

Fertilizing the future: A roadmap to scale low-emission ammonia fertilizers

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Context and approach

Nitrogen fertilizers are essential to life—they feed the soil and the crops that feed the world. Indeed, more than half of all food grown around the world, for people and animals, relies on the use of ammonia fertilizers manufactured in more than 60 countries.¹ Today, the production of ammonia-based fertilizers is an energy-intensive process that is responsible for 1% of global emissions,² comparable to the annual CO₂ emissions of Brazil or Germany.³ At the same time, technologies exist to substantially reduce those emissions.

Across the agri-food value chain, multiple solutions are being deployed to cut emissions, including nutrient-use efficiency, variable-rate application, and controlled- or slow-release products. Alongside these measures, low-emission ammonia offers an additional cost-effective lever. Decarbonizing fertilizer production while maintaining nutrient output will require coordinated, industry-wide action and strong public-private collaboration. Supply and demand dynamics are shifting: Low-emission ammonia projects totaling more than 15 metric tons per annum (Mtpa)⁴ have reached final investment decision (FID), and demand is rising as fast-moving consumer goods companies (FMCGs) pursue scope 3 reductions—nearly half of the largest players have set ambitious targets.⁵

Although broader sentiment toward sustainability has softened in recent years, the case for low-emission ammonia fertilizers remains strong due to their scalability and immediate applicability as a drop-in solution. Beyond climate benefits, they bolster food security, enhance supply chain resilience, and provide a credible pathway for companies and governments to demonstrate progress on lowering emissions.

To accelerate adoption, the Hydrogen Council's *Roadmap to scale low-emission ammonia fertilizers* (LEAF), developed in collaboration with McKinsey and agri-food stakeholders, provides a clear framework on how the agri-food industry could realize the transformative potential of low-emission ammonia fertilizers. These fertilizers offer a cost-effective decarbonization lever with wide-reaching benefits to increase the sustainability, resilience, and reliability of agricultural inputs.

Key priority actions to unlock scale include the following: (i) recognition of market-based mechanisms for environmental attributes to enable aggregated FMCG demand for fertilizers; (ii) alignment on carbon accounting standards, including industry-accepted ammonia and voluntary scope 3 standards; and (iii) policy incentives and other demand-side policies to support investment decisions.

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1. Nadia Shalaby, "Fertilizer Production & Food Self-Sufficiency in Global Growth Markets," MIT Sloan School of Management, Apr 5, 2025; 2. The International Fertilizer Association estimates that fertilizer production is 1.3% of global GHG emissions; 3. Our World In Data (Germany) (Brazil); 4. Throughout this report, the low-emission ammonia project capacity figures includes both retrofits of existing production facilities and new-build facilities and is sourced from the Hydrogen Council & McKinsey Project & Investment Tracker; 5. Methodology described in Exhibit 7, sourced from Global Data, SBTi; company sustainability reports; Euromonitor International database, accessed August 2025; Passport Sustainability Claims Tracker, accessed August 2025. Source: International Fertilizer Association, Hydrogen Council & McKinsey Project & Investment Tracker, as of May 2025, Global Data, SBTi, Company sustainability reports, Euromonitor International database, accessed August 2025, Passport Sustainability Claims Tracker, accessed August 2025, MIT Sloan Fertilizer Production & Food Self-Sufficiency in Global Growth Markets

Executive Summary

Nitrogen fertilizers are critical to global food security and are a large source of global emissions—but they can be decarbonized with technology that exists today, opening an opportunity to deploy low-emission ammonia fertilizers at scale

Low-emission ammonia fertilizers are among the most powerful and practical levers to decarbonize global food systems. Production of nitrogen-based fertilizer accounts for about 1% of global emissions today, but technologies to abate more than 80% of this footprint already exist and can be deployed to produce low-emission ammonia fertilizer as a drop-in solution, based on ammonia's contribution to fertilizer emissions. The challenges of a complex supply chain, the need for substantial investments at one end of the chain, cost inflation at the consumer level, and the lack of clear and substantial demand for low-carbon products have been limiting factors in the widespread adoption of technologies to manufacture low-emission ammonia. Yet the cost of adoption at the consumer level might be lower than expected: Switching to low-emission ammonia would raise potential end product costs by 1 to 3%, while cutting product-level emissions by up to 30%. By comparison, organic products typically require price premiums of 20 to 40%. As of May 2025, 15 Mtpa of low-emission supply projects have passed FID, with nearly 1.5 Mtpa of retrofits already online. On the demand side, nearly half of the world's 20 largest FMCGs—representing \$850 billion in annual food and beverage revenue—have set ambitious scope 3 targets, which could be met in part through low-emission ammonia-fertilizers from activated and aggregated demand for low-emission consumer goods. The case is compelling: This is a cost-efficient, scalable, and ready-to-deploy decarbonization lever that strengthens supply chain resilience and food security while delivering measurable climate impact. The lever can also be paired readily with other powerful decarbonization levers—for example, nutrient stewardship, enhanced efficiency, and nutrient enhancements such as biologicals.

First movers require demand activation to enable investment into new low-emission facilities

First-mover projects hinge on clear demand signals and firm offtake commitments. Aggregating FMCG demand for low-emission crops, grown with low-emission ammonia fertilizers, could provide the visibility and certainty needed to unlock investment and accelerate deployment. Demand mechanisms that pool commitments across multiple buyers reduce counterparty risk, create bankable offtake volumes, and send strong signals to financial institutions. Demand activation at scale also ensures that early projects are the foundation of a broader market development, giving producers confidence to move from front-end engineering design (FEED) to FID.

Policy incentives and market mechanisms that share risks and rewards can close the cost gap to unlock the early market

In early markets, governments and financial institutions could have a critical role in bridging the remaining cost gap and derisking early projects. Targeted instruments, such as carbon pricing, border adjustments, or contracts for difference (CfDs), can lower financing costs and improve project bankability. Importantly, these example tools could not only reduce the cost of capital but also distribute risk more equitably across the value chain, ensuring that producers, buyers, and financiers have aligned incentives. These potential mechanisms could assist many technically viable projects that may remain stranded at the pre-FID stage.

Greenhouse gas tracking mechanisms help provide confidence in emission reduction claims across the value chain

Consistent carbon accounting approaches and credible certification systems support recognition of the climate benefits of low-emission ammonia fertilizers. Emerging tools such as operational low-emission ammonia certification systems and book-and-claim can help companies demonstrate scope 3 progress even in complex, global supply chains. Aligning production-side standards with downstream reporting practices can reduce fragmentation, transaction costs, and extensive on-farm reporting. Transparent and verifiable systems also build trust among stakeholders and can create the basis for secondary markets in environmental attributes. In this way, reliable tracking and reporting are not only compliance measures but also enablers of scale and confidence in the adoption of low-emission fertilizer.

Fertilizing the Future

Key figures

**110% of Brazil's
annual CO₂
footprint**

Amount of fertilizer
production emissions
annually

Up to 30%

Of end product
emissions can be abated
through the adoption of
low-emission-ammonia
fertilizers (additional
details follow)

1-3%

Incremental end product
cost from adopting
low-emission-ammonia
fertilizers in the growing
process

50%

Of the largest FMCGs,
representing ~\$850
billion in sales, have
ambitious scope 3
decarbonization targets

15 Mtpa¹

Of low-emission
ammonia facilities
are at FID stage,
under construction, or
operational, with an
additional 20 Mtpa in
FEED (out of >300 Mtpa
announced)

1. Throughout this report, low-emission ammonia project capacity figures include both retrofits of existing production facilities and new-build facilities; 1.3 Mtpa of existing ammonia facility retrofits are currently online
Source: Euromonitor International database, accessed Aug 2025; Hydrogen Council & McKinsey Project & Investment Tracker, as of May 2025; International Fertilizer Association; McKinsey Catalyst Zero; Passport Sustainability Claims Tracker, accessed Aug 2025; UN FAOSTAT Emissions Totals Database; Our World In Data CO₂ Emissions Database



Chapter 1

Context and market fundamentals

Supply: An opportunity to enhance supply chain resilience and gain reliable access to sustainably produced agricultural inputs

Production from low-emission ammonia projects that have taken FID as of May 2025 amounts to 15 Mtpa. Of this, 1.3 Mtpa of retrofits are already in operation, with a further 20.0 Mtpa at FEED

Demand: An opportunity to deliver significant, certifiable, and cost-efficient emission reductions

Agri-food systems drive 30% of global emissions; fertilizer production accounts for 5% of that (approximately 1% of global emissions)

Source: Hydrogen Council & McKinsey Project & Investment Tracker, as of May 2025; International Fertilizer Association; McKinsey Catalyst Zero; UN FAOSTAT Emissions Totals Database

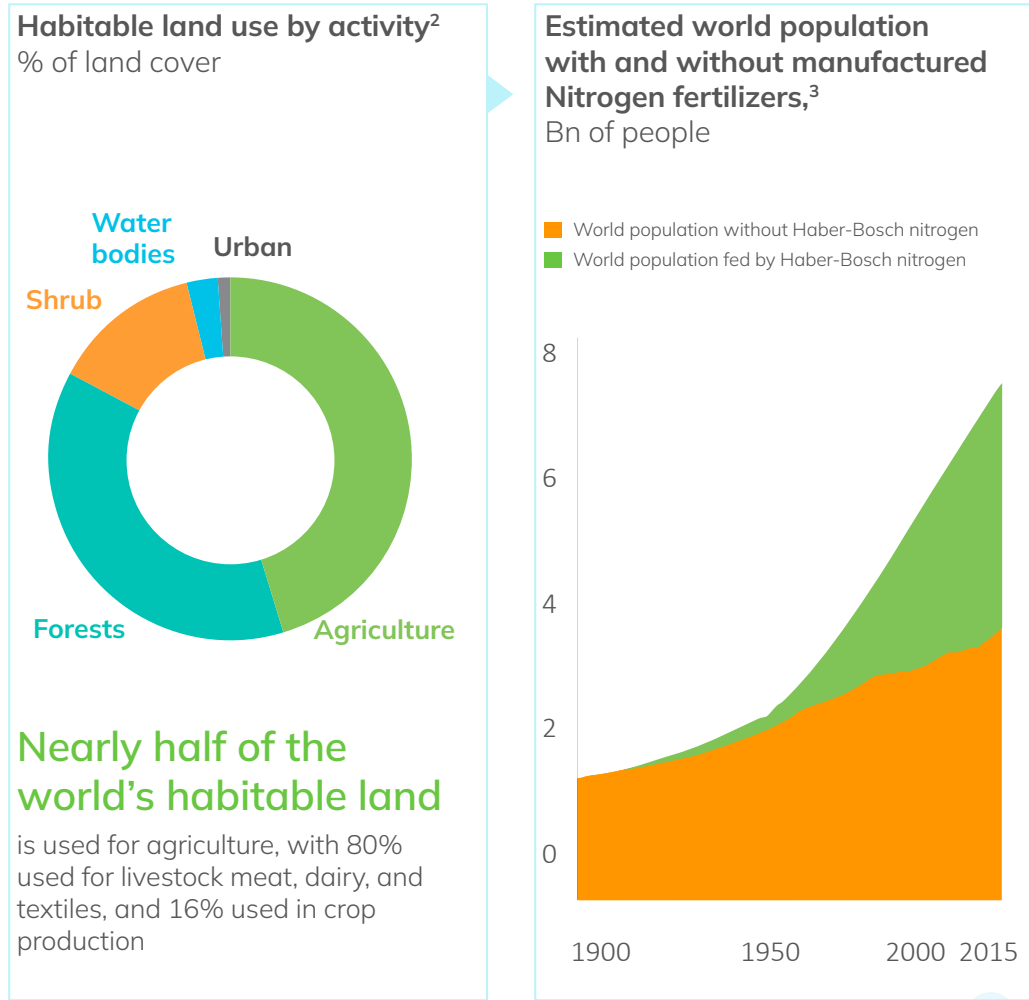
Context: Nitrogen fertilizers are critical for feeding the global population

Fertilizers feed nearly half the world

Nitrogen fertilizers are the backbone of modern agriculture, sustaining over 8 billion people. They are essential for grains, fruits, vegetables, and animal feed.¹ Without manufactured nitrogen, global croplands could not produce enough food. Today, 40 to 50% of the world's population depends directly on the use of manufactured nitrogen fertilizer.

By boosting yields on finite land and supporting plant growth, nitrogen fertilizers prevent deforestation and land conversion, support dietary shifts, and keep food supply aligned with population growth. They are not a convenience but a requirement for global food security, economic stability, and the well-being of nature and humans.

