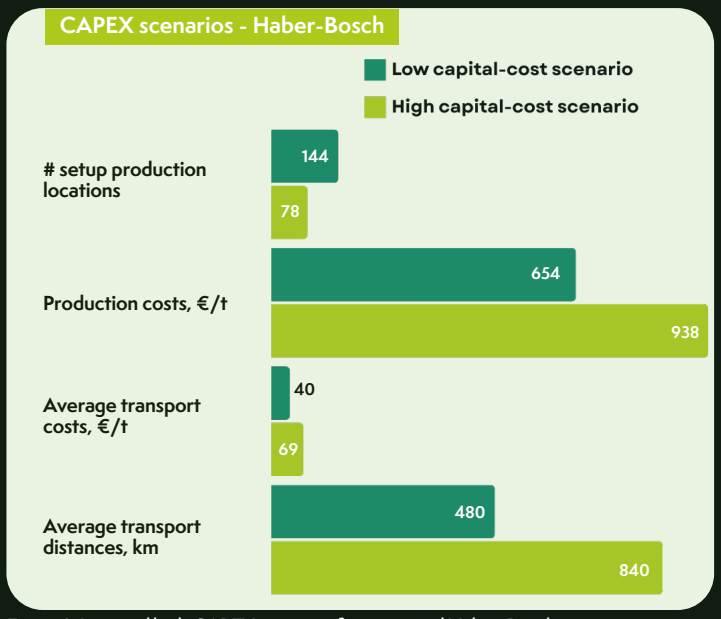



Figure 8: Low and high CAPEX scenarios for optimized Haber-Bosch ammonia production *

Figures 8 and 9 illustrate how the optimized setups under low and high CAPEX scenarios affect the degree of decentralization, production and transportation costs and distances. The models suggest that if projected technological advancements for 2050 materialize with CAPEX costs at the lower end, green ammonia produced with electric H-B could compete with grey ammonia facing high transportation costs or supply chain disruptions. However, comparison shows more promise for electrochemical technologies in achieving a high degree of decentralization and cost-competitiveness by 2050; that is if significant improvements in the energy efficiency are made and capital costs of the technology are driven down.

