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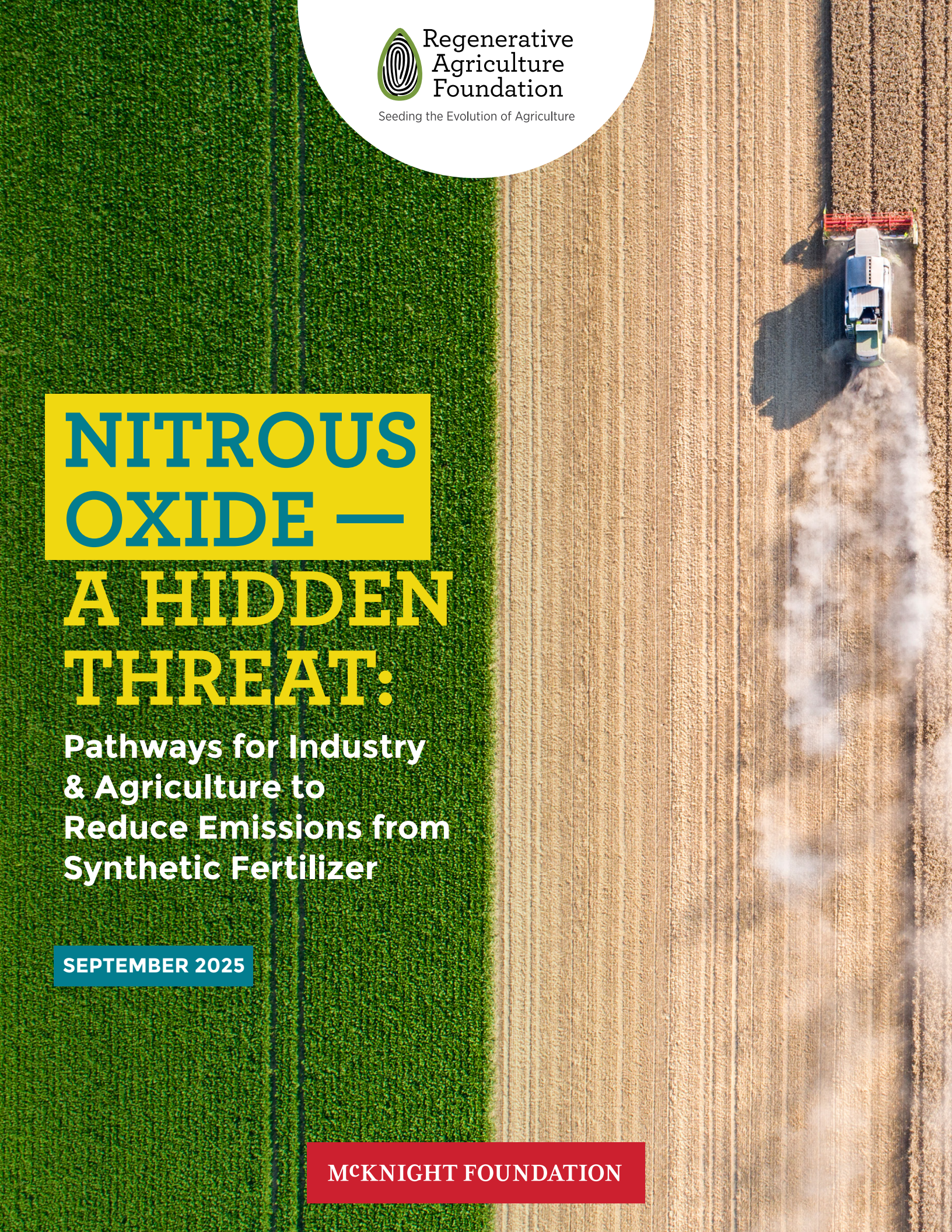

NITROUS OXIDE — A HIDDEN THREAT:

Pathways for Industry & Agriculture to Reduce Emissions from Synthetic Fertilizer

SEPTEMBER 2025

McKNIGHT FOUNDATION

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WHAT THIS REPORT COVERS:

Boundaries, Goals, and Approach

This report focuses on the role of synthetic nitrogen fertilizer in driving domestic agricultural nitrous oxide (N_2O) emissions through direct field-level emissions and upstream emissions associated with its manufacture. It also addresses the broader ecological and health consequences of these emissions —underscoring the need for integrated strategies to reduce fertilizer application and advance more sustainable nutrient management. It is offered with the recognition that through modern technology and testing, many farmers are working to reduce the amounts of synthetic fertilizer deployed on their fields as appropriate without negatively impacting crop yields.

It is recognized over the long-term, that more transformational opportunities to reduce overall greenhouse gases (GHGs), including methane and carbon dioxide released during the production and application phases, could yield even greater benefits including: increasing farm income through diversifying cropping systems, appropriately incorporating livestock to increase resiliency, and embracing agroforestry, pasture and other perennial systems to improve soil health.

It is also recognized that upstream methane leakage has significant impacts on climate change and human health and the extractive processes impacts water, land and wildlife. However, this report more narrowly addresses the impacts of N2O emissions and pathways for reducing emissions from synthetic nitrogen fertilizer production and application while acknowledging the additional impacts that conventional fertilizer production and application have on humans, wildlife, and the environment[i,ii]

This report seeks to inspire dialogue and foster implementation of innovative and common-sense solutions to reduce N_2O emissions while minimizing the health and environmental impacts of synthetic nitrogen fertilizers. It also puts forth target emission reduction goals for the United States over the next twenty-five years.

Achieving the goals and reforms set forth in this report will require commitment and partnership from stakeholders from across the entire agricultural ecosystem. Fertilizer producers, farmers and the agriculture industry must address this issue through market demand to mitigate the harmful impacts of nitrous oxide emissions on climate.

INTRODUCTION

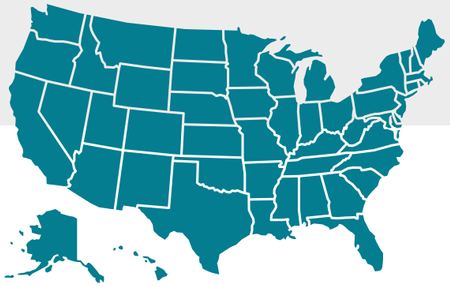
Synthetic nitrogen fertilizer is a cornerstone of modern agricultural production. Farmers have relied on synthetic fertilizer as a necessary soil nutrient to maximize crop yields and protect their economic viability. Yet the environmental and health impacts of emissions from synthetic nitrogen fertilizer are wide-ranging and increasingly urgent to address. Beyond its critical role in driving nitrous oxide (N_2O) emissions — a potent greenhouse gas (GHG) and contributor to stratospheric ozone depletion — synthetic nitrogen fertilizer overuse degrades soil health, contaminates drinking and surface waters with nitrate pollution and eutrophication, and is linked to a range of public health concerns.