Exhibit 1



20 kg
Of manufactured nitrogen fertilizer applied to crops globally per person⁴

1. Two other important macronutrient fertilizers, potash and phosphate, are also important to global food production and security; 2. Excludes non-habitable land such as glaciers, deserts, salt flats, beaches, and dunes; 3. As estimated in Erisman et al. accessed from Our World in Data; 4. Estimated based on 200 Mtpa NH₃ demand and global population of ~8 billion
Source: "The Haber-Bosch revolution: How hydrogen and nitrogen saved the world," H2GP Foundation, Apr 30, 2025; Hannah Ritchie and Max Roser, "Half of the world's habitable land is used for agriculture," Our World in Data, Feb 16, 2024; "World population with and without synthetic nitrogen fertilizers," Our World in Data; Gates Notes – Why I love fertilizer

Context: Agri-food systems drive 30 percent of global emissions, with fertilizer production accounting for 5 percent of that

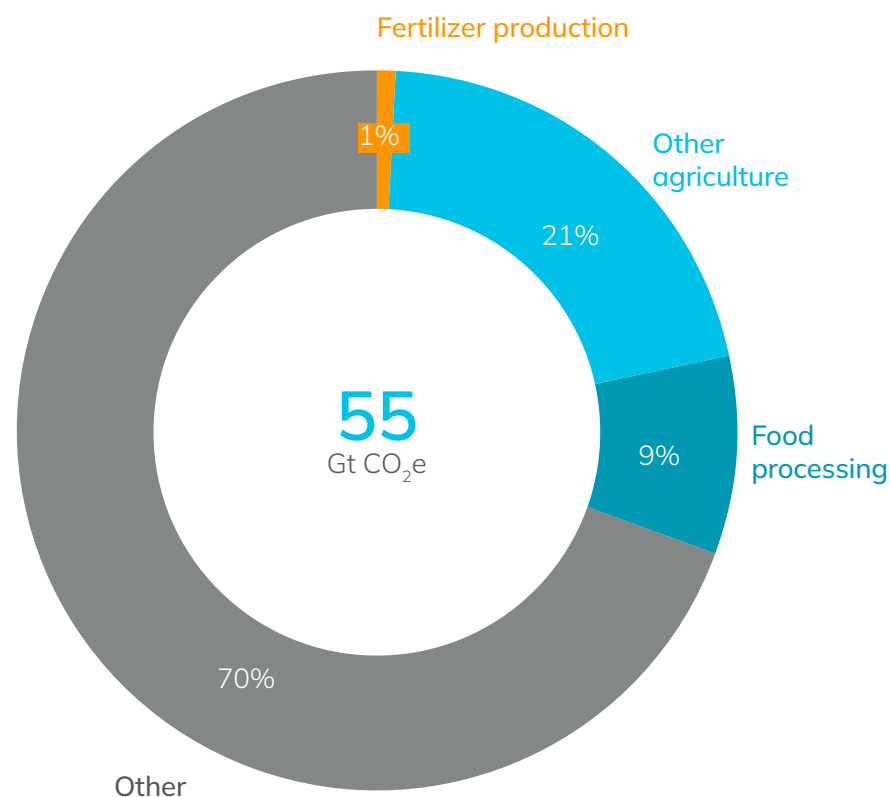
Fertilizer production produces 1% of global GHG emissions

Agri-food systems as a whole generate about 30% of global emissions,¹ two-thirds of which comes from farming and land use and the remainder from food processing. Within farming, emissions stem largely from livestock methane and deforestation, with fertilizer production contributing 5% of the total—more than Brazil's total annual emissions footprint and nearly equal to Germany's.

Low-emission ammonia offers a direct, scalable solution, unlike many other agri-food decarbonization levers that depend on behavioral change or costly new infrastructure. The trade-off is that unlocking these emissions reductions requires significant investment in new production capacity and supportive policy frameworks. Yet compared with alternatives—such as electrifying farm equipment or shifting consumer diets—low-emission fertilizers deliver large, verifiable reductions at relatively modest cost and with minimal disruption to existing systems. This combination of impact, scalability, and cost-effectiveness makes fertilizer decarbonization a uniquely worthwhile lever in the broader climate transition.

Exhibit 2

Global emissions by activity,² Gt CO₂e



Fertilizer production accounts for 5% of agricultural emissions, equivalent to³...



110%

of Brazil's total annual CO₂ emissions



90%

of Germany's total annual CO₂ emissions

1. 2022 values for CO₂ emissions taken from Our World in Data for country specific CO₂ emission footprints, fertilizer sector taken from UN FAOSTAT Emissions Totals Database; 2. Metric gigatons of CO₂ equivalent; 3. Taken from "Greenhouse gas emissions from agri-food systems. Global, regional, and country trends, 2000–22," FAO Source: FAOSTAT; IFA; Our World In Data (Germany) (Brazil); UN Environmental Program

Low-emission ammonia fertilizers offer a solution to address some of the key challenges of the agri-food system

Exhibit 3

NOT EXHAUSTIVE

Challenges in agri-food system	Overview	The case for low-emission ammonia fertilizers
 GHG emissions Main focus of this document	Fertilizer production accounts for ~5% of agriculture emissions, contributing to climate change and emerging extreme weather events	Emissions reduction: Low-emission ammonia fertilizer is an effective decarbonization tool; >80% of fertilizer production emissions are addressable with low-emission ammonia feedstock ³
 Supply diversity	Conventional ammonia production relies significantly on access to natural resources, including fossil fuels	Supply chain resilience and reliable access to sustainably produced agricultural inputs: Local renewable ammonia production can promote greater production diversity and security; building new production of low-emission ammonia fertilizer can help diversify and improve supply while providing a cost-effective and available lever to reduce final consumer costs
 Consumer inflation	Global food prices have risen on average >30% since 2020 ¹	
 Soil health & nutrient application	Healthy soils need balanced nutrients for optimal crop production, while providing farmer optionality for nutrients in the growing system. Across the value chain, other measures to optimize nutrient use on the field include strong nutrient stewardship practices, conservation and cropping changes, slow or delayed-release fertilizer application, N-fixing bacteria, and other methods for reducing nutrient demand ²	Ease of use: Using low-emission ammonia can be a drop-in solution in the fertilizer value chain, requiring no on-field application or equipment changes. It can also be easily paired with on-field practices to provide stronger incentives for farmer action

1. Increase in FAO Food Price Index between Jan 2020 and June 2025 (based on Jan 2020 number of 98.1 and June 2025 number of 128.1); 2. Included in these levers are the “4Rs” from the IFA’s 4R Nutrient Stewardship Framework: right nutrient source, right rate, right time, and in the right place; 3. Estimate from Anton Krimer and Elina Rodriguez, Green fertilizer markets and innovation, RMI, Mar 11, 2025
Source: Anton Krimer and Elina Rodriguez, Green fertilizer markets and innovation, RMI, Mar 11, 2025; Global “4R” Nutrient Stewardship Framework for developing and delivering fertilizer best management practices, IFA; UN Environmental Program; UN FAO Food Price Index, accessed Aug 2025; UN FAOSTAT Emissions Totals Database

Emissions reduction: Technology exists to reduce emissions by more than 95 percent, but action is needed to scale the industry and achieve competitiveness by 2030

Technology is ready—now policy and industry scale-up can close the cost gap

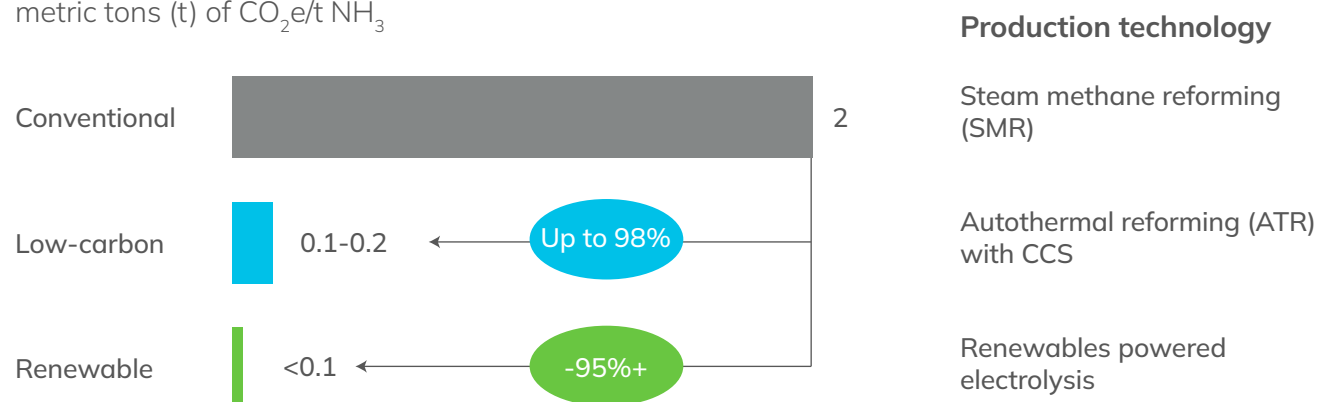
Proven technologies already exist to cut the emissions intensity of ammonia production by more than 95%, whether through renewable electrolysis or reforming¹ enabled by carbon capture and sequestration (CCS). These solutions are technically viable today and can produce low-emission ammonia fertilizers that can be integrated as drop-in replacements across fertilizer value chains. The challenge is not feasibility, but economics: Low-emission ammonia still carries a cost premium over conventional supply, and adoption at scale depends on closing this gap.

That gap could narrow by 2030, but only if decisive action is taken. Policy measures, such as the establishment of carbon pricing and border adjustments, can simultaneously reduce the cost gap for clean supply and raise the cost of high-emission products. In the European Union, the Emissions Trading Scheme (ETS) and Carbon Border Adjustment Mechanism (CBAM) penalize emissions from conventionally produced ammonia, boosting the competitiveness of low-emission alternatives. In the United States, tax credits such as 45Q or 45V lower the cost of CCS-enabled or renewable-enabled production, while in India, renewable-ammonia auctions and upstream renewable-energy support seek to deliver competitively priced supply. Together, these instruments are helping reduce supply costs, which is vital to enable a large-scale transition.

Exhibit 4

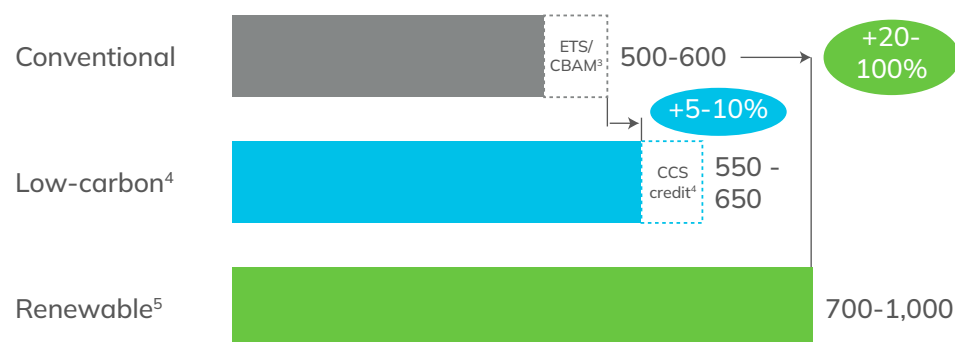
Meaningful emissions reductions are achievable with technology that exists today...

Carbon intensity of ammonia production by pathway,¹
metric tons (t) of CO₂e/t NH₃



... but action is needed to drive competitiveness with conventional supply as the industry scales

EU delivered ammonia cost, 2030,² post policy, \$/t NH₃



1. Retrofits of existing steam methane reforming plants with CCS can provide quicker and lower-cost low-emission production, but with higher carbon intensity (approximately 30-40%), ability to achieve >95% emissions reduction based on new-build ATRs that achieve high capture rates reported in NETL's Point Source Carbon Capture from Industrial Sources; Ammonia used as common denominator, emissions and costs savings differ based on fertilizer type and manufacturing process; 2. EU production/delivered import cost of ammonia in 2030, costs inclusive of capital recovery and reflective of new entrant costs; 3. Includes ETS/CBAM costs of ~\$130/ton CO₂ by 2030; 4. Range of import costs from US Gulf Coast post 45Q credits at \$85/t CO₂ and Middle East from new-build ATR with 95% CO₂ capture rate; 5. Lower range set by imports from India where renewable auctions completed at ~\$600/t NH₃, upper range reflects domestic production in Iberia
Source: McKinsey Catalyst Zero; McKinsey Global Hydrogen Trade Flow Model; NETL Point Source Carbon Capture from Industrial Sources; Solar Energy Corporation of India Limited (SECI)-Green Ammonia Tender under the National Green Hydrogen Mission

Supply chain resilience: Only 15 Mtpa of low-emission ammonia capacity has already passed FID, a small portion of the 300 Mtpa of announcements

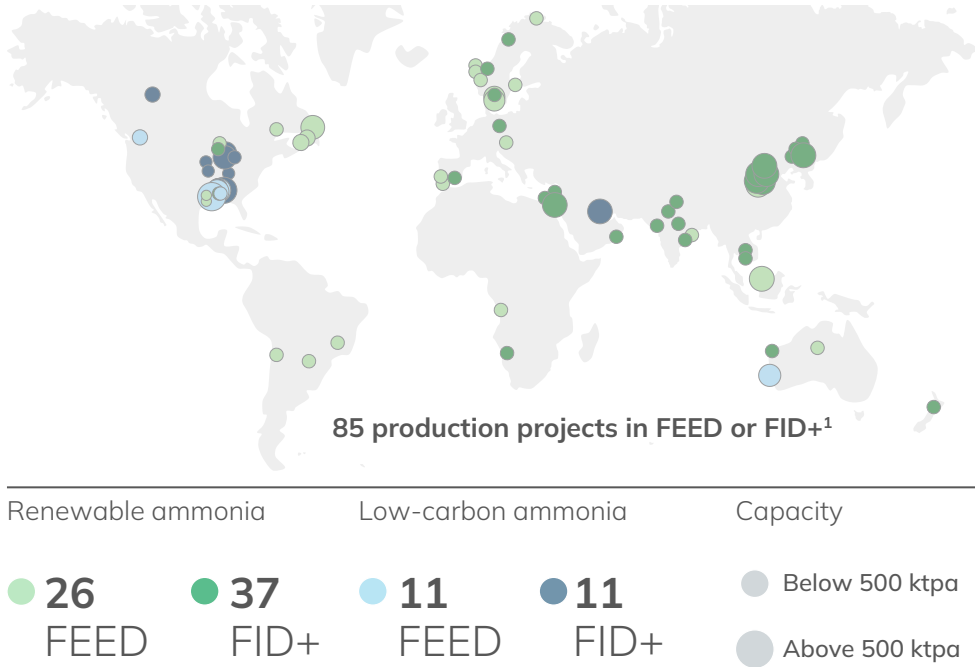
Global low-emission ammonia project pipeline

Despite progress, several barriers prevent the further deployment of low-emission projects, including cost-competitiveness with conventional supply, the inability to effectively track emission reductions, and a lack of long-term offtake.

As of May 2025, announced low-emission ammonia projects exceeded 300 Mtpa—already larger than the 2025 conventional market of 200 Mtpa. Yet, to date, only 85 projects (35 Mtpa) have reached the FEED stage, and 48 projects (15 Mtpa) have secured FIDs, of which 1.3 Mtpa is online as retrofits of existing infrastructure. The remaining capacity is largely greenfield investments.