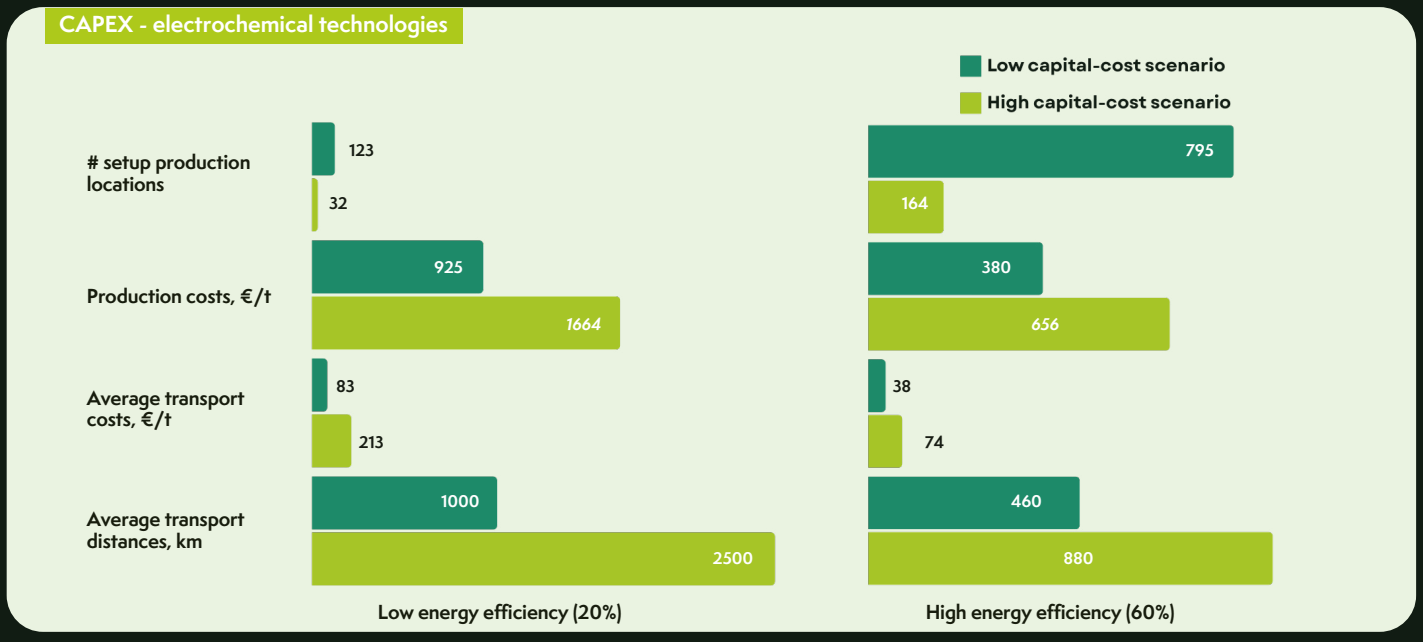



Figure 9: Low and high CAPEX scenarios for optimized electrochemical ammonia production: technologies with low (20%) and high (60%) energy efficiency *



* Converted from USD (see Annex)

# Exploring factors to decentralization viability: Country analysis

The following pages explore the elements affecting the viability of decentralized green ammonia production in three East and Southern African countries, which were selected based on their potential, existing capacities, and Clim-Eat's connection to local ecosystems. The country pages serve as an illustration of the potential that decentralized green ammonia production could have, looking at current fertilizer use, production and agricultural trends.

However, as there is a wide range of factors that affect the viability and feasibility of green ammonia (see figure 6), and due to limited availability and accesilbility of specific data, these country analyses contain assumptions and calculations based on limited data. As such, they only serve as an illustration of the potential impact. The calculations and sources are shared in the Annex, and the authors welcome suggestions and improvements to both calculations and factors identified for each country.

The countries included here are:

# Malawi

Malawi has one of the highest fertilizer use-rates in Sub-Saharan Africa (SSA). Decentralization could improve agricultural resilience against volatile fertilizer production prices and high transportation costs, and alleviate foreign currency shortage in Malawi by reducing fertilizer imports.

79% of all nutrients applied is nitrogen, indicating a high potential demand for decentralized green ammonia products. A high share of renewable energy in grid, solar irradiation, and governmental support programs for agriculture could further support the feasibility of such projects. However, substantive challenges remain with technology and energy system costs and inefficiencies, freshwater availability, and soaring interest rates for bank loans (26%, June 2024).

| MALAWI FERTILIZER OVERVIEW | | COMPARISON |
|---|---|---|
| Consumption | • 13,223 t/year - all fertilizers (2023)<br>• 98.4 kg/ha - all fertilizers (2023)<br>• 31.5 kg/ha - nitrogen (2023) | All fertilizers:<br>• 22.6 kg/ha - SSA average<br>• 140 kg/ha - World average |
| Production | • Fertilizers imported mainly via Mozambique's ports<br>• 2 blending plants for NPK products | |
| Markets<br>June 2024 | • 47.8 $/50kg - urea<br>• Low fertilizer availability due to forex scarcity | • 11.8 $/50kg - urea, US<br>• 16.8 $/50kg - urea, Black Sea |
| Politics<br>June 2024 | • Russia's invasion initiated elevated prices, economic challenges of Malawi have sustained them<br>• Affordable Inputs Program, 93M $ allocated for '23/'24, government aiming to support "productive" farmers | |

## Estimated potential of green ammonia*

**61**

**plants with 1.4 t/d capactiy**

How many decentralized green ammonia plants of different capacities would be needed, if we assume that 20% of all nitrogen applied on a yearly basis in Malawi could be met with anhydrous ammonia?

**5**

**plants with 20 t/d capactiy**

**12 970**

**# farmers per plant of 1.4 t/d capacity**

How many small-holder farmers' consumption of nitrogen-based fertilizers in Malawi (2021) could be met with one green ammonia plant of different capacities, assuming that all nitrogen needs of a farmer could be met with anhydrous ammonia?

**185 270**

**# farmers per plant of 20 t/d capacity**



* See Annex for calculations

# Kenya

Kenya has expressed political will to move towards more self-sufficient green ammonia production. With the help of foreign direct investment, 3 projects on green ammonia have been announced in Kenya: Talus Ag plant (1.4 t/d), already up and running, and plans for building larger-scale plants with Maire Tecnimont Group (550 t/d) and Fortescue Future Industries.