In the United States, synthetic nitrogen fertilizer use in agriculture is a major contributor to greenhouse gas emissions. In 2022, nitrous oxide accounted for at least 49%[1] of all U.S. agricultural greenhouse gas emissions and 6.1% of all U.S. greenhouse gas emissions (including production and use).[2]

Nitrogen loss occurs through multiple pathways—including nitrate leaching, ammonia volatilization, and nitrous oxide emissions—each with distinct environmental and health consequences. While a comprehensive view of nitrogen loss is critical to avoid unintended tradeoffs, this report focuses specifically on nitrous oxide emissions to improve clarity and engage readers with one of the most potent and least understood greenhouse gases. Nitrous oxide not only drives climate change but is also the leading cause of ozone layer depletion today. For farmers and communities, understanding and managing nitrous oxide emissions is essential—not just for climate goals, but also for improving nitrogen use efficiency, protecting water quality, and reducing air pollution, all of which have direct implications for farm profitability and public health.

> **Reducing nitrous oxide emissions from the production and use of fertilizers must be an urgent priority for the United States, both at the federal and state levels. The Midwest – home to 27% of the nation's agricultural output[3] – has an opportunity to lead this important work that can protect the climate and lower input costs for farmers.**

Reliance on synthetic nitrogen fertilizer contributes not only to direct nitrous oxide (N_2O) emissions but also plays an indirect role in both N_2O and methane (CH_4) emissions by influencing the structure and dynamics of modern agricultural systems. By enabling large-scale, densely planted monocultures, the use of synthetic nitrogen fertilizer facilitates an overreliance on commodities farming as the only profitable form of large industrial scale farming. These economic conditions compel farmers to intensify production—further increasing N_2O emissions while contributing to persistently low commodity prices. Low grain prices also support the expansion of industrial livestock systems, which generate substantial CH_4 and N_2O emissions through enteric fermentation and manure management. In addition to these indirect GHG emissions, the indirect ecological effects of synthetic nitrogen use can include: reductions in on-farm biodiversity, greater dependence on pesticides, long-term soil degradation through compaction, soil organic matter depletion, and diminished biological activity on farms. These interconnected outcomes highlight the need to address nitrogen management from a holistic systems perspective.



#4

THE U.S. IS THE WORLD'S FOURTH-LARGEST PRODUCER OF SYNTHETIC NITROGEN FERTILIZERS.

DOMESTIC PRODUCTION CAPACITY OF SYNTHETIC FERTILIZER COULD QUADRUPLE BY 2030.

INCREASING THE RESILIENCY OF AMERICAN AGRICULTURE

As the agricultural sector works to reduce nitrous oxide emissions over the coming decades, it is essential to take a holistic approach that enhances the resilience of American agriculture in the face of climate change. This includes protecting and restoring soil health, diversifying crops, and improving farmers' economic viability. A key strategy is investing in organic and regenerative agricultural systems at the local level, ensuring long-term soil health and sustainability.

Many American farmers are climate leaders and dedicated land stewards. Yet prevailing market pressures and policy gaps often make it economically challenging to align fertilizer use with crop uptake or to invest in alternative fertilizer practices. Without robust incentives or regulatory frameworks, overapplication of synthetic nitrogen can appear to be the most practical choice. While many farmers have adopted practices that improve nitrogen use efficiency, broader adoption is still needed. Policies that support widespread implementation of these practices—and simultaneously reduce nitrous oxide emissions, limit water pollution, and protect public health in rural communities, represent high-leverage climate strategies that deserve urgent attention.

In addition to smart policies and incentive structures that help producers reduce nitrous oxide emissions on farms, one of the most immediate and impactful opportunities lies upstream: in the factories where synthetic fertilizer is produced. Proven technologies to limit emissions during production remain underutilized in the U.S. due to weak regulations and lack of enforcement. Prioritizing emissions reductions at the point of manufacture is cost-effective and technologically feasible.

As this work is pursued, it is critical that all actors in the agriculture sector commit to transparency and accountability by internalizing the true costs of nitrous oxide emissions and environmental and public health impacts both upstream and downstream**. The work to reduce emissions must be done in a sustainable way that protects the economic well-being of farmers and rural and feceline communities and fosters ways to allow local communities and farmers to creatively forge new solutions, while transforming the sector's approach to synthetic nitrogen fertilizer production and application.**

There is good news. We have the scientific knowledge and technological tools to reduce N_2O emissions both during fertilizer production and application in the field. However, what remains lacking are effective policies — namely, smart regulations and adequate incentives — to drive widespread adoption.

The co-benefits of addressing nitrous oxide emissions could equitably address the longstanding health and water pollution impact in rural communities. As part of this work, agricultural climate strategies can reinvest in America's rural communities, creating economic opportunities – including new jobs and infrastructure investments - alongside environmental benefits for local residents.

Reducing Nitrous Oxide Emissions in the United States

GOALS FOR 2050

The United States, in collaboration with farmers, fertilizer companies, and the agriculture and food industries, should establish a target of achieving nitrous oxide emissions reduction from synthetic nitrogen fertilizer production and use by 2050.

To cultivate actionable results over the next two decades, we propose interim targets designed to drive enabling policies, market incentives, and regulatory actions, creating a clear pathway toward reducing emissions from synthetic fertilizer production and use. These goals, compared to 2020 levels, include:

1. **Reduce N_2O emissions from domestic fertilizer production by 75% by 2035.**

2. **Achieve net-zero GHG emissions from domestic fertilizer production by 2050.**

3. **Reduce the United States' total agricultural N_2O emissions related to synthetic nitrogen fertilizer, manure, and organic amendments use by at least 50% by 2050.** while safeguarding water quality, air quality, environment, and public health.

THE GROWING THREAT OF NITROUS OXIDE EMISSIONS

Nitrous oxide (N_2O) is both a potent greenhouse gas and the leading ozone-depleting substance in the atmosphere today. With a global warming potential 273 times greater than that of carbon dioxide and an atmospheric lifetime of 109 years,[4] N_2O is a powerful and long-lasting compound. Despite its relatively small share of total GHG emissions, N_2O concentrations are growing rapidly[5] — driven largely by agricultural sources.

Globally, nitrous oxide emissions increased by 40% between 1980 and 2020,[6] with the recent annual growth rate between 2021 and 2023 exceeding that from 2001 to 2022 by 53%.[7] By 2022, the concentration of atmospheric nitrous oxide reached 336 parts per billion, or 25% higher than pre-industrial levels (270 parts per billion).[8,9]

Communities near fertilizer manufacturing plants bear the brunt of air pollution and water pollution. For example, the stretch of the Mississippi River between Baton Rouge and New Orleans, Louisiana, is known as Cancer Alley because of elevated cancer rates. The area is home to several synthetic nitrogen fertilizer plants and could be home to more plants that are under development. Ammonia leaks and accidents at these plants have closed schools, killed workers, and caused residents to shelter in place.[10] Inhaling high concentrations of ammonia can cause respiratory irritation[11] and emissions contribute to fine particle pollution, which has been linked to heart and lung illnesses.[12]

The excessive application of synthetic fertilizer over the last 60 years has created environmental problems and significant health concerns for residents in rural communities across the nation. These areas experience elevated nitrate water pollution, soil degradation, and air contamination. For example, Iowa has seen a rise in colorectal cancer with ovarian, thyroid, kidney, and bladder cancer which may be linked to the rise of nitrate contamination in the state's drinking water.[13] A 2019 report estimates that air pollution from fertilizer use in corn production is associated with an estimated 4,300 premature deaths a year and $39 billion in estimated monetary damages in the United States.[14]

> **In addition to domestic production risks, at the time of this report's production, the global fertilizer industry faces significant unknowns under new tariffs on Canada, Mexico, and China proposed by the Trump Administration in the spring of 2025. Between 2020-2024, the U.S. imported $4.3 billion of fertilizer products from Canada, Mexico and the rest of the world. 30% of annual nitrogen imports come from Canada.[15]**

HOW FERTILIZER PRODUCTION AND APPLICATION CONTRIBUTE TO RISING N_2O EMISSIONS

Nitrous oxide emissions enter the atmosphere at two key stages: first, during the production of synthetic fertilizer, and later, when the fertilizer is applied to farms and fields.