Exhibit 5

Mature low-emission ammonia projects by pathway and status as of May 2025



Regional capacity		Average project size, ktpa			
		FID+		FEED	
North America	7.0 Mtpa Supply at FID+, 99% low-carbon +15.2 Mtpa at FEED	742	15	1220	400
Middle East	2.7 Mtpa Supply at FID+, 52% renewable	1320	506		
China & India	4.3 Mtpa Supply at FID+, 100% renewable +0.7 Mtpa at FEED		211		348
Europe	0.01 Mtpa Supply at FID+, +4.1 Mtpa at FEED		16		209
Latin America	0 Mtpa Supply at FID+, +0.3 Mtpa at FEED				254

Σ Global 15 Mtpa Supply at FID+
+20 Mtpa in FEED; +280 Mtpa announced

1. FID+ includes FID, Operational and Under construction
Source: Hydrogen Council & McKinsey Project & Investment Tracker, as of May 2025

Ease of use: Low-emission ammonia fertilizers are ready for integration in existing value chains

Low-emission ammonia as a drop-in solution that complements other agriculture levers

Low-emission ammonia fertilizers are a true drop-in solution, integrating seamlessly into existing production assets, logistics networks, and on-farm practices without costly retrofits or disruption. When used in combination with other agricultural decarbonization levers, low-emission ammonia fertilizers can deliver certifiable emissions reduction while minimizing the need for new infrastructure, retraining, or land-use changes. By aligning with emerging carbon standards and policy frameworks, they can reduce transition costs and support near-term decarbonization while maintaining the reliable flow of essential nutrients to global crops.

Exhibit 6

	 Lever fully meets criteria with potential to track and scale impact	 Lever could meet criteria with potential to track and scale impact	 Lever does not easily meet criteria with potential to track and scale impact	NOT EXHAUSTIVE
Criteria for drop-in replacement	Organic fertilizers	Precision ag technologies	Regenerative practices	Low-emission ammonia fertilizers
Brownfield infrastructure compatibility	 Requires separate processing	 Requires digital hardware	 Alters land management	 Leverages existing assets for downstream production
Existing supply chains & logistics	 Fragmented feedstock(s) & distribution	n/a	 Localized implementation	 Aligns with current channels
Farmer familiarity	 If enrolled in organic system	 Adoption emerging	 Behavior changes required at scale	 Same application methods and practices
Scalable certification and traceability	 If enrolled in organic system	 Digital traceability	 Multiple quantifiable levers	 Scalable with carbon markets and market-based mechanisms
Cost-effective emissions reduction	 Variable performance	 Low/negative abatement cost	 Low/negative abatement cost based on practice	 Cost parity with conventional achievable with enabling incentives and policies in place

Takeaways

Up to 1% of global emissions could be reduced through low-emission ammonia fertilizer production. This solution uses technologies that exist today, produces drop-in products with measurable and certifiable emissions reductions, and increases supply chain resilience

Emissions reductions

Low-emission ammonia fertilizer contributes 1% to global greenhouse gas emissions—roughly equivalent to Germany or Brazil's annual CO₂ emissions—and can be decarbonized with existing technology as a drop-in measurable and certifiable replacement

Supply chain resilience

Production pathways with existing technological readiness can become cost competitive with conventional pathways by 2030. In some cases, such as where complementary policies meet high costs, low-emission pathways may directly compete with costlier conventional supply

Ease of use

Low-emission ammonia can be a drop-in to the existing conventional ammonia supply chain, with no need for on-field application changes or changes in equipment and high supply chain and technology readiness



Chapter 2

Why this matters for first movers

Nearly 50%

of the largest fast moving consumer goods companies (FMCGs) have set scope 3 emissions targets, which could be supported by low-emission fertilizer deployment

Up to 30%

of product emissions come from fertilizer production, of which up to 95% can be abated with low-emission ammonia fertilizers

1-3%

of incremental end-product cost increase when adopting low-emission ammonia fertilizers in the production process

Source: Euromonitor International database, accessed Aug 2025; Passport Sustainability Claims Tracker, accessed Aug 2025; McKinsey Catalyst Zero

Nearly half of the largest consumer goods companies have set aggressive scope 3 decarbonization targets, which can be supported by low-emission ammonia fertilizer adoption

Consumer goods are leading agricultural decarbonization

Global consumer goods companies are moving to decarbonize agriculture, with most setting ambitious scope 3 targets that address indirect value chain emissions. For food and beverage firms, agriculture accounts for 50–80% of total emissions,¹ making it the core focus of their strategies.

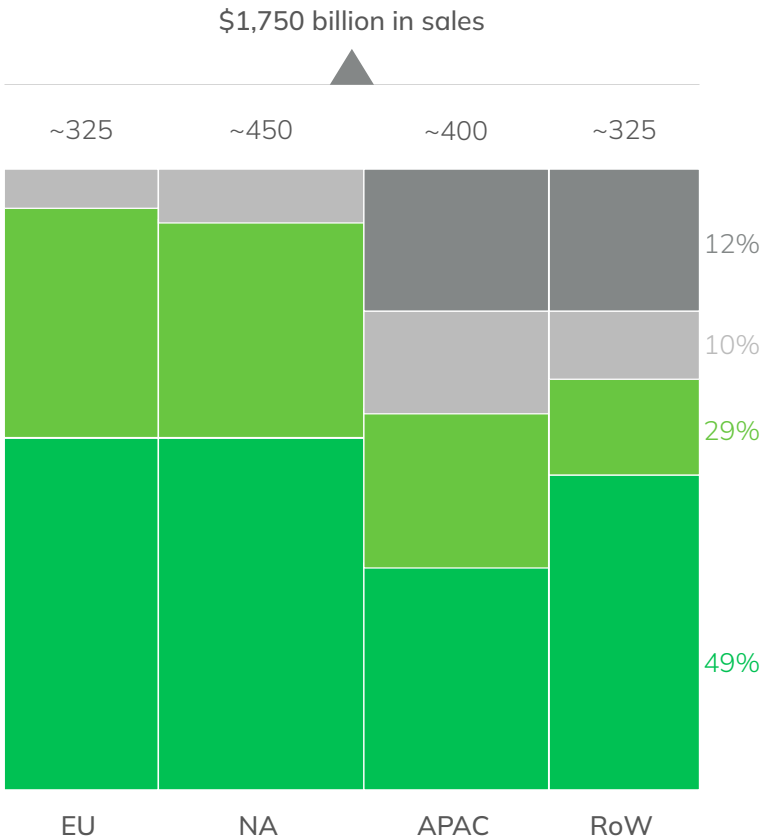
Among the top 20 food and beverage companies by regional sales, nearly 90% have decarbonization targets. More than three-quarters include scope 3 forest, land, and agriculture (FLAG) goals, and almost half have set measurable, time-bound commitments—signaling a shift from ambition to action.

Current initiatives emphasize farm-level measures: capturing livestock methane for renewable natural gas, promoting regenerative agriculture, using organic fertilizers, and improving nutrient use efficiency to cut fertilizer emissions. These efforts are advancing, but the next wave of reductions will require coordinated action across entire systems.

Exhibit 7

Decarbonization targets as of Aug 2025² for 20 largest FMCGs by revenue and geography
\$ billion

Target type: No decarbonization General decarbonization Scope 3 specific Aggressive scope 3



Industry targets

Nearly 50%

Of the largest FMCG companies, equivalent to \$850 billion in sales, have aggressive scope 3 decarbonization targets, with some beginning to take action

>75%

Have specific scope 3 decarbonization targets, which would be directly affected by fertilizer production emissions

Σ = 78%

1. Range across sources, including Manufacturing Digital, World Economic Forum, and company sustainability reports; 2. No decarbonization target: Company does not have a specific, measurable GHG reduction goal. General decarbonization: Any measurable decarbonization target. Scope 3 specific: Decarbonization target specifically mentions Scope 3 emissions. Aggressive Scope 3: Absolute Scope 3 emissions target with more than 40% reduction or FLAG target
Source: Company sustainability reports; Euromonitor International database, accessed Aug 2025; Global data, SBTi; Passport Sustainability Claims Tracker, accessed Aug 2025

Low-emission ammonia fertilizer is a highly scalable lever to reduce food and agricultural production emissions

Fertilizer powers staple crops and consumer goods

Nitrogen fertilizers are indispensable to modern agriculture, especially for nitrogen-intensive crops such as corn, cotton, rice, and wheat. Corn and wheat alone covered more than 400 million hectares (MHa) in 2024. Their importance extends beyond food for a growing population: They supply animal feed and serve as feedstock for sustainable fuels such as ethanol. Roughly 40% of global cropland is dedicated to animal feed. The emissions footprint of nitrogen fertilizers in these systems is therefore substantial.

This road map assesses the potential of low-emission ammonia fertilizers through a consumer basket analysis spanning animal-based products (such as milk and eggs) and everyday goods (such as tomatoes, coffee, beer, and bread). The product-level view shows how targeted interventions can cut emissions while preserving the availability and affordability of daily staples. Low-emission ammonia fertilizers are central to decarbonizing agriculture and advancing a sustainable food system.

Exhibit 8

Crop type	Nitrogen (N) intensity, ktpa N/MHa	Global crop area, 2024 MHa	Consumer goods for analysis
Corn ¹	154	205	Eggs, milk, chicken
Cotton ²	146	40	T-shirts (cotton)
Rice ²	138	160	Rice
Oil palm ³	136	30	n/a
Wheat ¹	121	215	Bread, eggs, milk, chicken
Sugar crops ³	110	30	Sugar
Fruit & vegetables ¹	92	130	Tomatoes
Other oilseeds ¹	76	140	Canola oil, potato chips
Other CG ^{1,4}	59	150	Beer, eggs, milk, chicken
Soybean ³	9	130	n/a
Other crops ^{3,5}	155	225	Potato chips, coffee

Sample consumer basket used in analyses

1. Uses EU N intensity; 2. Uses India N intensity; 3. Uses Brazil N intensity; 4. Coarse grains including barley, buckwheat, millet, rye, quinoa, and sorghum; 5. Includes tubers, legumes, coffee, and lentils
Source: Euromonitor; "Fertilizer use by crop," IFASTAT; "A few facts about livestock and land use," FEAC

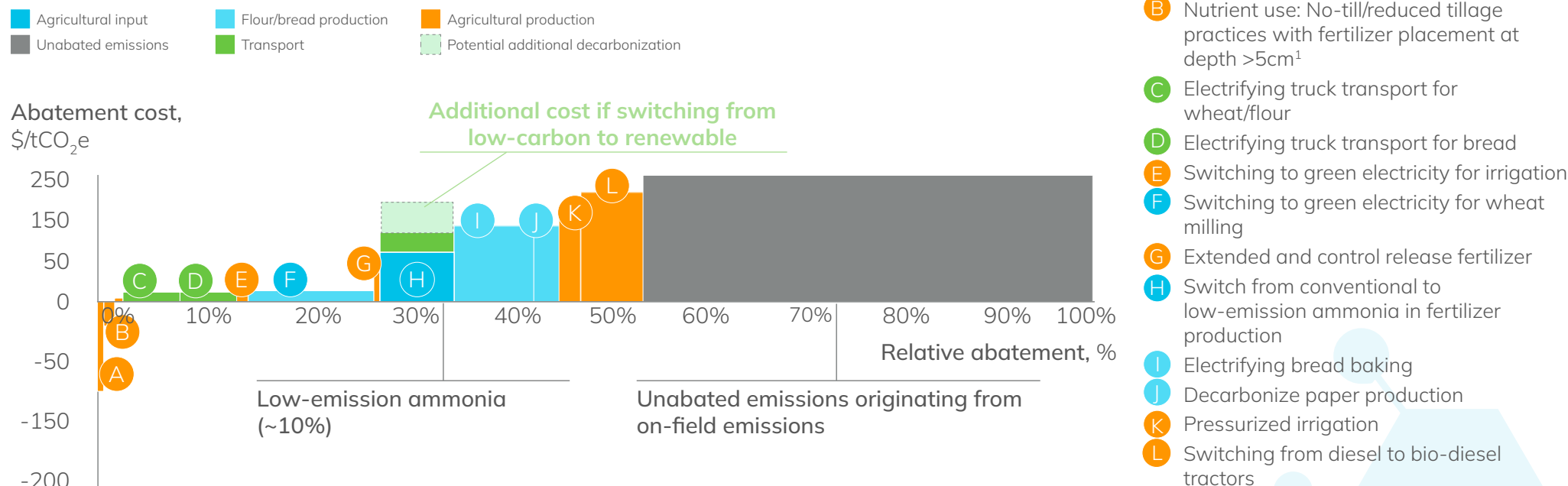
Low-emission ammonia fertilizer delivers competitive abatement costs compared with the electrification of processing and fuel switching in farm equipment

Low-emission ammonia fertilizers: The next cost-effective lever

The marginal abatement cost curve (MACC) ranks decarbonization levers by cost per metric ton of CO₂ abated. Exhibit 9 shows an example for white bread in the European Union. The left side is dominated by farm-level practices, such as regenerative agriculture, that are currently the main focus of food companies. These practices include cover cropping, reduced tillage, crop rotations, optimized nutrient use, and agroforestry. They are generally low-cost and deliver co-benefits, such as healthier soils, better water retention, and resilience to climate shocks. Yet regenerative practices are hard to scale and aggregate, making it difficult to turn farm-level gains into standardized, verifiable reductions at the scale that global supply chains require. The next tranche on the curve is adopting low-emission ammonia at modest incremental cost, though infrastructure investments into renewable energy and CCS networks are needed to scale supply. Further right are capital-intensive measures such as electrifying process heat and deploying low-emission farm equipment (for example, hydrogen tractors). These advances, like low-emission ammonia fertilizers, require up-front investment and new infrastructure. Fertilizers therefore represent the next tranche of agricultural abatement, offering a drop-in option for sizable decarbonization.