Nitrogen accounts for 56% of all nutrients applied in Kenya, and with high levels of fertilizer use there is likely to be demand for green ammonia products too. Kenya has an over-capacity of electricity, and over 90% of grid energy comes from renewable sources. Water stress is high, but access to (desalinated) sea water could provide feedstock for hydrogen production without competition over scarce freshwater. Similarly to Malawi, decentralized green ammonia challenges are concentrated around technology and energy system costs and inefficiencies.

| KENYA FERTILIZER OVERVIEW | | COMPARISON |
|---|---|---|
| Consumption | • 818,030 t /year - all fertilizers (2023)<br>• 127.6 kg/ha - all fertilizers (2023)<br>• 29.7 kg/ha - nitrogen (2023) | All fertilizers:<br>• 22.6 kg/ha - SSA average<br>• 140 kg/ha - World average |
| Production | • Importing via national Mombasa port<br>• 1 production facility for SSP & sulphuric acid, 6 blending units<br>• 1 active decentralized green ammonia project, 2 large-scale green ammonia projects planned | |
| Markets<br>June 2024 | • 37.8 $/50kg - urea<br>• Fertilizer import levels are lower than previous years, speculated to be related to government's new procurement approach | • 11.8 $/50kg - urea, US<br>• 16.8 $/50kg - urea, Black Sea |
| Politics<br>June 2024 | • The protests in Kenya have not affected fertilizer distribution<br>• Ministry of Agriculture has budgeted 77M $ for fertilizer subsidy program (24/25) | |

## Estimated potential of green ammonia*

**83**

**plants with 1.4 t/d capactiy**

**6**

**plants with 20 t/d capactiy**

How many decentralized green ammonia plants of different capacities would be needed, if we assume that 20% of all nitrogen applied on a yearly basis in Kenya could be met with anhydrous ammonia?

**33 399**

**# farmers per plant of 1.4 t/d capacity**

**477 124**

**# farmers per plant of 20 t/d capacity**

How many small-holder farmers' consumption of nitrogen-based fertilizers in Kenya (2021) could be met with one green ammonia plant of different capacities, assuming that all nitrogen needs of a farmer could be met with anhydrous ammonia?



* See Annex for calculations

# Rwanda

The government of Rwanda is working to increase fertilizer use from 2020 levels of 46 kg/ha to 75 kg/ha by 2024. The recently launched blending plant is envisaged to increase crop yields by 40%, and free up foreign currency as Rwanda can now procure more bulk products for blending instead of finalized fertilizer products.

Although the trend for increased fertilizer production and consumption is favorable for decentralized green ammonia, several obstacles remain. In addition to high costs and lagging efficiencies of green ammonia technologies, Rwanda's demand for nitrogen is still moderate, and limited grid-connectivity can pose challenges to grid-powered decentralized systems. High freshwater withdrawal rate without access to sea water can also form an obstacle for feedstock.

| RWANDA FERTILIZER OVERVIEW | | COMPARISON |
|---|---|---|
| Consumption | • 54,602 t /year - all fertilizers (2023)<br>• ~60 kg/ha - all fertilizers (2023)<br>• 7 kg/ha - nitrogen (2021) | All fertilizers:<br>• 22.6 kg/ha - SSA average<br>• 140 kg/ha - World average |
| Production | • Fertilizers imported via Mozambique's and Kenya's ports<br>• High inland transportation price ($ 140/t, from Dar es Salaam)<br>• Second blending plant launched in December 2023 | |
| Markets<br>June 2024 | • 25 $/50kg (subsidy markets) - urea<br>• 38 $/50kg (open markets) - urea | • 11.8 $/50kg - urea, US<br>• 16.8 $/50kg - urea, Black Sea |
| Politics<br>June 2024 | • Government aims to increase fertilizer use from 46kg/ha to 75 kg/ha by 2024<br>• Supporting farmers through subsidy programs to stabilize the prices of fertilizers, targeted for cash crop production | |

## Estimated potential of green ammonia*

**7**
**plants with 1.4 t/d capactiy**

**0.5**
**plants with 20 t/d capactiy**

How many decentralized green ammonia plants of different capacities would be needed, if we assume that 20% of all nitrogen applied on a yearly basis in Rwanda could be met with anhydrous ammonia?

**150 294**
**# farmers per plant of 1.4 t/d capacity**

**2.1 million**
**# farmers per plant of 20 t/d capacity**

How many small-holder farmers' consumption of nitrogen-based fertilizers in Rwanda (2021) could be met with one green ammonia plant of different capacities, assuming that all nitrogen needs of a farmer could be met with anhydrous ammonia?