In 2022, in the United States, the production and use of synthetic nitrogen fertilizer generated approximately 80 million metric tons of CO_2-equivalent (CO_2e) from nitrous oxide emissions, encompassing both direct and indirect nitrous oxide emissions. This accounts for about 1.3% of the total U.S. gross GHG emissions. Of that, fertilizer production accounted for approximately 9.5% (~7.6 million metric tons of CO_2e from nitrous oxide), with the remainder resulting from synthetic nitrogen fertilizer applications.[16] [1]

Calculating the Correlation Between Fertilizer Production and GHG Emissions

No one-size-fits-all formula exists for the volume of fertilizer produced and the resulting levels of greenhouse gas emissions. It depends on a multitude of inputs including: feedstocks, process technology, pollution controls, and other site-specific considerations. However, the underlying chemistry and current research suggests:

Ammonia produced from natural gas generates 2.3 metric tons of carbon dioxide per ton of ammonia.[17] The more ammonia a plant makes, the more they can be expected to emit. Some plants capture some carbon dioxide to make urea (another form of synthetic nitrogen fertilizer).

For nitrous oxide, the equation is 6-9 kg of N_2O (or 1.9-3.2 metric tons of CO_2e) per ton of nitric acid produced.[18] This emission rate will be lower for plants with N_2O controls installed.

FERTILIZER PRODUCTION

The discovery of the Haber-Bosch process — at the core of the synthetic nitrogen fertilizer production process — is one of the most consequential scientific discoveries in human history. The process enabled the growth of industrial-scale farming and dramatically increased global food production.[19]

However, the Haber-Bosch process is heavily fossil fuel reliant and a significant source of GHGs – N_2O and CO_2 – as well as a driver of detrimental environmental impacts from fossil fuel extraction, processing, and transportation. It also emits other air pollutants, such as nitrogen oxides, ammonia, fine particulate matter, sulfur dioxide, volatile organic compounds, and carbon monoxide–that pose significant public health risks including respiratory illnesses.

1 CO_2e (carbon dioxide equivalent) is a standard unit used to compare the warming potential of different GHGs by expressing them in terms of carbon dioxide.

Furthermore, the Haber-Bosch process' dependence on fossil fuel subjects fertilizer production to fuel market volatility, affecting farmer input costs and consumer costs. For example, Russia's invasion of Ukraine caused global natural gas prices to soar, triggering a sharp rise in fertilizer prices – increasing by more than 50 percent between February 2022 and April 2022.[20]

Currently, in the United States, there are at least 36 industrial plants making nitrogen-based synthetic fertilizer products including ammonia, urea, ammonium nitrate, and ammonium sulfate.[21] In 2023, these plants reported emitting 42.16 million metric tons CO_2e. 82% of these emissions were carbon dioxide, and nitrous oxide accounted for nearly all of the remainder.

Nitrous oxide emissions from fertilizer plants come almost entirely from the production of nitric acid, a key ingredient needed to make ammonium nitrate.

Nearly all (99.9 percent, or 7.9 million metric tons as CO_2e) of reported nitrous oxide emissions came from 25 of the 36 plants that make nitric acid for use in ammonium nitrate fertilizers.[22]

Production capacity of synthetic ammonia in the United States may quadruple by 2030.[23]

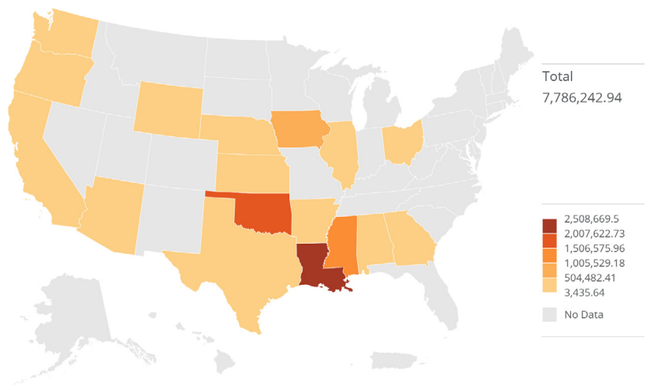
At least 38 projects to build new or expand ammonia production facilities had been announced as of December 2024, largely along the Gulf Coast in Texas and Louisiana. Many of these projects are focused on new ammonia use sectors such as exports and shipping fuels, but will have direct implications for fertilizer markets. These projects could add 60 million metric tons of ammonia to the market if they are built.[24] While some of the developers of these projects say they plan to make ammonia for use as a green fuel in shipping or other industries, it is unclear if, or when, this relatively new use of ammonia could materialize. These plants can also sell their ammonia for use as fertilizer.

Nitrous Oxide Emitted by Fertilizer Plants that Make Nitric Acid in the U.S.

(2023, metric tons CO_2e)

The U.S. has at least 36 industrial plants that produce synthetic fertilizer.

11 are in the Midwest.



Sources: Environmental Protection Agency (2023) Greenhouse Gas Reporting Program; Permit records and company websites reviewed by the Environmental Integrity Project.

#1 IN N_2O EMISSIONS FOR ALL U.S. FERTILIZER PLANTS

CF INDUSTRIES' DONALDSONVILLE COMPLEX

One of the largest ammonia and fertilizer manufacturing sites in the world is CF Industries' Donaldsonville Complex in Ascension Parish, Louisiana.[25] Located in a primarily low-income Black and Latino community on the west bank of the Mississippi River, the Donaldsonville Complex produces up to eight million metric tons of fertilizer each year. The site has long been the largest source of direct greenhouse gas emissions in Louisiana.[26]

In 2023, CF Industries reported that the plant emitted 7.8 million metric tons of CO_2 and 1.7 million tons of nitrous oxide (as CO_2e), accounting for 22 percent of the total N_2O emitted by U.S. fertilizer plants that year.[27] **According to a review of permit records and greenhouse gas reporting data, only one of the plant's four nitric acid production units has pollution controls for nitrous oxide.[28]**

CF Industries also reported that the Donaldsonville Complex emitted 3,567 tons of health-harming air pollutants, including nitrogen oxides, ammonia, fine particulate matter, sulfur dioxide, volatile organic compounds, and carbon monoxide, along with 337 tons of hazardous air pollutants in 2023.[29] Furthermore, between 2006 and 2023, the plant reported hundreds of accidental chemical releases, with the frequency of events increasing in recent years.[30]

In addition to air pollution, the Donaldsonville Complex has negatively impacted surrounding waterways. In 2021, the site discharged more than a million pounds of nitrogen into the Mississippi River – intensifying eutrophication and contributing to the ongoing 'dead zone' in the Gulf of Mexico. These discharges were legal because the Complex operates with high permit limits under outdated federal technology-based regulations.[31]