Exhibit 9

Illustrative marginal abatement cost curve (MACC) in the EU for white bread, 2030



1. Negative abatements cost and yield optimized to avoid yield outcomes. Greater variation in tillage/fertilizer application likely alters yield outcomes
Source: McKinsey Catalyst Zero; McKinsey Global Hydrogen Trade Flow Model

Bread example: The use of low-emission ammonia fertilizer could reduce emissions by nearly 10 percent at an incremental cost of less than 1 percent across the value chain

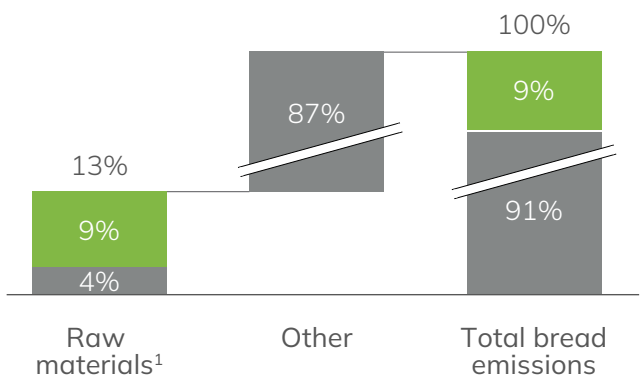
Outsize emissions reduction in final products

A detailed breakdown for bread (Exhibit 10) illustrates the cost-effectiveness of low-emission ammonia fertilizer adoption across the production of food end products. Bread was selected as a representative product with average reduction potential and cost impact.

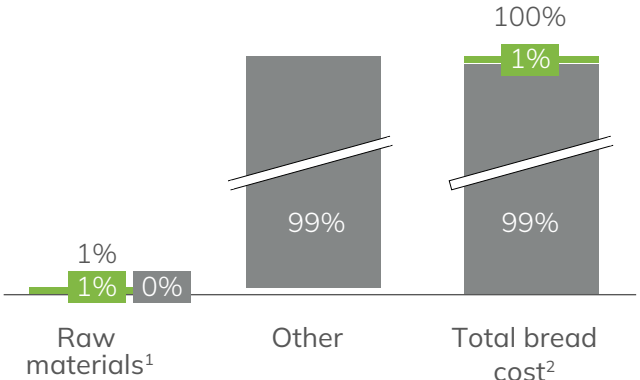
Processing and baking drive more than 80% of bread's cost but only 20% of its emissions. By contrast, ammonia fertilizer contributes less than 1% of cost yet nearly 10% of emissions. Switching to low-emission ammonia fertilizer in the production of wheat would cut almost 10% of emissions with an incremental cost of about 1% of a loaf of bread (at the point of departure for retail sales).² Using higher-cost renewable ammonia at \$850–\$1,000/ton NH₃ raises the cost increase to 1.5–3%.

Exhibit 10

Emissions breakdown, share of total emissions



Cost breakdown, share of total cost



Nearly 10% reduction

potential emissions savings from adopting low-emission ammonia fertilizers in bread production; other products range from 5 to 30%



<1% cost gap with conventional

on product cost when adopting low-emission ammonia fertilizer in existing agriculture processes. Additional products follow

1. Materials purchased by farmers in the growing process, including fertilizer, wheat seeds, sugar, salt, and yeast; 2. Total production cost of bread at departure point for FMCG (ie, packaged in a warehouse, awaiting delivery to final customer)
Source: McKinsey Catalyst Zero; McKinsey Global Hydrogen Trade Flow Model

Across different foods, low-emission ammonia fertilizer can drive product emissions reductions of up to 30 percent, with an incremental cost increase of 1 to 3 percent

Low-emission ammonia fertilizer: High impact, low cost

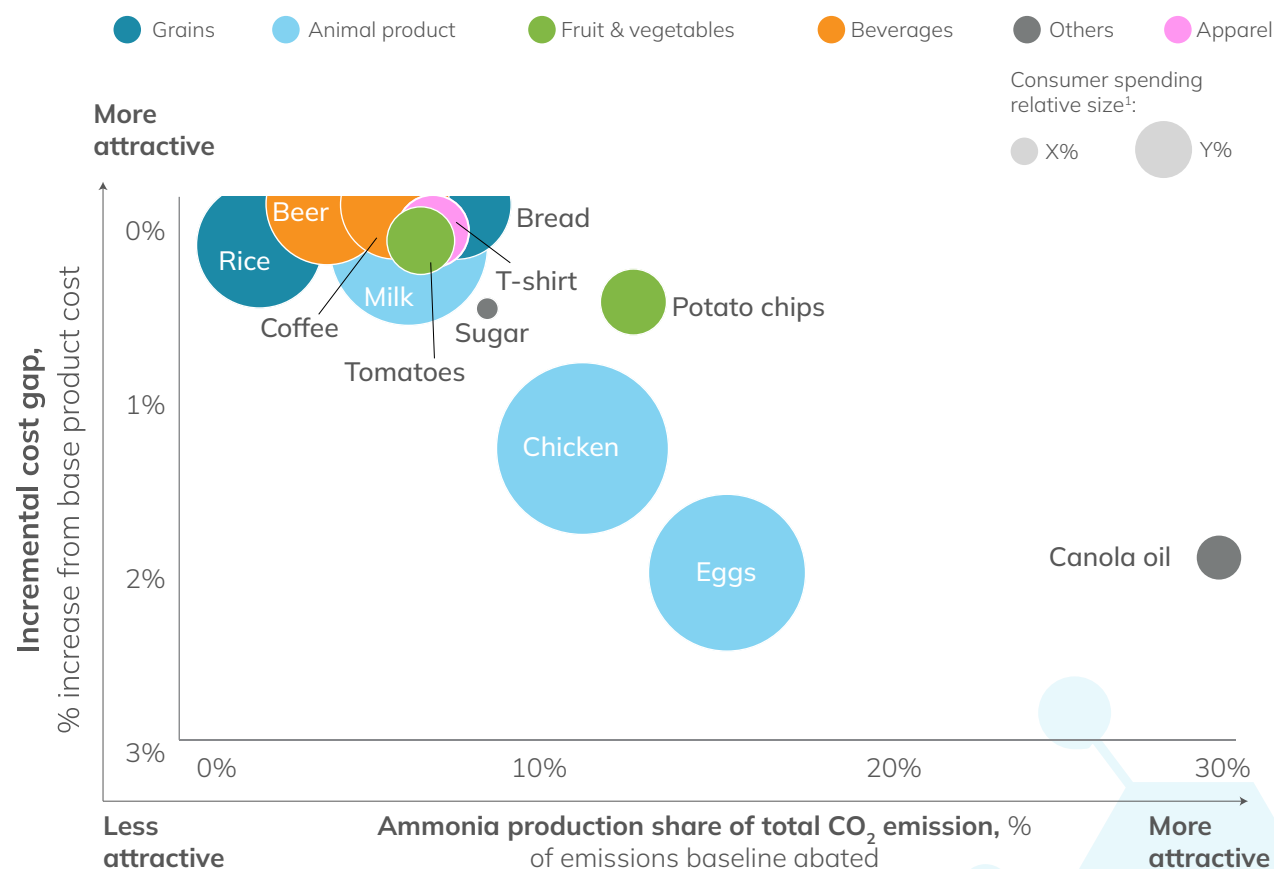
By 2030, low-emission ammonia fertilizers should exhibit strong economic attractiveness across a wide range of consumer goods (Exhibit 11). The x-axis reflects ammonia's share of product emissions; the y-axis shows the incremental cost of switching to low-emission supply.

Because fertilizer emissions scale proportionally with ammonia use, transitioning to low-emission ammonia can deliver meaningful cost reductions. In most cases, emissions savings are achievable with <1% increase in the cost of the end product. Animal protein carries higher incremental costs but also delivers the largest emissions cuts. While any end product cost increase should not be overlooked, it will typically fall far below the premium range for organic products: Product prices have ranged from 20 to 40% above base-product prices³—in some cases over 80% above base-product prices⁴—and can vary by product type.

Cross-basket analysis confirms that low-emission ammonia fertilizer is a cost-effective lever for decarbonizing agriculture—reducing emissions while preserving the affordability of essential consumer goods.

Exhibit 11

Estimated economic attractiveness of low emission ammonia fertilizer adoption (2030), total product cost impact,²
% of base cost increase



1. Based on consumer spending importance as of May 2025 from US Consumer Price Index; 2. Uses ammonia as common denominator as fertilizer input for comparison and low-carbon values used for input ammonia costs; 3. From "Charts of note: Gap between select organic and conventional produce prices has narrowed in recent years," USDA; 4. From "Investigating retail price premiums for organic foods," USDA.
Source: Consumer Price Index as of May 2025, USDA; Eurostat; McKinsey Catalyst Zero

Key takeaways

Scaling adoption of low-emission ammonia fertilizers by first-mover FMCGs is an opportunity to meet their robust GHG emission reduction targets and deliver tangible emissions reductions across consumer goods

Cost-efficient emissions reduction lever

Across a basket of consumer end products, emissions can be reduced through low emissions ammonia fertilizer by 5-30%, with an incremental cost to final end products of 1-3%

Robust FMCG GHG reduction targets

Fast moving consumer goods companies are taking strong stances on reducing their scope 3 emissions portfolio in a cost-effective manner, but need a mechanism to share the benefits and risks associated with being a first mover

Next meaningful decarbonization lever

On the decarbonization MACC curve, adopting low-emission fertilizers is the next large emission reduction lever, but requires collective efforts to unlock



Chapter 3

Barriers & actions to accelerate deployment

Demand activation at scale

Activate demand and secure supply through first mover industry alliances

Policy incentives and financial risk-reward sharing instruments

Advance public policy and financial instruments to de-risk early mover projects and close the cost gap

Evidencing and reporting GHG emissions reductions

Promote the adoption of low-emission ammonia and fertilizer standards and market-based solutions, including those that enable FMCGs to claim emission reductions

Key barriers at a glance: Challenges to adopt low-emission ammonia fertilizers includes demand, cost gap and GHG tracking

Scaling adoption requires unlocking demand, cost, and tracking barriers

Low-emission ammonia fertilizers are technically viable and increasingly cost competitive, but several barriers still slow deployment. On the demand side, commitments remain fragmented and uncertain, making it hard to aggregate sufficient offtake to unlock investment. On the cost side, low-emission fertilizers still carry a premium, and without mechanisms to share risk and bridge the gap, many projects stall before FID. Finally, the absence of robust, standardized systems for evidencing and reporting GHG reductions undermines credibility and prevents consumer goods companies from confidently claiming scope 3 benefits. Overcoming these barriers in parallel is essential to move from pilots to a scalable market.

Exhibit 12

Challenges for low-emission ammonia fertilizer adopters



Fertilizer producers

Fertilizer producers need to secure returns from costly and capital-intensive new investments that will operate for decades

- Face risk from uncertain/fragmented demand in an existing, highly competitive global commodity market
- Require firm offtake for project financing
- Rely on downstream demand to commit early



Growers

Growers need assurances they will be compensated for any material cost changes

- Limited ability to commit to multi-year offtake
- Sensitive to input cost increases
- Require user-friendly monitoring and reporting systems for low-emission ammonia fertilizer usage



FMCGs

FMCGs need confidence in supply availability and the ability to deliver cost-competitive GHG emissions reductions with ability to evidence and claim these reductions

- Meet scope 3 targets cost effectively
- Limited ability to pass costs to consumers
- Open to share incremental end-product cost across value chain
- Require market-based solutions to evidence and claim GHG emission reductions achieved with low-emission ammonia fertilizer deployment

Summary of barriers and actions for adoption



Demand activation at scale

Circular dependency results in players waiting for other first movers



Policy incentives and financial risk-reward sharing instruments

No single actor wants to bear the total cost increase—requiring a system of risk and benefit sharing



Evidencing and reporting GHG emissions reductions

Recognized certification and verification systems and chains of custody are needed to demonstrate emissions reduction

Demand activation at scale – industry led: Other similar alliances provide examples to learn from

Industry alliances strengthen demand and build trust

Industry-led alliances have already shown that collective demand can unlock new markets and derisk first-mover projects. The Sustainable Aviation Buyers Alliance (SABA) has secured nearly 50 million gallons of SAF certificates for 2024, ZEMBA has launched collective tenders covering over a billion ton-miles of zero-emission shipping, and Frontier has aggregated 1.5 Mtpa of carbon-removal commitments. These successes demonstrate that when offtakers join forces, they can send clear market signals, reduce risk for producers, and attract large-scale investment.

Robust GHG tracking and third-party verification are common features across these alliances, providing the transparency and credibility needed to build trust among first movers, financiers, and regulators. By embedding verified carbon accounting into their frameworks, these initiatives are not only activating demand but also laying the foundation for scalable, market-based mechanisms in other sectors—including for ammonia-based fertilizers.

Exhibit 13

	Sustainability first-mover alliances		
	 Sustainable Aviation Buyers Alliance	 Zero Emission Maritime Buyers Alliance	 Frontier
Overview	Sustainable aviation fuel alliance connecting producers with airlines	Shipping credit alliance for CPGs to purchase zero-emission shipping credits	Aggregate corporate demand for carbon offsets to unlock early technologies
1. Volumetric commitment	Nearly 50 million gallons SAF certificates that corporate customers committed to in 2024	1.15bn TEU-nm/year (twenty-foot equivalent unit nautical miles/year). First auction result for a minimum three-year duration	1.5 Mtpa CO₂ Aggregate advance market removal commitments as of 2025
2. Abatement price	\$135–\$800/t CO₂ Range of abatement cost for 1G and 2G sustainable aviation fuels ²	N/A Relies on a bidding process to aggregate demand	~\$380/ton CO₂ Average cost ¹ , with end goal of <\$100/ton CO ₂
3. Regions	Global	Global	Global
4. Environmental Attribute Credit type	SAF certificates (SAFc) Book-and-claim based on different SAF types	Scope 3 emissions reduction. Book-and-claim based on quantified emissions reduction	Carbon removal units (CRU) ROFO (right of first offer) for buyers in prepurchase and offtake agreements
5. Methodology	3rd-party verification Providers must demonstrate compliance with sustainability criteria and life cycle emissions accounting	3rd party verification Nonprofit entities to prove emissions reduction verification	Technical review team Network of technical experts to evaluate carbon removal technologies
6. Procurement method	RFPs and member database Secure online platform to connect buyers with SAFc providers	Targeted tenders Collective forward procurement aggregates shipping demand of members	Member database Growing list of companies joining to buy permanent carbon removal

1. As of August 2025 where \$595M had been contracted by credit purchasers for 1.5M tons CO₂; 2. Lower range for HEFA 2nd generation, post-incentives in US, upper range Alcohol to jet (AtJ) before incentives
Source: Sustainable Aviation Buyers' Alliance press releases and website, Zero Emission Maritime Buyers' Alliance press releases and website, Frontier Climate press releases and website; McKinsey Sustainable Fuels Cost Model

Demand activation at scale – industry led: Potential design features of a demand activation mechanism for an industry-led coalition

Choosing smart, early design features for an industry-led coalition can support ambitious growth

The examples from the prior page show that choosing smart, early design features is essential to supporting ambitious growth. The first emerging example alliances in fertilizers show how design levers can enable coalitions to scale effectively, as seen in the Low-Carbon Fertilizer Alliance (right). Choosing early design features means balancing ambition with practicality. In establishing initial coalitions, levers and design features need to be established to support practical growth and scale and to incorporate the needs of both suppliers and users, such as realistic volume commitments and purchase methods. For FMCGs, design levers must also include considerations that allow them to claim emissions reductions from the production of low-emission ammonia.