* See Annex for calculations

# Annex

## Currencies

To make the results of the viability scenarios more comparable, USD currencies were converted into EUR with the rate of $1=0.925€

## Calculations

Table 1: How many decentralized green ammonia plants of different capacities would be needed, if we assume that 20% of all nitrogen applied could be met with anhydrous ammonia?

| Country | 20% of 2023 annual nitrogen consumption (tonnes ammonia) | # plants (1.4 t/d capacity) | # plants (4 t/d capacity) | # plants (20 t/d capacity) | # plants (50 t/d capacity) |
|---|---|---|---|---|---|
| Malawi | 30,731 t for total arable land | 61 | 21 | 5 | 1.7 |
| Kenya | 42,015 t for total arable land | 83 | 29 | 6 | 3 |
| Rwanda | 3,568 t, total country consumption | 7 | 3 | 0.5 | 0.2 |

| | | | | | |
|---|---|---|---|---|---|
| Malawi | 6.3 kg/ha (20% of N kg/ha, *31.5*) * 4,000,000 ha (*total arable land*) =25,200,000 kg = 25,200 t / 0.82 (N content of ammonia) = 30,731 t ammonia | *1.4* t/d* 365 =511 t/y 30,731/511 = 61 plants | *4* t/d* 365 = 1460 t/y 30,731/1460 = 21 plants | *20* t/d * 365 = 7300 t/y 30,731/7300 = 5 plants | *50* t/d * 365 = 18250 t/y 30,731/ 18250 = 1,7 plants |
| Kenya | 5.94 kg/ha (20% of N kg/ha, *29.7*) * 5,800,000 ha (total arable land) =34,452,000 kg =34,452 t/ 0.82 / 0.82 (N content of ammonia) = 42,015 t ammonia | *1.4* t/d* 365 =511 t/y 42,015/511 = 83 plants | *4* t/d* 365 = 1460 t/y 42,015/1460 = 29 plants | *20* t/d* 365 = 7300 t/y 42,015/7300 = 6 plants | *50* t/d* 365 = 18250 t/y 42,015/ 18250 = 3 plants |
| Rwanda | 14,630 t (*total N consumption in 2023*) * 0,2 (20% of total consumption) = 2,926 t/ 0.82 (N content of ammonia) = 3,568 t ammonia | *1.4* t/d* 365 =511 t/y 3,568/511 = 7 plants | *4* t/d* 365 = 1460 t/y 3,568/1460 = 3 plants | *20* t/d* 365 = 7300 t/y 3,568/7300 = 0.49 plants | *50* t/d* 365 = 18250 t/y 3,568/ 18250 = 0.2 plants |

Notes:

- Assuming plants run year-round → t/d 365 * d/y
- All calculations and references to t refer to metric tonnes
- Numbers of plants are rounded up to whole numbers if > 2
- Assuming all arable land would be fertilized and following average nutrient consumption per hectare
- For Rwanda used total apparent country consumption of nitrogen in 2023, for Malawi and Kenya used 2023 data for N kg/ha and multiplied by total arable land
- Links for data sources are embedded in the table.

# Annex

## Calculations

Table 2: How many small-holder farmers' consumption of nitrogen-based fertilizers (2021) could be met with one green ammonia plant of different capacities, assuming that all nitrogen needs of a farmer could be met with anhydrous ammonia?

| Country | Average small-holder farmer's ammonia needs (kg) | # farms (1.4 t/d capacity) | # farms (4 t/d capacity) | # farms (20 t/d capacity) | # farms (50 t/d capacity) |
|---|---|---|---|---|---|
| Malawi | 39.4 kg | 12,970 | 37,056 | 185,279 | 463,198 |
| Kenya | 15.3 kg | 33,399 | 95,425 | 477,124 | 1,192,810 |
| Rwanda | 3.4 kg | 150,294 | 429,412 | 2,147,059 | 5,367,647 |