CF Industries plans to upgrade one of its nitric acid plants by the end of 2025, and the work is already underway. According to permit records, this upgrade does not include adding pollution controls that could also reduce nitrous oxide emissions.[32]

The pollution from the Donaldsonville Complex is unfortunately not an isolated issue. Most fertilizer plants across the country have similar pollution footprints, though they may vary in size. Several plants in the Midwest and central U.S. also lack nitrous oxide pollution controls. These plants include CF Industries' Port Neal Complex in Sergeant Bluff, Iowa; Koch Fertilizer's Fort Dodge plant in Duncombe, Iowa; and CF Industries' Woodward plant in Oklahoma. Three more plants (CF Industries' Verdigris plant in Claremore, Oklahoma; CVR Energy's Coffeyville Nitrogen Fertilizer Plant in Coffeyville, Kansas; LSB Industries' Fertilizer Plant in Pryor, Oklahoma) lack nitrous oxide controls on half of their nitric acid plants. Together, these plants emitted 2.8 million metric tons of nitrous oxide (as CO_2e), with over 1.3 million coming from the Verdigris plant alone.[33]

Regulatory reform is needed at the federal and state levels to ensure these facilities are adopting best in class technology and practices to reduce harmful pollutants and N_2O emissions during the fertilizer production process.

The Challenge

FERTILIZER APPLICATION ON FARMS & FIELDS

Addressing N_2O emissions from fertilizer manufacture is crucial, but the significant opportunity to reduce emissions comes through on-field practices as using nitrogen fertilizers in the field emits roughly 13 times as much N_2O. Effectively addressing field N_2O emissions through on-farm practices is a complex challenge that requires a more systemic approach. Farmers, as stewards of the land, will play a crucial role in advancing this work.

In the field, nitrous oxide is produced by soil microbes as part of the nitrogen cycle, including from fertilizer nitrogen that is not taken up by crops and remains in the soil. Emissions tend to spike under specific conditions, primarily excess nitrogen introduction from overapplication of synthetic fertilizer or manure. This can be exacerbated by wet or compacted soils that limit oxygen availability, warm temperatures that accelerate microbial activity, crop types and growth stages that influence the timing and intensity of emissions, and tillage or residue management practices that alter soil structure and microbial habitats.

Nitrogen plays a critical role in maximizing crop yields, particularly for nitrogen-intensive crops like corn, potatoes, cotton, wheat, rice, hops, and certain fruits. These crops typically receive between 100 and 250 pounds of nitrogen per acre annually. Additionally, nitrogen fertilizer in the Midwest serves multiple purposes beyond supporting food and animal feed production; it is also used to produce fuel for vehicles. A conservative estimate suggests that at least 35% of corn harvests are allocated for ethanol production, accounting for about 16.5% of U.S. synthetic nitrogen use.

IMPROVING THE BOTTOM LINE FOR FARMERS WHILE REDUCING N_2O EMISSIONS ON THE FIELD

In 2022, U.S. farmers collectively spent more than $30 billion on synthetic nitrogen fertilizer, a significant operations cost.[1]

1 In alignment with the USDA Economic Research Service, this report uses Iowa production costs as a proxy for U.S. expenses due to its central location

Current fertilizer application levels are reinforced by federal policies, financial, market, and institutional structures. Changing fertilizer practices may compromise a farm's productivity, and can make the transition to alternative systems financially risky and logistically difficult. Policies that could meaningfully reduce fertilizer-related emissions may face opposition from industries that profit from the status quo. Their current business model and influence on U.S. farm policies encourages the overapplication of synthetic fertilizer.

A GROWING CONSOLIDATED FERTILIZER MARKET

American farmers' use of fertilizers is heavily influenced by the international fertilizer market and greatly dependent on consolidated fertilizer corporations. In 2024, four companies controlled 82% of the nitrogen fertilizer market in North America: CF Industries (39% of total nitrogen capacity), Nutrien (22%), Koch Industries (15%), and Yara (6%). [34]

This consolidation has weakened choices for American farmers and redirects resources to large multinational corporations rather than supporting local seed cooperatives and nearby sources of organic fertilizers, such as animal waste and food processing byproducts.

OVERAPPLICATION OF FERTILIZER ON FIELDS

The recommended levels of applied fertilizer is complex and could be overestimated at the outset, and thus overapplied. First, when recommendations are calculated by land-grant universities — with strong recommendations from industry which farmers rely on — may not fully account for a diversity in soil nutrient needs. Additionally crop consultants work directly with farmers on application and implementing the '4Rs' - Right Source, Right Rate, Right Time, Right Place - for on-field use. This may artificially increase or decrease the final calculated recommended volume. Second, the fertilizer industry has supported U.S. farm policies and financial incentives that have treated overapplication of fertilizers as a form of insurance to increase crop yield.

Additionally, there are current limitations in federal and state policies — including farm safety nets — and financial incentives to explore alternative fertilizer sources, including legumes, free-living nitrogen-fixing soil microbiota, and locally or regionally available organic nutrients like manure, food industry byproducts, and other organic residues. These alternative fertilizer sources must be pursued if we are to reduce America's dependence on the international fertilizer market.

On-Field Action Is Key

HOW FARMERS CAN LEAD

Approximately 12% of agriculture-related greenhouse gas emissions are the result of synthetic nitrogen fertilizer application on farms and fields. Fertilizer application has boosted yields, but it is also a significant driver of costs for farmers. In fact, fertilizers can account for up to 25% of a farmer's input cost.[35]

DRIVING BEHAVIORAL CHANGE ON THE FIELD

According to Practical Farmer of Iowa's *Crop Diversification in the Corn Belt* report there are three interventions that farmers need to break from conventional cropping cycles:[36]

- Technical support
- Cultural Acceptability
- Financial Incentives

This framework may be applied to encouraging farmers to adopt on-field practices that can help lower nitrous oxide emissions during the application phase.

	Today...	The Shift...
Technical Support	Agronomists, Ag Retailers, and Farmers are all experts in conventional agriculture, and emission reduction processes	Introducing technical expertise in N_2O emission synthetic fertilizer application and soil health would give farmers the tools needed to implement practice changes on-field and reduce N_2O emissions
Cultural Acceptability	Conventional agriculture is part of the social norm in many ag communitites	Addressing cultural barriers makes farmers feel more comfortable with experimenting with practices without worrying about social exclusion
Financial Incentives	Government subsidies and the Farm Bill currently minimize risks for conventional farmers	Providing financial inventives and markets for regenerative agriculture and diverse crops would lower the risk and cost of switching practices, enabling more farmers to adopt fertilizer reducing practices and stick with them

TOP FIVE MOTIVATORS FOR BEHAVIORAL CHANGE FOR FARMERS

In 2025, the Land Stewardship Project surveyed 500 farmers on what motivated them to diversify their soil health practices. The findings may be indicative of drivers for additional N_2O reduction practices. Motivators included:

1	2	3	4	5
Ability to talk to other farmers who are using the practice	Proven evidence that the practice improved soil health	See successful examples of the practice in action	Attend a workshop or field day on the practice	Evidence that it would improve the farmer's financial bottom line

MAKING A LOW N_2O AG ECONOMY WORK FOR FARMERS AND WORKERS

The production of fertilizer has a significant economic impact on the nation's agriculture economy – through revenue and local jobs. The fertilizer industry estimates that in 2024 it contributed to $140 billion economic impact to the domestic economy, supported 500,000 jobs, and $36 billion in payroll for workers.[37] In 2022, U.S. farmers collectively spent more than $30 billion on synthetic fertilizer which contributed to total farm income of more than $530 billion.[38] For farmers who want to stay in business and for workers who want a higher wage (often union wages) in communities surrounding fertilizer plants, there are few alternatives than to maintain the status quo – no matter how they feel about the environmental impacts of fertilizer production. Farmers and workers are trapped in a production system that exploits and pollutes their communities.