Any coalition will need to align on standards proposed by both upstream and downstream sides. Approaches that are being used include establishing certified product traceability and market-based mechanisms. Producers of low-emission ammonia fertilizers seek voluntary certification of their product, and farmers and FMCGs track and trace certified low-emission ammonia fertilizer throughout the value chain.¹ FMCG buyers then claim verified reductions, using an inseting approach in which they purchase low-ammonia attributes directly from ammonia fertilizer producers.²

Environmental attributes should align with policy definitions and recognized standards to avoid duplicate verification and ensure claims are accepted across markets.

Exhibit 14

Levers and potential design features for an industry-led coalition

1. Volumetric commitment, Mtpa ammonia

2. Carbon abatement price (up to x), \$/t CO₂e

3. Regional scope

4. Environmental Attribute Certificates accounting method

5. Methodology

6. Purchase method



Industry example

Low Carbon Fertilizer Alliance

1 Mt CO₂e reductions committed globally to date through 2030 with a large pipeline of projects

\$8-35/t CO₂e. Range of abatement cost based on intervention type and geography

Global

Scope 3 emission reduction, book-and-claim based on quantified emission reduction

3rd party verification Alliance-led technical review team to identify best fit methodologies based on project specifics

Targeted tenders. Collective procurement with spot and forward purchased commitments

1. Depending on customer preference, this may entail a segregated supply chain through the use of a mass balance approach or could use book-and-claim chain of custody methods for certified low-emission products; 2. Such mechanisms could be managed through tender facilitation, contract deal room, or dedicated RfP database based on standardized contracts and pilot tenders to provide early price signals and reduce transaction costs, without disrupting logistics or maintaining segregated agri-food value chains, thereby providing for a simplified transactional process with fewer participants. FMCGs or others may seek to manage the environmental footprint of agricultural supply chains by assessing emissions, water use, and other impacts within specific geographic sourcing areas ("sheds") rather than at the individual farm level and could incorporate the use of low-emission ammonia fertilizer in those systems
Source: 3Degrees; Low Carbon Fertilizer Alliance

Demand activation at scale–policy-led: Market-based instruments from policy makers can help close the cost gap and activate demand

Learning from existing CfD schemes and auction platforms

While industry-led demand activation is critical, policy-led instruments should also be employed to scale and activate demand. Existing incentives designed for renewables, hydrogen, and derivatives provide examples of market-based instruments to help close the gap between low-emission solutions and traditional products. These instruments reduce exposure to price volatility, providing long-term offtake contracts with strike-price formulas. These solutions help derisk early-mover projects and attract financing.

Lessons learned from CfDs and auction platforms can inform dedicated instruments for fertilizers and help scale and accelerate adoption.

Exhibit 15

Market-based instruments for unlocking early supply and demand

Example programs	Description	Transferrable features
UK Renewables CfD	Government guaranteed fixed strike prices through CfDs, reducing investor risk and creating long-term certainty	Set strike and reference prices to guarantee revenue and bridge cost gap
Japan CfD for Ammonia/H2	Government offers CfD to bridge cost gaps	Provide long-term certainty for suppliers and buyers (20y take-or-pay offtake contracts)
Korea CHPS	CfD scheme aggregated corporate demand for clean hydrogen/power supply	Mandate low-emission product quotas to create guaranteed demand pools supported by carbon reduction goals
India Green Ammonia Auction (SIGHT)	Government auctioned capacity, awarding long-term contracts to match producers with fertilizer buyers	Run competitive auctions to secure cost-efficient supply
Aggregate EU	EU platform pooled demand across buyers, matched bids with suppliers, and ensured supply security	Use a central demand platform to pool buyers and match them with suppliers
H2Global	Intermediary signs long-term purchase contracts with producers to re-sell to shorter-term buyers	Run competitive auctions on the supply and demand side
U.S. Production Tax Credit (PTC) and Investment Tax Credit (ITC) for Wind and Solar	Investible tax credits provide certainty and transparent cost-gap mechanisms that provide investors and developers to reach FID	Provide certainty and transparent cost reductions

Source: UK Renewables CfD, Japan's Hydrogen Society Promotion Act (CfD subsidy), Climate Policy Database, India SIGHT Scheme, AggregateEU, Inflation Reduction Act

Policy incentives and financial risk-reward sharing instruments: Public and financial institutions have multiple instruments to de-risk first mover projects

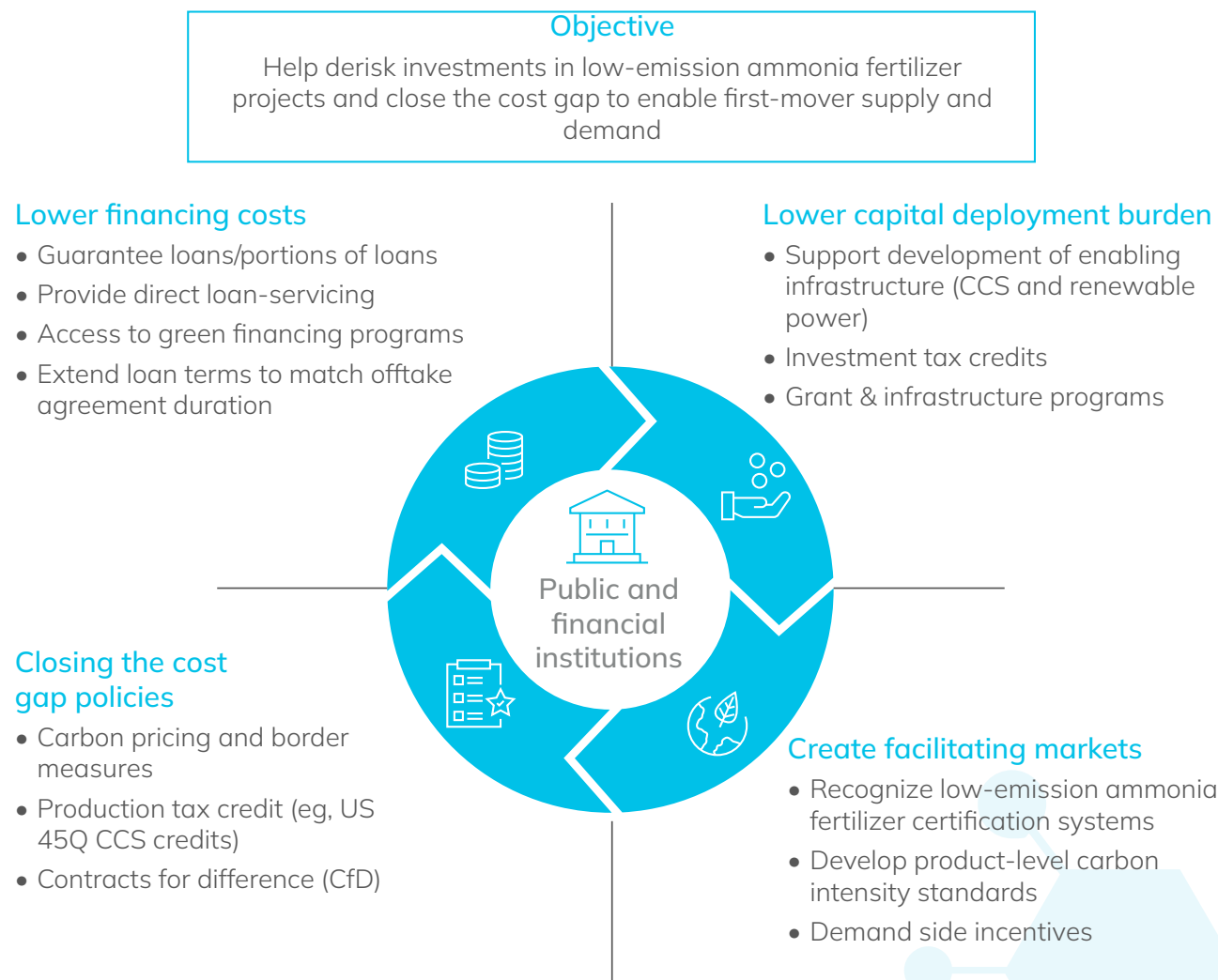
Finance instruments and policy incentives can help close the cost gap

In addition to demand activation, policy incentives can also be employed to overcome challenges to adoption. To overcome this challenge, governments, banks, including multilateral development banks, and financial institutions can play a critical role in unlocking a new wave of low-emission projects. Potential levers include the following:

- Develop targeted derisking facilities for capital-intensive investments in low-emission ammonia fertilizer assets.
- Roll out blended-finance instruments that combine concessional public funds with private capital to reduce borrowing costs for value chain actors in developing markets.
- Reduce the cost of capital for low-emission fertilizer projects through targeted bonds, favorable debt conditions, and lower capital requirements for financial institutions providing such loans.
- Support farmers adopting low-emission fertilizers with financial incentives and credit instruments, training and capacity building, and improved access to premium markets for low-emission crops.

Policy incentives on the production side of low-emission ammonia, which remain critical, include carbon pricing, carbon border adjustments, and instruments such as tax credits. In the United States, the Section 45Q tax credit has proved to be an effective policy instrument to advance cost-effective production of CCS-enabled ammonia, and the 45V tax credit may provide some incentives for renewable ammonia production.

Exhibit 16



Source: EU H2Bank; US Inflation Reduction Act

Evidencing and reporting GHG emissions: Recognizing key market-based instruments can enable FMCGs to claim GHG emissions reductions from low-emission fertilizer uptake

Industry-wide standards and market-based instruments for claiming GHG emissions reductions by FMCGs are key to unlocking scale

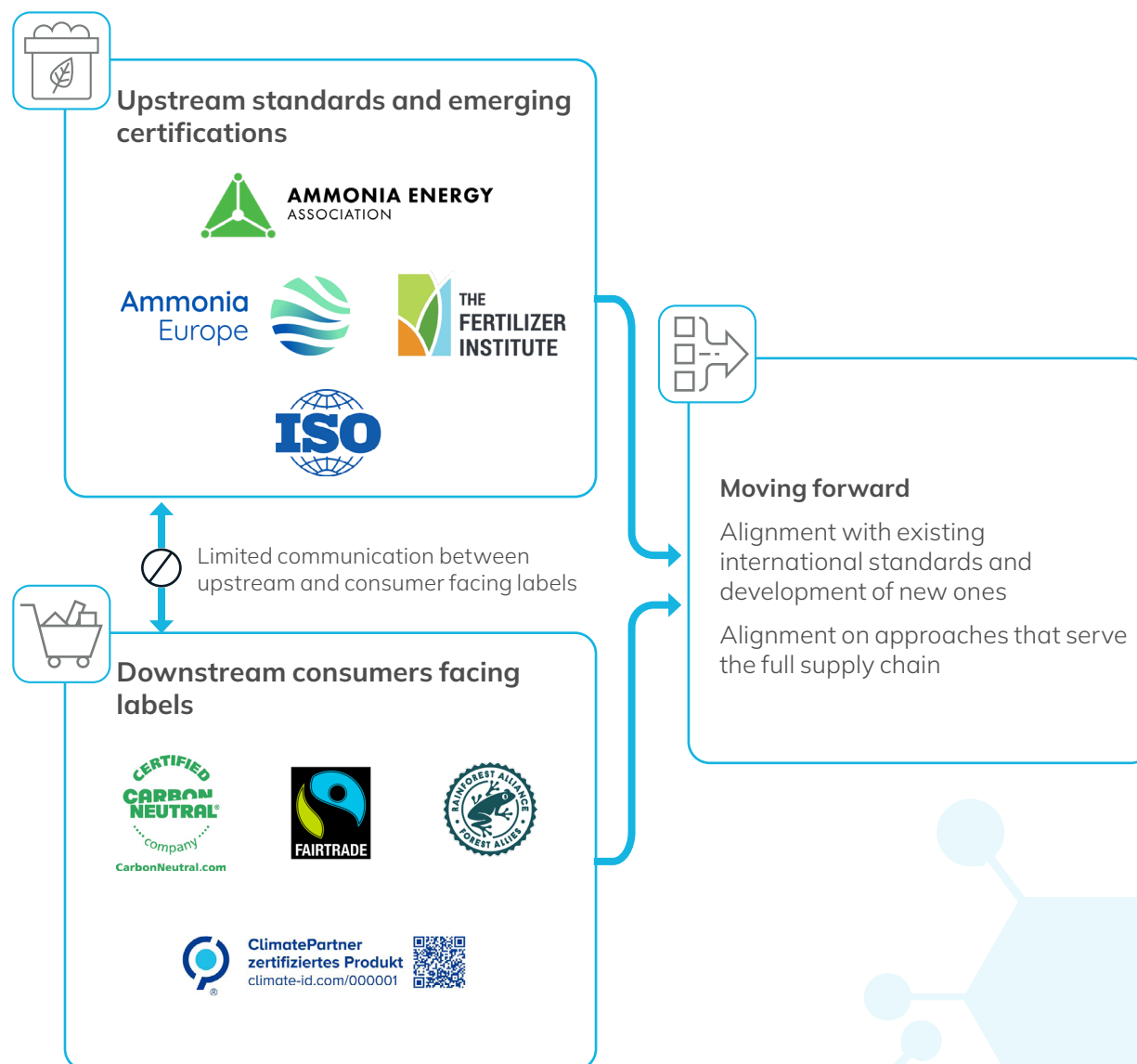
Lastly, there is a need to evidence and report emissions reductions. To this extent, unlocking the potential of low-emission ammonia fertilizers will require robust, industry-wide GHG assessment standards and credible, efficient certification solutions to evidence reductions for end-users.