| | Average small-holder farmer's yearly ammonia consumption (kg) to meet yearly N needs | Farmers supplied per plant of 1.4 t/d capacity | Farmers supplied per plant of 4 t/d capacity | Farmers supplied per plant of 20 t/d capacity | Farmers supplied per plant of 50 t/d capacity |
|---|---|---|---|---|---|
| Malawi | 26.054 kg/a (*av. N/acre used for croplands*) / 0.82 (N content of ammonia) * 1.24 acre (mean size of smallholder farms) = 39.4 kg per farm | *1.4* t/d* 365 =511 t/y * 1000 = 511,000 kg / 39.4= 12,970 farms | *4* t/d* 365 = 1460 t/y* 1000 = 1,460,000 kg/ 39.4= 37,056 farms | *20* t/d * 365 = 7300 t/y* 1000 = 7,300,000 kg / 39.4= 185,279 farms | *50* t/d * 365 = 18250 t/y* 1000 = 18,250,000 kg/ 39.4 = 463,198 farms |
| Kenya | 15.36 kg/a (*av. N/acre used for croplands*) / 0.82 (N content of ammonia)* 1.16 acre (mean size of smallholder farms) = 15.3 kg per farm | *1.4* t/d* 365 =511 t/y * 1000 = 511,000 kg / 15.3 = 33,399 farms | *4* t/d* 365 = 1460 t/y* 1000 = 1,460,000 kg / 15.3= 95,425 farms | *20* t/d * 365 = 7300 t/y* 1000 = 7,300,000 kg / 15.3 = 477,124 farms | *50* t/d * 365 = 18250 t/y* 1000 = 18,250,000 kg / 15.3= 1,192,810 farms |
| Rwanda | 3.4 kg/a (*av. N/acre used for croplands*) / 0.82 (N content of ammonia)* 0.99 acre (mean size of smallholder farms) = 3.4 kg per farm | *1.4* t/d* 365 =511 t/y * 1000 = 511,000 kg / 3.4 = 150,294 farms | *4* t/d* 365 = 1460 t/y* 1000 = 1,460,000 kg / 3.4= 429,412 farms | *20* t/d * 365 = 7300 t/y* 1000 = 7,300,000 kg / 3.4 = 2,147,059 farms | *50* t/d * 365 = 18250 t/y* 1000 = 18,250,000 kg / 3.4 =5,367,647 farms |

Notes:

- Assumes all smallholders' farm sizes are equal to the country average
- Average nitrogen use has increased significantly from 2021 levels (especially in Rwanda), which the calculations are based on
- Assuming plants run year-round → t/d 365 * d/y
- All calculations and references to t refer to metric tonnes
- Links for data sources are embedded in the table

# Final notes

## The purpose of this document

The purpose of this Quick Guide is to provide a concise overview of the potential of decentralized green ammonia. The estimates presented are based on the best available data; however, due to the limitations in data availability and the numerous influencing variables, these calculations should only be regarded as rough indications. We actively invite comments and suggestions on how to strengthen our estimates.

The primary goal is to help assess the viability of decentralized green ammonia and its potential impact on sustainable agriculture. It is important to recognize that this Quick Guide does not suggest that decentralized green ammonia is a silver bullet solution. Rather, it emphasizes that any significant transformation of food systems will require a bundle of efforts and innovations, with green ammonia being one of many critical components.

## Sources of the viability scenarios


Fernández CA, Chapman O, Brown MA, Alvarez-Pugliese CE & Hatzell MC. (2024). Achieving Decentralized, Electrified, and Decarbonized Ammonia Production. Environ Sci Technol. 2024 Apr 23;58(16):6964-6977. doi: 10.1021/acs.est.3c10751. Epub 2024 Apr 11. PMID: 38602491; PMCID: PMC11044596.

Tonelli D, Rosa L, Gabrielli P, Parento A & Contino F. (2024). Cost-competitive decentralized ammonia fertilizer production can increase food security. Nat Food 5, 469-479 (2024). https://doi.org/10.1038/s43016-024-00979-y


## Read more


AfricaFertilizer by International Fertilizer Development Center (IFDC).
Fertilizer Dashboard [website]. Available at: https://africafertilizerwatch.org/#/en
Africa Fertilizer Watch [website]. Available at: https://africafertilizerwatch.org/#/en

Campbell BM, Nyirongo J, Duchoslav J, Eliste P, Munthali MW, Nyondo C, Wollenberg E (2023). Rethinking inorganic fertiliser subsidies: Could 'payments for soil health services' be an option in Malawi?. Discussion Starter: 4. Wageningen, the Netherlands: Clim-Eat.

Campbell BM, Nyirong J, Botha B, Duchoslav J, Munthali MW, Nyondo C, Sunga I & Wollenberg E. 2023. From input subsidies to compensating farmers for soil health services. CompensACTION Policy Brief.

International Energy Agency (IEA). (2021). Ammonia technology roadmap. IEA. https://www.iea.org/reports/ammonia-technology-roadmap

IRENA and AEA (2022), Innovation Outlook: Renewable Ammonia, International Renewable Energy Agency, Abu Dhabi, Ammonia Energy Association, Brooklyn.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