Philanthropy and advocates can learn from the successes and failures of the movement to retire fossil fuel plants to build support for N_2O reduction by offering real alternatives for farmers and workers. The economic wellbeing of farmers, workers, and rural communities must be centered in the push to reduce N_2O emissions from the agriculture sector not just because it will help build rural vitality, but doing so will also build support and reduce opposition to accomplishing the goal of reducing nitrous oxide emissions.

Strategies to prioritize the economic wellbeing of farmers, workers and rural communities while reducing N_2O emissions could include:

- **Convene farm groups, organized labor, rural community groups, communities impacted by pollution,** progressive industry leaders, rural economic development leaders, and other stakeholders to further develop an equitable framework.
- **Developing new cash crops**, value added chains, and markets that can replace the dependable N_2O intensive commodities farmers rely on.
- **Precision Fertilization**: By applying fertilizers more efficiently using precision agriculture techniques, farmers can reduce fertilizer costs by **$8–$12 per acre**. This approach minimizes waste and ensures nutrients are delivered exactly where needed, improving crop yields while cutting expenses.
- **Cover Crops**: Legume cover crops, such as clover or vetch, can fix **50 to 100 pounds of nitrogen per acre**, reducing the need for synthetic fertilizers. Over time, improved soil health from cover cropping can lead to **fertilizer cost savings of $19–$54 per acre**, which increase as soil biology and organic matter improve.[39]
- **Identifying new economic development opportunities** in communities reliant on fertilizer manufacturing to provide comparable alternatives to replace retiring fertilizer plants.

POTENTIAL N_2O EMISSIONS REDUCTION STRATEGIES

As agricultural technology evolves, there are common sense ways to reduce nitrous oxide emissions during the fertilizer production process and application processes on the farm.

FERTILIZER PRODUCTION

Reducing N_2O emissions from agricultural sources will require a shift from conventional fertilizer production practices to a more sustainable approach that mitigates the complex externalities of industrial agriculture. To align with evolving priorities, the industry must incorporate 'least harm principles,' ensuring its business model prioritizes environmental stewardship and resource conservation while maintaining food security and addressing how fertilizer production impacts emissions.

There are immediate actions that fertilizer manufacturers can take to reduce N_2O emissions during the production process. These actions include:

EXPAND THE USE OF POLLUTION CONTROL TECHNOLOGY IN FERTILIZER PRODUCTION PLANTS

Fertilizer manufacturing plants that process ammonia into nitric acid, a key ingredient used to make popular ammonium nitrate fertilizers, create nitrous oxide as a byproduct. The deployment of market-ready and cost-effective technologies that currently exist can nearly eliminate these emissions from fertilizer manufacturing.

In the United States, 25 plants that make nitric acid for use in fertilizer reported emitting 7.9 million metric tons of nitrous oxide in 2023 (as CO_2e).[40] That amount is roughly equivalent to the annual emissions from nearly three coal-fired power plants operating around the clock or nearly two million cars (assuming 4.6 metric tons per car per annum) and it is almost completely avoidable.[41]

50%

US Fertilizer Production Plants Do Not Have Control Mechanisms In Place to Reduce N_2O Emissions.

0

Technology-based Standards Are in Place to Limit N_2O Emissions From Fertilizer Plants.

Only half of the US plants that make nitric acid for use in fertilizer have installed control mechanisms for N_2O emissions. These technologies are impactful in significantly reducing N_2O emissions and are also well-developed. It is estimated that production-linked nitrous oxide can be reduced by between 70-90% using the best available technology.[42]

For example, low-cost add-on technologies like non-selective catalytic reduction (NSCR) can reduce these emissions by up to 80% at an operating cost of less than a dollar per ton (of CO_2e).[43] Non-selective catalytic reduction is also used to control emissions of another group of health-harming pollutants, nitrogen oxides. Secondary process-gas catalytic decomposition (PGCD) reduces N_2O formation just after ammonia oxidation and can reduce emissions by 90-95%.[44]

Plants that have installed control technologies report emitting significantly less nitrous oxide than plants that lack emission controls. For example, Koch Fertilizer's Dodge City plant in Kansas has installed controls and only reported emitting 106 metric tons of nitrous oxide (as CO_2e) in 2022, while the same company's plant in Fort Dodge, Iowa lacks controls and reported emitting 278,097 metric tons the same year.[45]

70-90%

Production-Linked N_2O Can Be Reduced If Fertilizer Manufacturers Invest In Technology Controls.

Existing Technology Solutions For N_2O Emission Reductions

Examples of market-ready pollution control technology solutions that are currently available for fertilizer corporations to deploy include:

- Catalyst and operational optimization during ammonia oxidation
- Secondary process-gas catalytic decomposition (PGCD)
- Non-selective catalytic reduction
- Thermal destruction

There are currently no technology-based standards that limit nitrous oxide emissions from fertilizer plants, and policies can be introduced at the state and federal level to require the installation and operation of pollution control technology.

Existing federal regulations, however, already set technology and health-based limits on nitrogen oxide emissions. Some of the same technologies that reduce nitrous oxide also reduce emissions of nitrogen oxides. These regulations, which govern all Clean Air Act permitting, should be used to encourage and increase the installation and use of technologies that control nitrous oxide in addition to other health-harming pollutants. These existing regulations need to be fairly and vigorously enforced.

» **RECOMMENDATION: Invest in and deploy existing pollution control technology in the synthetic fertilizer production process.**