Standards and certification frameworks for ammonia are already being developed by groups such as Ammonia Europe, the Fertilizer Institute,¹ and the Ammonia Energy Association, feeding into global voluntary standards aligned with the International Organization for Standardization, though most efforts currently do not move beyond ammonia production into fertilizer production. Coordinating these producer-driven efforts with those of FMCGs will unlock the full climate value of low-emission adoption.

Key practical actions include:

- **Align with emerging standards** for low-emission ammonia, fertilizers, crops, and consumer goods to ensure interoperability, reduce transaction costs, unlock lead markets, and enhance transparency and verifiable claims across the value chain.
- **Develop credible market-based mechanisms**, particularly transparent and credible systems for environmental attribute certificates, to enable FMCGs to invest confidently in fertilizer decarbonization at scale.
- **Align mechanisms with global standards**—such as certification systems, Greenhouse Gas Protocol, and the Science Based Targets Initiative (SBTi)—to reduce fragmentation, ensure consistent scope 3 accounting, and provide verifiable claims that underpin offtake commitments.

Exhibit 17



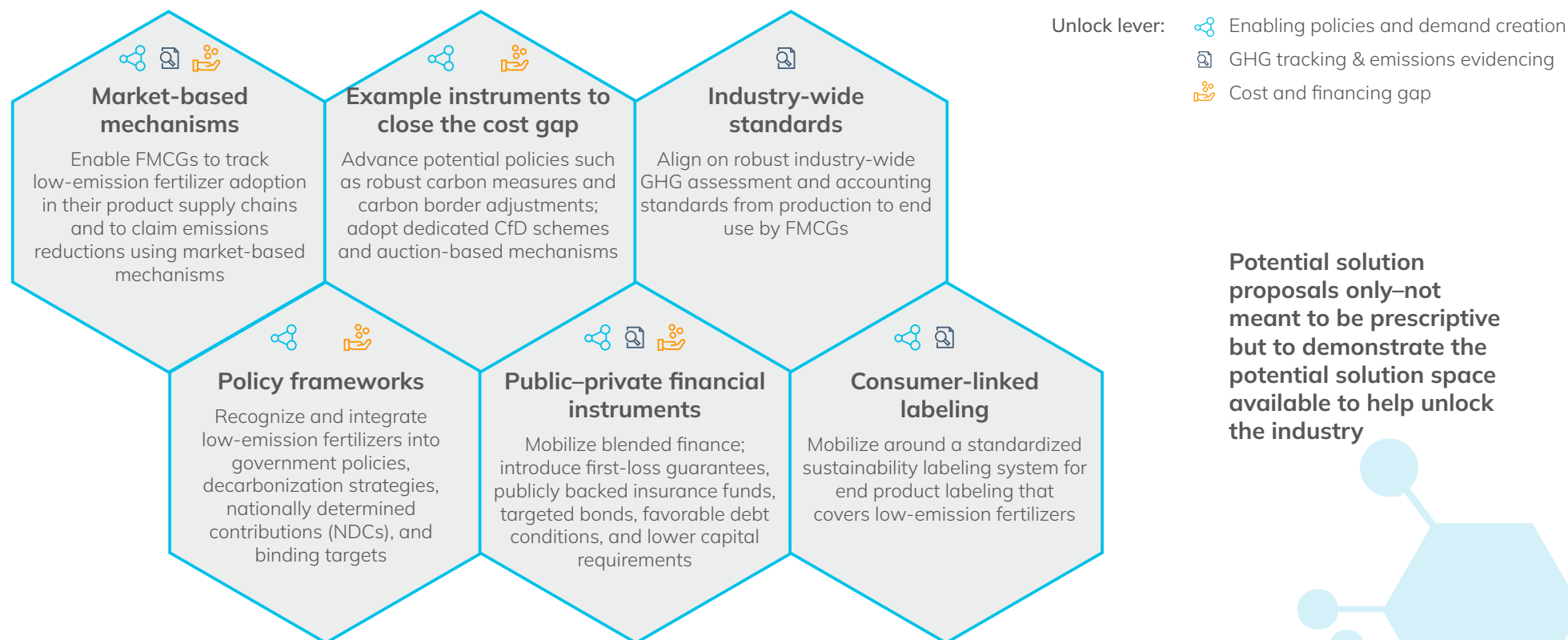
1. The Fertilizer Institute addresses fertilizer products beyond ammonia. The other upstream bodies have to date been focused on ammonia production only
Source: The Fertilizer Institute

Summary: To unlock deployment at scale, a range of potential solutions should be considered over the next 24 to 36 months

Building on progress to date, further steps to scale low-emission ammonia fertilizer supply and demand drivers could be considered and advanced

Decarbonizing fertilizers is a distinct challenge compared to other early industries due to the complexity of the global market and relationships among fertilizer producers, growers, and consumer goods companies. While existing industrial decarbonization literature has emphasized tools such as carbon contracts for difference, book-and-claim systems, and standards for steel, cement, and aviation,¹ the agri-food value chain has an additional layer of complication. Market-based solutions, including those that link consumer-facing companies with fertilizer producers through auditable, transferable certification, are needed to push the industry forward.

Exhibit 18



1. See, eg, Nilsson et al., "An industrial policy framework for transforming energy and emissions-intensive industries towards zero emissions," Climate Policy, 2021, Volume 21, Number 8; Industrial Transformation 2050, Material Economics, 2019

Summary of findings: Unlocking low-emission ammonia fertilizers at scale

Summary of findings

Fertilizers are essential to global food security but require an energy- and emission-intensive production process

Sustain nearly half the world's population through higher yields

Critical to economic stability and agricultural productivity

Responsible for 1% of global GHG emissions

Technology exists today to cut emissions by >95%, making this a cost-effective decarbonization lever

Proven pathways: Renewable electrolysis and CCS-enabled reforming

Measurable drop-in solutions into existing value chains among a suite of other decarbonization levers

Adoption adds an incremental 1–3% to end product costs while cutting up to 30% of product-level emissions

Low-emission ammonia fertilizer supply is ready to move forward—but faces barriers

15 Mtpa of projects already past FID

Existing facilities can be updated with lower emissions technology

Despite large announcements, more projects struggle to take FID due to cross-value-chain barriers and high costs of initial capital investments

Three main barriers prevent adoption, and cross-value-chain coordination is the solution

Demand aggregation across a fragmented agri-food value chain

Closing the cost gap by enabling policy and financial mechanisms

Tracking GHG emissions reductions to build credibility in claims

> Moving forward

Aggregate and activate demand across the value chain to pool commitments, send strong market signals, and create the scale needed for financing and adoption

Reduce risk, accelerate FID, and send a strong market signal

Use pooled offtake and tenders to match supply with demand in a derisked environment (eg, through industry alliances)

Close the cost gap through effective policy and financial instruments to derisk projects, mobilize capital, and support farmer adoption of low-emission fertilizers

Align trade and disclosure frameworks to ensure competitiveness and avoid fragmentation

Support farmers and producers through derisking tools such as guarantees

Deploy policy programs—carbon pricing, CfDs, border adjustments

Advance and align certification, GHG tracking, and market-based mechanisms to scale low-emission fertilizer adoption

Align with already-operational industry low-emission ammonia certification systems to provide creditable and verifiable information

Support common, credible GHG tracking system to cut transaction costs and foster farmer uptake

Enable FMCGs to claim scope 3 reductions while farmers adopt fertilizers seamlessly

Develop market-based mechanisms, downstream certifications



Appendix 1

Selected deep dives

Regional deep dives and early movers in the emerging low-emission ammonia market

Regional deep dives

Differences in barriers and adoption drivers across the high-potential geographies of the European Union, India, and Brazil

Project case studies

Overview of first mover projects and agreements that highlight factors for success

Regional deep-dives and first mover projects: Early potential and success cases are emerging globally, with regions and projects ready to meet the moment

Donaldsonville

CF Industries low-carbon ammonia production in operation

Blue Point

CF Industries, JERA, and Mitsui & Co. low-carbon ammonia production, commercial operation 2029

Villeta renewable ammonia and fertilizer

Atome calcium ammonium nitrate (CAN) fertilizer production from Itaipu dam energy

Yara & PepsiCo

Agreement to supply low-emission fertilizer across 5 countries in Europe

SIGHT Auctions

India completed a successful tender for 724 ktpa NH_3 in 2025

Fertiglobe-H2Global

Fertiglobe's winning H2Global bid to supply into the EU

Below 500 ktpa

Above 500 ktpa

Regional deep-dives follow

Regional case study on barriers and potential: European Union



EU: Supportive regulation and willingness to pay for sustainable products make it a suitable region for using low-emission ammonia fertilizers

Context:

The European Union is advancing adoption of low-emission ammonia fertilizers through mandates—eg, REDIII (Renewable Energy Directive III)—and market tools (eg, CBAM). Farmers are rapidly adopting tracking technologies, and consumers show strong willingness to pay—55% of food and beverage spend carries a sustainability claim (mostly organic).

Barriers:

- **Cost gap:** Beyond Scandinavia and Iberia, production of low-emission ammonia fertilizers remains expensive without incentives, given modest renewables and limited CCS.

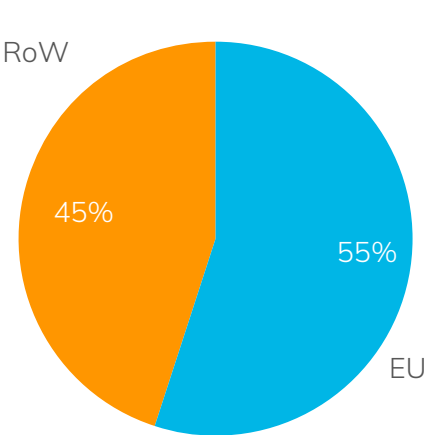
Potential roadmap to address barriers:

The EU is well placed to market low-emission food. Closing gaps will require robust tracking systems, direct production incentives, and selective imports of low-emission ammonia or fertilizers.

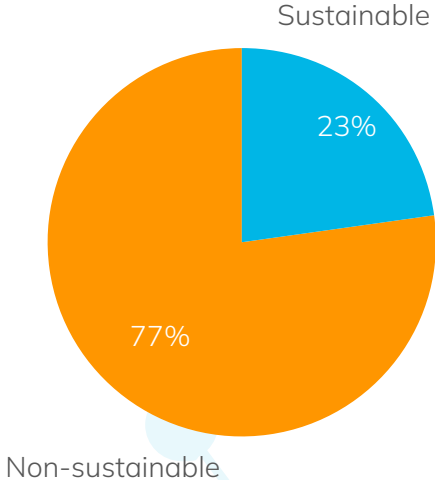
Region metrics	~13Mtpa NH ₃ consumption (pa) ¹	~\$450 billion Total agricultural production ²	~\$700 billion Spending on food & beverages across core products ³
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Sales of products with sustainability claims in food & beverage categories, %

EU spend as percentage of world spend⁴



EU sustainable spend excluding organics as percentage of EU spend



1. 2024 for EU+UK values for crop N-Nutrient demand equivalent of NH₃ (~82% of NH₃ content is N); 2. Gross Production Value from UN FAO for 2023 for EU + UK; 3. Encompasses six categories: hot drinks, cooking ingredients and meals, dairy products and alternatives, staple foods, snacks, and soft drinks; 4. Represented by 8 European countries and 17 RoW countries representing ~75% of global spend due to data availability

Source: Euromonitor International database, accessed Aug 2025; FAO; Fertecon; "Fertilizer use by crop," IFASTAT; Passport Sustainability Claims Tracker, accessed August 2025; McKinsey Global Hydrogen Trade Flow Model

Regional case study on barriers and potential: Brazil



Brazil: Regional characteristics show potential for low-emission food exports

Context:

Brazil is a leading crop grower and exporter with a renewable grid dominated by hydropower, which creates favorable conditions for renewable ammonia. Heavy reliance on imported fertilizers also makes low-carbon imports viable. Inland logistics can add up to \$330/t NH₃ equivalent, making domestic production more attractive inland and imports more competitive at the coast.

Barriers:

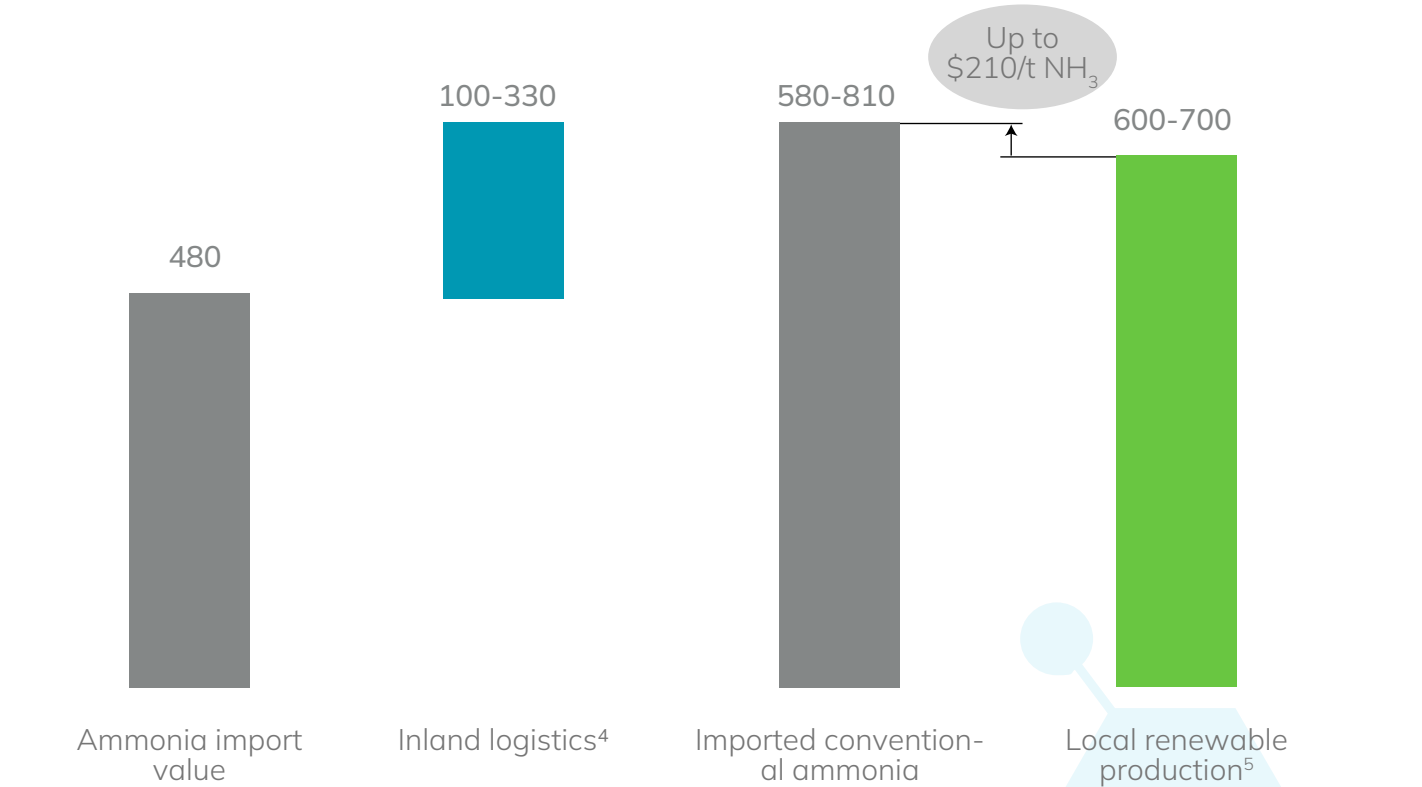
— **Cost gap:** Significant investment is needed to establish inland renewable low-emission ammonia fertilizers facilities, while imports require incentives to offset the premium.

Potential roadmap to address barriers:

Brazil can leverage low-emission fertilizers to grow low-emission row crops for export to regions with higher willingness to pay. The cost gap could be bridged through firm offtake commitments or government or multilateral guarantees. Coastal regions may favor imports, while inland areas could focus on renewable production and specialty export crops.

Region metrics	~7Mtpa NH ₃ consumption (pa) ¹	~\$350 billion Total agricultural production ²	~\$165 billion Spending on food & beverages across core products ³
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Imported conventional ammonia cost vs 2030 local renewable ammonia cost in Brazil, inland use, \$/tNH₃



1. 2024 values for crop N-Nutrient demand equivalent of NH₃ (~82% of NH₃ content is N); 2. Gross Production Value from UN FAO for 2023 values; 3. Encompasses six categories of: hot drinks, cooking ingredients and meals, dairy products and alternatives, staple foods, snacks and soft drinks; 4. Inland logistics can be up to 330 \$ton/NH₃; 5. Based on firm-hydropower sourced at \$35-40/MWh
Source: IFA, Fertecon, FAO, Euromonitor International database, accessed August 2025; Passport Sustainability Claims Tracker, accessed August 2025; McKinsey Global Hydrogen Tradedflow Model

Regional case study on barriers and potential: India



India: Announced investments show potential for renewable-ammonia production for the global market

Context:

India’s agriculture sector is among the world’s largest, with a fragmented farmer base but centralized fertilizer purchasing. Strong government support, such as the National Green Hydrogen Mission support schemes, and low capital expenditure costs give India rising potential in decarbonization and as a renewable-energy exporter.

Barriers:

- **Lack of firm demand:** Indian consumers have limited purchasing power for low-emission products.
- **Financial instruments:** Support for introducing low-emission into the domestic supply, which currently relies on fossil imports, once the industry is proven at scale for export.

Potential roadmap to address barriers:

India has strong potential for renewable production, but most crops serve domestic consumers with limited purchasing power. One path is to focus on exporting renewable ammonia and supporting the development of additional export infrastructure. Another is to grow specialty export crop systems (such as tea, cotton, and spices) for markets with higher purchasing power to build a dual track of demand from ammonia and crops.

Region metrics	~25Mtpa NH ₃ consumption (pa) ¹	~\$600 billion Total agricultural production ²	~\$125 billion Spending on food & beverages across core products ³
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Renewable ammonia project capacity in India with COD by 2030, Mtpa NH₃

Project status

Announced



10

Feasibility and FEED



0.5

FID+



0.8

Total potential by 2030



11.3

1. 2024 values for crop N-Nutrient demand equivalent of NH₃ (~82% of NH₃ content is N); 2. Gross Production Value from UN FAO for 2023 values; 3. Encompasses six categories: hot drinks, cooking ingredients and meals, dairy products and alternatives, staple foods, snacks, and soft drinks
Source: Euromonitor International database, accessed Aug 2025; FAO; Fertecon; "Fertilizer use by crop," IFASTAT; Passport Sustainability Claims Tracker, accessed August 2025; McKinsey Global Hydrogen Trade Flow Model

Low-emission case studies: India's Renewable Ammonia Auctions (SIGHT Scheme)

Companies involved	Sun for Ever Ministry of new and renewable energy				
Location	Capacity	Status	COD	Pathway	Offtake
Multiple projects across India	724 ktpa NH ₃ (across 7 producers)	1st round completed 2025	Deliveries starting 2027	Renewable	10-year contracts across 13 offtakers in fertilizer manufacturing

Project description

Under the National Green Hydrogen Mission, India launched renewable-ammonia auctions through the SIGHT Scheme (Mode-2A), managed by the Solar Energy Corporation of India (SECI). These competitive reverse auctions aggregate demand from fertilizer companies and award long-term supply contracts to developers at fixed tariffs.

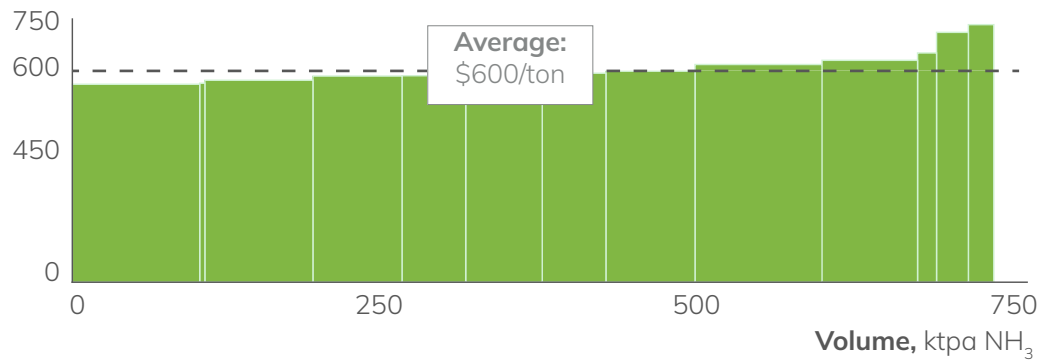
Winners include ACME Cleantech Solutions, Jakson Green, NTPC Renewable Energy, and Oriana Power, with projects located in Odisha, Andhra Pradesh, and other renewable-rich states. Prices have fallen rapidly, with record lows of 50.75–55.75 Indian rupees per kg (average of \$600/t),¹ making renewable ammonia increasingly cost competitive. Contracts typically span 10 years, with assured offtake and payment security mechanisms to derisk investment.

Lessons learned

India's auctions show how transparent, competitive procurement can accelerate cost discovery and scale deployment of renewable ammonia. The reverse-auction model has driven tariffs down by nearly half compared to early international benchmarks, proving the value of aggregated demand and long-term certainty. By tying offtake directly to domestic fertilizer producers, the scheme addresses one of the sector's biggest barriers—market risk—while also reducing import dependence.

The auctions also highlight the importance of policy alignment and subsidy design: SECI's fixed incentive structure under the SIGHT Scheme bridges the cost gap in the early years, while gradually phasing down support as costs fall. Finally, the geographic spread of awarded projects demonstrates how India's renewable-resource base—from solar in Rajasthan to wind in Gujarat and hydropower integration—can underpin a diversified, resilient ammonia supply chain.

Auction buyers by bid and cleaning price, ktpa, \$/ton NH₃



Suppliers and buyers of the 2025 ammonia auction; data obtained from SECI

1. Conversion rate: 1 Indian rupee = \$0.011
Source: AEA; H2Global, SECI; S&P

Low-emission case studies: Blue Point Ammonia Facility in USA

Companies involved	CF Industries	Jera	Mitsui		
Other Partners	Linde	Topsoe	Technip Energies	OXY	
Location	Capacity	Status	COD	Pathway	Offtake
Louisiana, United States	1.4 mtpa ammonia	FID (taken in Q2 2025)	2029	Low-carbon	JV partners to offtake according to ownership share (CF 40%, JERA 35%, Mitsui 25%)



Blue Point | Aerial project rendering of Blue Point production facility | image provided by CF Industries; for illustration purposes only

Project description

Blue Point, which will produce approximately 1.4 million metric tons of low-carbon ammonia per year, is projected to start operations in 2029. The project will leverage carbon capture, utilization, and storage (CCUS) processes to permanently sequester approximately 2.3 million metric tons of CO₂ per year, reducing CO₂ emissions by more than 95% compared to conventional ammonia.

This project will build on CF Industries' existing footprint in low-emission ammonia. The company initiated low-carbon operations at its Donaldsonville Complex in July and is already delivering tens of thousands of tons of certified low-carbon ammonia, certified under the Verified Ammonia Carbon Intensity program.

Lessons learned

Advancing low-emission projects in these early stages of the ammonia transition will require leading industry expertise, a shared vision, and partnerships with industry leaders. CF Industries, JERA, and Mitsui & Co. share a vision for the future of low-carbon ammonia that enabled these global leaders to join together to leverage their expertise across ammonia project development and operations, worldwide distribution, and end use to help grow a reliable and affordable low-carbon ammonia value chain. The project benefits from a shared ownership and offtake structure and leverages partnerships with industry-leading firms to reduce risk across engineering, procurement, industrial gas supply, and CO₂ transport and sequestration.

Strategically located on the US Gulf Coast, the Blue Point project benefits from access to US resources, deep-water access to enable exports, and developing carbon capture and sequestration infrastructure.

Source: CF Industries

Low-emission case studies: PepsiCo & Yara long-term low-emission fertilizer partnership in Europe

Companies involved	Yara	PepsiCo Europe		
Location	Capacity	Status	COD	Pathway
Across 5 countries in Europe	165 ktpa ammonia	Long-term partnership	2030-target for full fertilizer supply from Yara Climate Choice	Low-carbon & renewable

Project description

PepsiCo Europe and Yara have launched a long-term partnership to equip farmers across multiple European countries with precision-agriculture tools, crop nutrition programs, and low-emission fertilizers to reduce the carbon footprint of crop production. The collaboration aims to supply up to 165,000 metric tons of fertilizer annually, about 25% of PepsiCo's European fertilizer needs. The delivered fertilizer will be a mix of Yara's standard premium nitrate-based fertilizers and Yara Climate Choice fertilizers produced from renewable or low-carbon ammonia—with the goal of fully switching to Climate Choice fertilizers by 2030.

Lessons learned

This long-term agreement between PepsiCo, a leading global food and beverage corporation, and Yara, a global leader in nitrogen-based fertilizers, reflects the companies' shared commitment to transforming the European food system across the full value chain. The secured offtake of Yara's renewable, low-carbon ammonia allows for the production to scale up and the technologies to mature, while supporting farmers with transition costs to avoid negative livelihood consequences.



Representatives from Yara and PepsiCo with a farmer in a potato field| image provided by Yara

Source: Hydrogen Council & McKinsey Project & Investment Tracker, Yara, Pepsico, Press releases

Low-emission case studies: Villeta renewable ammonia and fertilizer

Companies involved	Atome	Yara Clean Ammonia	ANDE	Hy24	Casale
Location	Capacity	Status	COD	Pathway	Offtake
Villeta, Paraguay	255 ktpa NH ₃ (260 ktpa CAN ¹)	FEED	2028	Renewable	100% from Yara International with non-binding heads of agreement signed

Project description

Located in Paraguay, the project is a 145-MW electrolyzer-powered fertilizer plant that will source 100% of its electricity needs from renewable sources (the majority of which is hydro) and is expected to achieve COD in 2028. ATOME has strategically partnered with ANDE, the Paraguayan national utility, to supply power; with Casale to provide technology and engineering procurement and construction (EPC); and with Yara International for offtake.

Lessons learned

Strategic, firm power sourcing is provided by the Itaipu Dam, and the project benefits from proximity to inland demand that would otherwise be served through conventional imports. Paraguay owns 50% of Itaipu, the world’s third-largest hydroelectric dam (14 GW), which provides Paraguay with over 90% of its energy needs. Paraguay only uses 30% of its 50% share of Itaipu’s power generation, resulting in excess renewable energy available for consumption. The ATOME project capitalized on this excess by securing a 145-MW 24/7 baseload power purchase agreement (PPA) from the Itaipu Dam at the lowest industrial tariff in Paraguay.

The project is also located close to brownfield infrastructure, such as ports and transmission and distribution equipment, as well as to the Paraguay River, which provides direct access to water.



Villeta renewable ammonia and plant renderings and Itaipu Dam, which provides hydro power to the plant | images provided by Hy24

1. Calcium ammonium nitrate fertilizer
Source: Hydrogen Council & McKinsey Project & Investment Tracker, Yara, Press releases

Low-emission case studies: Fertiglobe-H2Global export project

Companies involved ¹	Fertiglobe				
Location	Capacity	Status	COD	Pathway	Offtake
Ain Sokhna, Egypt	Up to 397 kt cumulatively by 2033	Pre-FID	2028	Renewable	H2Global auction award at 1,000 EUR/ton NH ₃

Project description

Fertiglobe, a joint venture of ADNOC and OCI Global, won the first H2Global pilot auction in 2024 to supply renewable ammonia to Europe. Hydrogen will be produced via a 100-MW electrolyzer powered by new solar and wind capacity in Egypt's Suez Canal Economic Zone and then converted into ammonia at Fertiglobe's EBIC plant in Ain Sokhna. The ammonia will be shipped to the Port of Rotterdam, supplying European buyers under H2Global's double-auction mechanism.