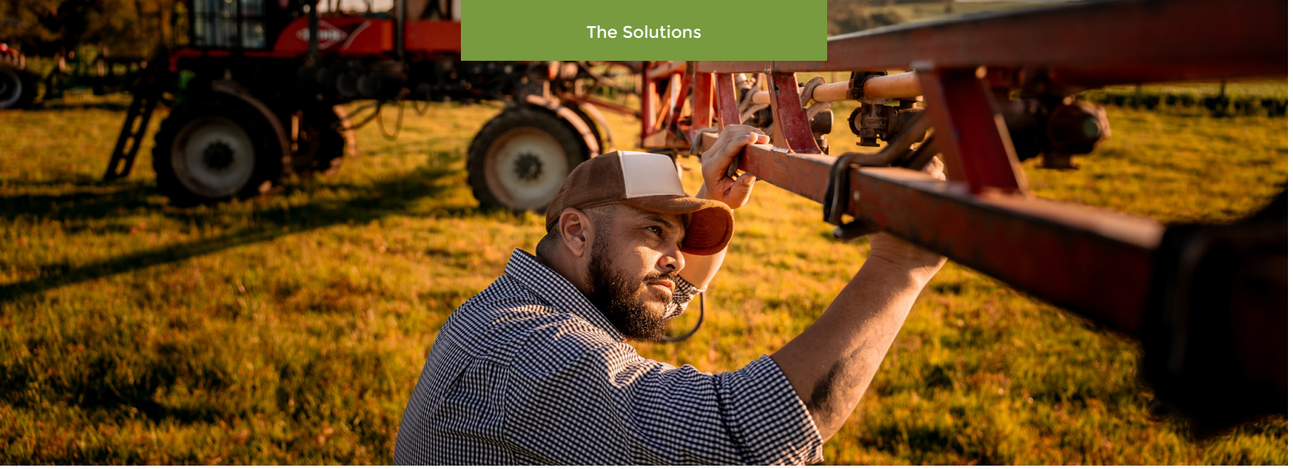
» **RECOMMENDATION: Enact technology-based pollution control standards at federal and state levels for nitrous oxide emissions from nitric acid plants.**

» **RECOMMENDATION: Leverage current permitting and enforcement laws.** Both federal and state governments should leverage permitting and enforcement within the current laws to encourage and increase the usage of pollution control technology in the fertilizer production process.

INVEST IN A DOMESTIC CLEANER FERTILIZER ECONOMY

Innovation in how the United States develops green synthetic fertilizer is critical to creating more stable prices, dependable sources of fertilizer productions, and to bring economic benefits back to rural communities. Nitrogen fertilizer does not need to be made with fossil fuels. Cleaner technologies exist that can make ammonia from water and renewable electricity.

While 'green' ammonia production is not currently available at the scale of fossil fuel-based ammonia fertilizers, their flexibility in scale allows for smaller facilities that can be placed in nearby farms or near demand centers, allowing farmers to access and apply fertilizer when their crops need it most. Scaling the domestic green fertilizer industry will enable local farmers to reduce their dependence on internationally produced synthetic fertilizers.



It must be noted that the growth of the green ammonia industry will not reduce or offset nitrous oxide emissions. And without a well-thought-out regulatory framework and policies, it may contribute pollution and health and environmental risk to rural farmland communities. However, it will offset other greenhouse gases emissions and offer increased stability in the domestic fertilizer marketplace.

The production of fertilizer without reliance on fossil fuels will stabilize the cost of fertilizers and will reduce the over-reliance on global fertilizer markets and the fluctuating cost of oil and gas prices. Investing in local production will also spur jobs in manufacturing, logistics, and other related jobs and will strengthen rural economies.

Midwest states are starting to move in this direction. In 2023, the Minnesota legislature passed $7 million in grants to agriculture and rural cooperatives[46] to invest in green fertilizer production facilities. The grant is combinable with the federal investment incentives such as the Inflation Reduction Act Green Hydrogen Tax Credit (45V) and/or US Department of Energy Loan Programs. This can directly reduce the footprint of the fertilizers used by improving the production emissions and reducing the logistics-based emissions footprint. Green ammonia and related fertilizers are chemically the same and still pose health hazards and risks in contributing to water pollution and, if not managed, air pollution risks; as such, the management of application remains an important focus.

» **RECOMMENDATION: Prioritize local rural commodities production as the domestic green fertilizer market grows.** Federal and state governments can introduce policy and tax incentives to propel the growth of green fertilizer production in rural communities, led by rural co-ops and owned by farmer-members.

» **RECOMMENDATION: Update policies and incentives to protect air and water as we grow the nation's green fertilizer economy.** States interested in supporting the growth of green ammonia in their rural communities need to update their air and water pollution policies and incentivize fertilizer production that minimizes air and water pollution.

FERTILIZER APPLICATIONS IN THE FIELD

As the precision of agricultural technologies advances and fertilizer efficiency improves, the industry must prioritize reducing reliance on synthetic fertilizers without compromising crop yields or farmers' revenue.

Mitigating nitrous oxide emissions from fertilizer use in the field is complex. There are current deployable synthetic fertilizer strategies with varying potential, including changes in the type, amount, and placement of fertilizers, changes in irrigation management, as well as changes in crop selection that can reduce emissions. Both physical application practices and financial incentives to support on-field application must be re-evaluated to reduce nitrous oxide emissions by 2050.

Improving On-Farm Fertilizers

The science of fertilizer is evolving. There are many ways existing sources can be improved to reduce nitrous oxide emissions.

NITROGEN (N) SOURCE	HOW IT CAN BE IMPROVED	KEY OPPORTUNITY
Synthetic Fertilizer (e.g., urea, UAN, anhydrous ammonia)	Use Enhanced Efficiency Fertilizers (EEFs). (e.g., nitrification/urease inhibitors, slow-release coatings) Improve timing of fertilizer application. (i.e., closer to spring/in-season)	Reduce N losses via volatilization, leaching, runoff and nitrous oxide emissions. Science is still evolving to determine the scale of potential, as well as tailoring it to individual farm needs.
Manure / Slurry	Test for nutrient content. Time applications with crop demand. Inject/incorporate instead of broadcasting. Do not apply more than the crop demand.	Improve N recovery and reduce ammonia volatilization, leaching, runoff, and nitrous oxide emissions.
Legume-based Cover Crops / Green Manures or Diversified Rotations with Legumes	Select efficient N-fixing species. Optimize termination timing. Integrate into rotation to align with N needs.	Provide biologically fixed N and reduce synthetic fertilizer use.

LEADING THE WAY: LANDUS AND TALUS RENEWABLES

Landus and Talus Renewables are examples of companies investing in green fertilizer production facilities in the U.S.

Photo: Landus.ag

EXPANDED ADOPTION OF AVAILABLE MITIGATION STRATEGIES ON FARMS AND FIELDS

There are many ways to reduce nitrous oxide emissions from synthetic nitrogen fertilizer use, each with varying potential. A combination of strategies can be implemented by farmers based on local soil conditions, to effectively reduce nitrous oxide emissions. However, one of the main barriers to improved nitrogen management in the field is farmers' reluctance to change practices due to economic uncertainty and field variability. One successful case study comes from Iowa.

The Iowa Nitrogen Initiative, launched in 2022, encourages the adoption of stronger nitrogen management by engaging farmers directly in on-farm nitrogen rate trials. Through a public-private partnership, volunteer farmers use variable rate technology and advanced analytics to test different nitrogen application rate strategies on their own fields, generating tailored, data-driven insights. This participatory approach avoids top-down regulation, instead it builds trust by allowing farmers to retain operational control.

By 2023, the initiative had conducted 270 trials with minimal farmer burden—participants only needed to provide basic information like field boundaries, nitrogen applications, corn varieties, and yield data. Iowa State University researchers supplemented this with soil and management data to refine nitrogen recommendation models. Trial results, spanning zero to over 200 pounds of nitrogen per acre, highlighted substantial variation in optimal nitrogen rates, with some fields needing as little as 50 pounds and others exceeding 300 pounds. This site-specific approach enhances nitrogen use efficiency, increasing yields while minimizing environmental impacts, including nitrous oxide emissions. Scaling this model to other regions could make nitrogen management more precise, cost-effective, and sustainable nationwide.