Lessons learned

Fertiglobe's success in the H2Global auction highlights how structured procurement mechanisms can provide the demand certainty needed to advance large-scale renewable-ammonia projects toward the investment decision. By securing a long-term, auction-backed contract, the project demonstrates how price stability can bridge the gap between production costs and European market prices, reducing risk for both producers and buyers. Its location in Egypt's Suez Canal Economic Zone underscores the strategic advantage of combining abundant renewable resources with direct shipping access to Europe, while also showing how existing ammonia infrastructure can be repurposed for low-emission production. The project's phased delivery schedule—starting with smaller volumes in 2027 and scaling up through 2033—illustrates a replicable model for building confidence in new supply chains. Finally, alignment with EU RFNBO (renewable fuel of non-biological origin) definitions and sustainability criteria ensures credibility for scope 3 accounting, setting a precedent for how policy frameworks and certification standards can underpin international trade in low-emission ammonia.



Fertiglobe winning overview at H2Global auction | Fertiglobe EBIC Plant | Images sourced from Ammonia Energy Association, H2Global

¹Fertiglobe has been supported in its bid by Egypt Green Hydrogen (EGH), a partnership between Fertiglobe, Scatec ASA, Orascom Construction, The Sovereign Fund of Egypt, and the Egyptian Electricity Transmission Company
Source: Hydrogen Council & McKinsey Project & Investment Tracker, Fertiglobe, H2Global, Pres releases



Appendix 2

Upstream readiness

Insights into the readiness of low-emission supply systems

Upstream readiness

Overview of the state of the upstream production landscape ready to supply the industry by 2030

\$40 billion

Committed investments globally into low-emission ammonia projects as of 2025

35 Mtpa

Low-emission ammonia supply has advanced to FEED or later, with 2 Mtpa already in operation

Upstream readiness: Today's ammonia landscape shows room for growth, and low-emission supply will be ready to meet the market by 2030

Exhibit 19

Ammonia market today¹

240 Mtpa existing ammonia supply

Installed supply in 2024 to meet conventional need for fertilizers and chemicals

200 Mtpa existing ammonia demand

Of which ~80% is used in fertilizer production and agriculture

45 Mtpa global merchant ammonia market

25% of ammonia production leaves plant gate for merchant sales, with 16 Mtpa traded via sea routes

Low-emission supply readiness by 2030

15 Mtpa committed supply (FID+)

Includes operational retrofits, with an additional 22 Mtpa in FEED that could be online by 2030, equivalent to 15–20% of global demand today

\$40billion+ committed investments

Total committed (FID+) investments into low-emission NH₃ production

<\$75/t CO₂e pre-policy cost of abatement

Cost differential with conventional ammonia before policy measures. By 2030, with existing policy mechanisms, this gap could close to <\$20/t CO₂e

1. 2024 values based on IFA (through Hydrogen Europe), McKinsey Chemical Insights
Source: Hydrogen Compass 2025; Hydrogen Europe; IFA

Upstream readiness: The low-emission ammonia supply landscape is making progress with \$40 billion in committed investments and 35 Mtpa of supply having reached FEED

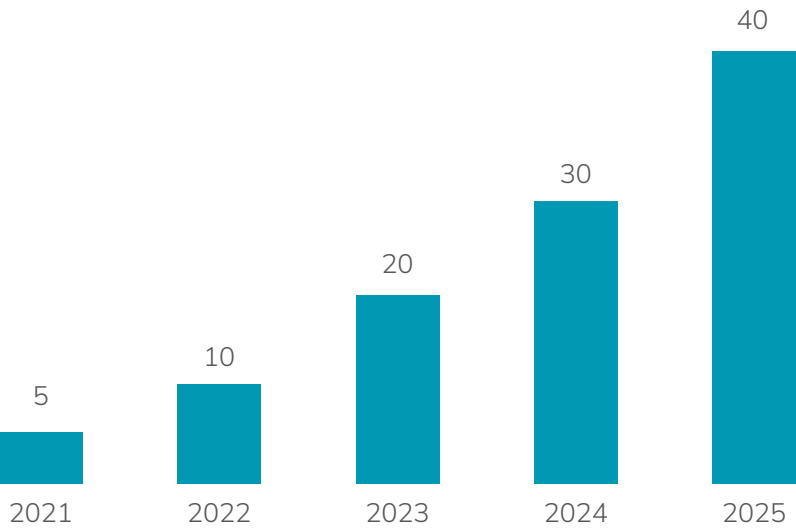
Supply is beginning to scale with early signs of progress

Global momentum behind low-emission ammonia is accelerating, with \$40 billion in committed investment by 2030 and 35 Mtpa of projects already at FEED. The infrastructure and technology to deliver at scale are available today, and offtake is already materializing: Yara and PepsiCo are advancing fertilizer applications, CF Industries, JERA and Mitsui & Co. are pursuing very low-emission ammonia production that could be used for fertilizer, or for new ammonia uses such as power generation in East Asia, and NEOM is positioning ammonia as a global hydrogen carrier.

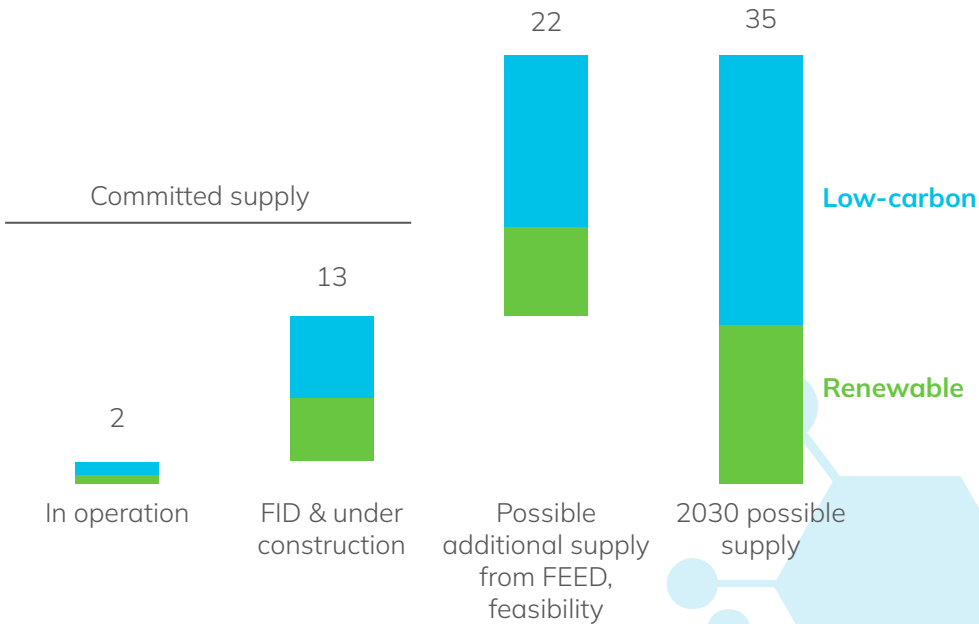
New-build low-carbon plants achieve capture rates above 95%, proving the maturity of carbon capture and storage in large-scale applications. Meanwhile, electrolysis capacity is expanding, with 35 GW of electrolysis expected globally by 2030. Together, these advances-backed by committed capital and early offtake agreements-show the supply side is ready to scale, positioning low-emission ammonia as a proven solution to decarbonize fertilizer demand and beyond.

Exhibit 20

Global committed¹ investment into low-emission ammonia projects by 2030, \$B



Global low-emission ammonia capacity by 2030 by pathway and status, Mtpa NH₃



1. Includes FID and under construction investments into low-emission ammonia production
Source: Hydrogen Compass 2025; Hydrogen Council & McKinsey Project & Investment Tracker, as of December 2020, May 2022, May 2024 and July 2025

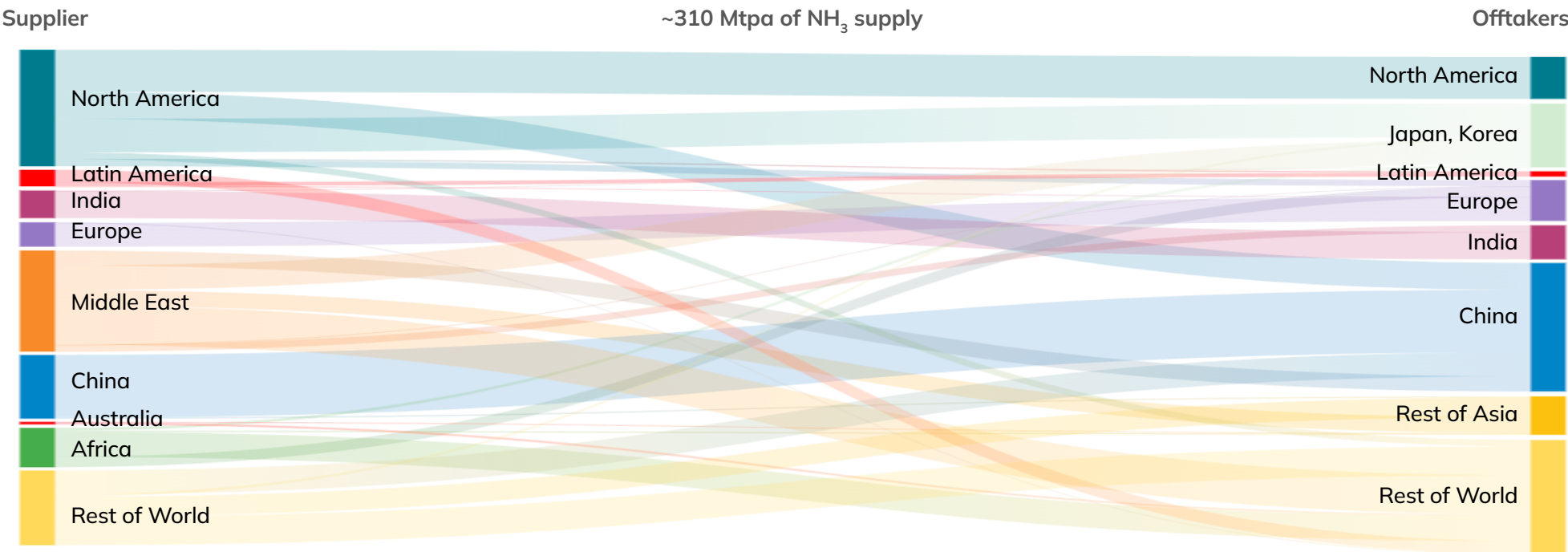
Upstream readiness: Emerging trade flows of low-emission ammonia support the diversification of supply for key fertilizer feedstock

Ammonia trade enables more supply options and efficient decarbonization

Ammonia trade today is limited, with many countries relying on imported fossil fuels like LNG-leaving them exposed to volatile prices, geopolitical shocks, and ocean-borne trade risks. Low-emission ammonia can reshape this dynamic by diversifying supply across low-carbon and renewable sources, opening new options for import-dependent regions such as the EU and East Asia. At the same time, production can become more regionalized, with Latin America and Africa leveraging abundant renewables to build independent supply, thus reducing exposure to disruptions that have previously strained access to fertilizers and energy. This shift promises more resilient trade flows, closer alignment of supply with demand, and greater security where local renewables compete with fossil imports. The following below illustrates what 2040 ammonia trade flows could potentially look like based on the Hydrogen Council and McKinsey's trade flow model.

Exhibit 21

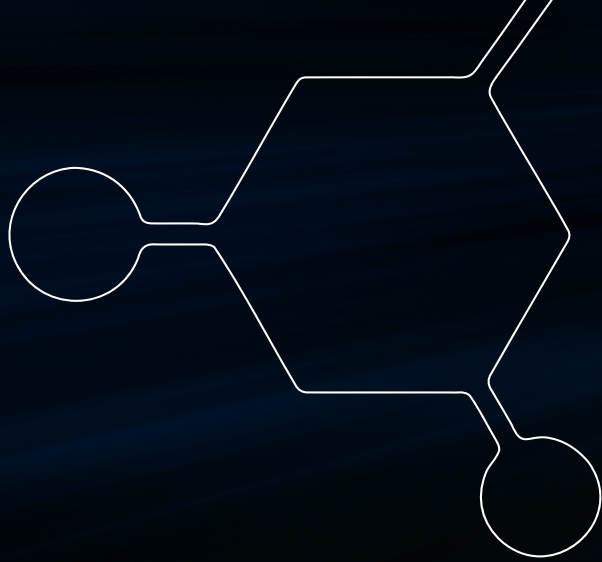
Global ammonia trade flows, 2040,
Mtpa NH₃



Source: McKinsey Global Hydrogen TradeFlow Model 2025-Continued Momentum Scenario EIA

Glossary of key terms

Term	Definition
Conventional ammonia	Ammonia produced from hydrogen derived from unabated fossil fuels
Renewable ammonia	Ammonia that has been produced with electrolytic-derived clean hydrogen produced from renewable energy
Low-carbon ammonia	Ammonia produced from hydrogen produced with low-emissions technologies with significantly lower greenhouse gas emissions impact than conventional production pathways, based on robust life-cycle analysis-based methodologies for GHG emissions assessment, including i) hydrogen produced using natural gas feedstock with SMR or ATR coupled with CCS; ii) hydrogen produced through pyrolysis of natural gas into hydrogen and solid carbon; iii) hydrogen produced through gasification of coal with CCS; iv) hydrogen produced through electrolysis using electricity of non-renewable origin as feedstock. Throughout this document, low-carbon typically refers to ATR with CCS
Low-emission ammonia	Combined term referring collectively to ammonia derived from either renewable or low-carbon pathways
ETS/CBAM	Emissions Trading Scheme/Carbon Border Adjustment Mechanism in the EU market that aims to place a price on the value of carbon within a product (i.e., ammonia takes into account the emissions from the production whether it is imported or produced domestically)
IRA	Inflation Reduction Act in the USA that created the 45V clean H2 production tax credit along with the expanded 45Q credit for carbon sequestration



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