Existing strategies that can be more fully deployed to reduce nitrogen application rates and nitrous oxide emissions include:

» **RECOMMENDATION: Change the timing or location of synthetic fertilizer applications to support crop yields while reducing emissions.** Switching from fall to spring applications (closer to when crops need it) may cut as much as 42% of nitrous oxide emissions in the Midwest.[47] The current practice of fall synthetic fertilizer applications to a spring crop can result in high losses since nitrogen sits unused for months before crop uptake. Furthermore Y-drops and 2x2 placement can have a significant impact on peak plant uptake and increase the likelihood of use at the time of planting.

» **RECOMMENDATION: Deploy alternative irrigation practices.** For example, one study found that changing from gravity irrigation to drip and subsurface irrigation could reduce nitrous oxide emissions in California by 55% and 67%, respectively.[48] This same study found sprinkler irrigation may reduce nitrous oxide emissions by 38% compared to surface gravity. In rice systems, adopting non-continuous irrigation in U.S. rice production has been estimated to reduce methane and nitrous oxide emissions by 51% and improve yields by 12%.[49] The conversion of 15% of furrow-irrigated acres to center-pivot sprinkler irrigation in Nebraska's central Platte River Valley between 1988 and 2003 contributed to a 50% decline in groundwater nitrate levels.[50] Though this was not a nitrous oxide measurement, it shows the capacity of improved water management to reduce nitrogen loss and, thereby, increase nitrogen use efficiency.

» **RECOMMENDATION: Invest in nitrogen fixing plants and planting of cover crops.** Planting cover crops has multiple benefits for reducing nitrous oxide emissions including: controlling soil erosion; suppressing weeds; reducing soil compaction; increasing moisture and nutrient content of soil; improving crop yield potential; attracting pollinators and providing habitat and food for beneficial insects and wildlife. Additionally, nitrogen-fixing cover crops, such as legumes, can greatly increase nutrients back in the soil.[51] These practices offer farmers a sustainable way to improve soil health while reducing their dependence on internationally produced fertilizer.[52]

» **RECOMMENDATION: Diversify crop choices and crop production locations.** The current structure of the payments under the Farm Bill is a serious constraint to greater diversification of crops in the Midwest and nationally. Changing crop choices and avoiding crop production in places that are more likely to result in nitrogen 'hot moments' in agricultural soil can also reduce nitrous oxide emissions.[53] Many crops demand less nitrogen than corn. For example, growing corn in rotation with other crops, rather than growing corn for consecutive years, can result in a significant reduction in greenhouse gas emissions.[54] Avoiding the production of corn or other crops that are fertilizer-intensive and typically fertilized with nitrogen fertilizers in floodplains or other poorly drained soils can also reduce nitrous oxide emissions.[55]

» **RECOMMENDATION: Conduct further research to identify proper synthetic fertilizer application ratio to protect crop yield, farm revenue and nutritional value.** To ensure optimal production, further research is needed to quantify the precise amount of fertilizer required for optimal crop yields, farm income and health and environmental benefits. Findings must be communicated and marketed to farmers to increase the utilization of more accurate ratios.

‘Oats Mafia’ on oats field day in southeastern Minnesota

Photo credit: Land Stewardship Project, July 2021

OATS AND OTHER SMALL GRAINS:

A Win-Win for Economic and Agronomic Diversification And N_2O Emissions Reduction

Oats and other small grains fit into the current corn-soybean rotation in a way that enhances yields, lowers input costs, reduces water and mitigates climate change through the lowering of the application of nitrogen fertilizers. According to research conducted by the University of Minnesota and Iowa State University, adding a small grain on the field can reduce fossil fuel use, water pollution, and damage by 50% and an estimated 54% of greenhouse gas emissions.[56]

Buyer and consumer demand for oats is on the rise. According to one market analysis, oat sales climbed nearly 45% during the 2022 growing season.[57] In contrast to the shrinking number of oat acres in the U.S., the $5.16 billion domestic market for the grain is projected to have a 7.8% return on investment between now and 2030.[58]

Rural communities and farmers are seizing this opportunity to expand growing and process to meet this growing demand. For example, the ‘Oat Mafia’, a group of 60 farmers in southeastern Minnesota, are collaborating on growing and marketing oats as a strategy for reducing the need for synthetic nitrogen and diversifying their income.

Rural communities and members of the Oat Mafia farmers are supporting the launching of the new Green Acres Mill which will break ground on construction in 2025. Expanding the supply chain for oat processing will create jobs in processing, transportation, and distribution, with local oat mills and infrastructure investments keeping economic benefits within Minnesota.

IMPROVE INCENTIVE STRUCTURE FOR FARMERS

Even as crop yields have gone up with the use of synthetic fertilizer, farmers’ revenue has been inconsistent. Federal and state incentive programs can be more fully leveraged to reduce N_2O emissions if it is prioritized. The existing suite of financial incentives available to farmers are designed to promote the aggressive pursuit of short-term yield improvements over the improvement of nitrogen and irrigation management systems, even if those improvements benefit farmers over the long term. A sizeable portion of United States Department of Agriculture (USDA) conservation spending flows to industrial farm practices, which do little to reduce nitrous oxide emissions.

Additionally, farm subsidies often incentivize farmers to expand production, leading to increased nitrogen and water use. These subsidies do not discourage farming on moisture-rich land, such as floodplains. Existing biofuel policies and financial incentives promote the conversion of grasslands and forests, driving higher crop production that may require nitrogen-based fertilizers. The potential use of biofuel in aviation as a ‘green technology solution,’ a type of sustainable aviation fuel, should also account for nitrous oxide emissions from fertilizer production and application when calculating carbon offsets and benefits.

In the development of federal policies to reduce N20 agricultural emissions, USDA should work more closely with local field offices, farmer-led organizations, and state policymakers to complement these policies at the local level.

» **RECOMMENDATION: Improve federal farm subsidy programs and the Crop Insurance Program to reduce agricultural emissions and improve farm resilience.** Policymakers should reduce subsidies to large commercial farms that encourage the conversion of grasslands and forestlands to cropland. Federal farm subsidies should be designed to improved farm management practices, including conservation compliance beyond only highly erodible lands and wetlands to establish a minimum conservation standard on all farms with cropland. Subsidies and crop insurance should be strengthened to provide more support to growers of diverse crops that produce lower nitrous oxide emissions. Less support should be provided to growers of corn and other fertilizer-intensive crops. Access to Whole Farm Revenue Protection, the only crop insurance policy that rewards the risk-reducing value of commodity and business diversification, should be streamlined and the program’s coverage should be improved. These programs also need to discourage the production of crops in frequently flooded areas that serve as nitrous oxide hotspots. Furthermore, crop insurance should be reformed to make it simpler for farmers to farm in ways that reduce emissions and improve financial resilience. This could mean adjusting the program’s risk rating methodology to take into account soil health and biodiversity as well as exposure to inclement weather to prioritize farms that are more resilient against external threats.

» **RECOMMENDATION: Reform federal conservation programs to increase incentives for better field management practices.** To increase incentives for nitrogen and irrigation management practices that reduce nitrous oxide emissions, federal policymakers should reform USDA conservation programs like the Environmental Quality Incentives Program (EQIP) to increase cost-sharing for practices that reduce nitrous oxide emissions and reduce federal assistance for farm projects that produce few benefits, or which might increase nitrous oxide emissions. Policymakers could also change tax policies to discourage conversion and encourage wider adoption of nitrogen and irrigation efficiency strategies. Policies that encourage land conversion to produce crops for biofuels should be phased out.

» **RECOMMENDATION: Update EQIP state allocations to accelerate wider adoption of nitrogen and irrigation efficiency strategies.** The Institute for Agriculture and Trade Policy estimates that a substantial amount of current EQIP funding goes towards industrial practices including manure lagoons, waste facility covers and other solutions like drainage tile that are contrary to conservation goals.[59] Policymakers should change EQIP state allocation formulations to reflect the urgent need to reduce nitrous oxide emissions and improve soil health.

» **RECOMMENDATION: Accelerate sustainable approaches to nitrogen management.** Research, develop, refine, and implement truly sustainable approaches to management of nitrogen and other crop nutrients, and thereby curb **N2O** and other GHG emissions from U.S. agricultural operations.

» **RECOMMENDATION: Focus USDA programmatic support for soil health practices. USDA should support improved soil health practices through working lands conservation programs by increasing the focus of the Natural Resources Conservation Service (NRCS), EQIP, and Conservation Stewardship Program (CSP) on a suite of soil health practices.** Additionally, USDA should work with land grant institutions to change current online fertilizer calculators to incorporate newer findings on biological nutrient release from soil organic matter and other organic nitrogen sources as well as studies that demonstrate that fertilizer requirements are often substantially lower than existing official recommendations.

STRENGTHENING ENFORCEMENT OF EXISTING POLICIES AND REGULATION

Making policy and establishing incentives is just the beginning. As states implement nitrogen and nutrient management plans, it is critical that these policies establish and maintain a strong adoption mechanism to drive progress towards reducing nitrous oxide emissions. In Wisconsin, all farms which receive nutrient amendments are supposed to have a nutrient management plan according to state water protection regulations passed in 2002. However, funding to assist with adoption and enforcement of this requirement has never been fully provided to the county governments and conservation agencies who would enforce those requirements. Many farmers are not aware of these requirements and see limited benefit to them. Because of this, nutrient management plan adoption still is not above half of the crop acres in the state. This example shows that we cannot simply pass regulatory requirements and policies and assume that adoption will occur.

» **RECOMMENDATION: Expand local resources to properly incentivize and enforce existing reduction policies and regulations.** Equip state regulatory agencies, farmer-led organizations and land-grant university partners with appropriate funding to track compliance, provide education and technical assistance to adopt on-farm practices to improve soil health, emissions reduction policies and regulations.

CONCLUSION

Now is the time to take action to reduce N_2O's long-lasting and negative impact on planetary and human health. Funders, farmers, agriculture corporations, and advocates must come together to implement common-sense recommendations to reduce N_2O emissions during fertilizer production and application in the fields.

It is critical that there is accountability and transparency from all actors as we work to achieve the goals set forth in this report: Reduce N_2O emissions from domestic fertilizer production by 75% by 2035 (compared to 2020 levels). Achieve net-zero GHG emissions from domestic fertilizer production by 2050 and reduce the United States' total agricultural N_2O emissions by at least 50% by 2050.

By collectively implementing these recommendations laid out in this report, the United States' agriculture industry can make significant progress in reducing N_2O emissions and help lead the way towards a more resilient climate, with farmers as leaders and greater economic resiliency for the industry.

Recommendations to Reduce N_2O Emissions From Domestic Synthetic Fertilizer Production and Application by 2050

UPSTREAM

Actions the fertilizer industry can take to reduce N_2O emissions during the fertilizer production process

- Invest in and deploy existing pollution control technology in the synthetic fertilizer production process.
- Conduct further research to identify proper synthetic fertilizer application ratios.
- Prioritize local, rural farm communities as the domestic green fertilizer market grows.

DOWNSTREAM

Actions farmers can take to make a difference on the farm and field

- Change the timing of nitrogen applications to support crop yields while reducing emissions.
- Deploy alternative irrigation practices like drip and subsurface irrigation.
- Reevaluate crop choices and crop production locations.
- Accelerate sustainable approaches to nitrogen management.
- Advance soil health practices and tools.

REGULATORY

Actions federal/state policy makers can take to accelerate N_2O emissions reduction

- Expand resources to properly enforce existing or new emission reduction policies and regulations.
- Update policies and incentives to grow the nation's green fertilizer economy.
- Leverage permitting and enforcement within the current federal and state laws to encourage and increase the usage of pollution control technology in the fertilizer production process.
- Enact technology-based pollution control standards at federal and state levels for nitrous oxide emissions from nitric acid plants.
- Improve federal farm subsidy programs and the Crop Insurance Program to reduce agricultural emissions and improve farm resilience.
- Reform federal conservation programs to increase incentives for better field management practices.
- Update EQIP allocations to states to accelerate wider adoption of nitrogen and irrigation efficiency strategies.
- Focus federal programmatic support for soil health practices.

ADDITIONAL IDEAS FOR FUTURE CONSIDERATION

This report establishes goals and priority recommendations for urgent action on nitrogen emission reduction. The recommendations below are a menu of additional ideas for further consideration. As funders and partners consider taking action, it is prudent that farmers and fenceline communities are central to decision making surrounding the investments, policies, and industrial systems that are advanced to address nitrous oxide emissions.

FUTURE ACTIONS AND REFORMS TO CONSIDER

- **Adopt N2O emission reduction goals in state and federal policy frameworks** from the United State's agriculture sector in partnership with industry, food producers, and farmers.
- **Leverage existing citizen enforcement and public permitting processes** to compel nitric acid plants to install and operate pollution control technologies for nitrous oxide.
- **Establish universal standards** for transparency, tracking, and reporting of nitrous oxide emissions at fertilizer production facilities.
- **Establish universal standards** for transparency, tracking, and reporting of nitrous oxide emissions at fertilizer production facilities.
- **In partnership with farmers, shift the United States' financial structures to support diverse food and cropping systems**, including but not limited to, commodity subsidies and crop insurance subsidies (prices).
- **Reassess biofuel policies and incentives:** To curb the Midwest region's excessive reliance on synthetic fertilizers, policymakers must take proactive steps to reform national biofuel policies and incentives.
- **Invest in synthetic fertilizer production and application public health research.** The National Institute of Health should study the link between fertilizer production and use with health risks such as cancer.
- **Strengthen partnerships with food producers and agriculture companies.** Seek, support, and monitor commitments from food and agriculture companies to track, measure, and reduce nitrous oxide emissions from their products.
- **Establish a fertilizer efficiency standard for fertilizer corporations.** This standard could be modeled after the Corporate Average Fuel Economy (CAFE) standard with targets aligned with 2035 and 2050 goals.

SPONSORS

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In the summer of 2024, more than a dozen climate leaders, rural and/or ag leaders met to discuss the agriculture industry's contribution to the climate crisis. The group brainstormed possible pathways to reduce nitrous oxide from fertilizer use and to decrease carbon emissions from fertilizer production between the years 2030 and 2040. Their collective thinking resulted in this report.

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