Ceres

CULTIVATING INNOVATION
Practical Solutions for Companies to Reduce Agricultural Emissions

November 2023

About Ceres

Ceres is a nonprofit organization working with the most influential capital market leaders to solve the world's greatest sustainability challenges. Through our powerful networks and global collaborations of investors, companies, and nonprofits, we drive action and inspire equitable market-based and policy solutions throughout the economy to build a just and sustainable future. For more information, visit ceres.org and follow @CeresNews.

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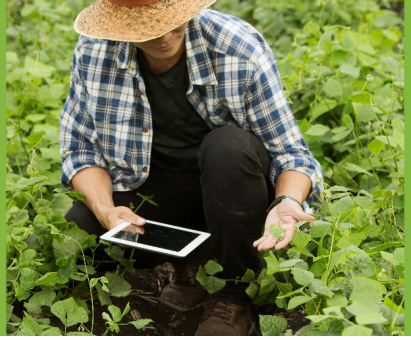


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INTRODUCTION

As more companies publicly commit to reducing their greenhouse gas (GHG) emissions in line with a low carbon future, a key question remains: how will companies achieve these ambitious targets? The clock rapidly ticks toward 2030, a critical milestone for avoiding the worst impacts of climate change, and companies across all sectors must look deep within their operations and supply chains to accelerate the transition to a lower emissions economy.

Reducing global agricultural emissions is a critical solution to climate change. Even if all fossil fuel emissions were eliminated immediately, emissions from the global food system alone would make it impossible to limit warming to 1.5°C.

The linchpin to reducing emissions in the food sector is companies' scope 3 emissions related to the production of agricultural ingredients and products within food and beverage companies' supply chains. Globally, roughly 39% to 59% of emissions from the food sector come from agricultural activities, including methane emissions from raising livestock and growing rice, nitrous oxide from applying fertilizer to grow crops, and fossil fuels like oil and natural gas for powering farm equipment. The remaining emissions come from food processing, packaging, distribution, and waste.

Agriculture is commonly considered a hard-to-abate sector because many of the solutions to reduce agricultural emissions will require significant investments and possibly a fundamental redesign of the food system. The difficulty of reducing agricultural emissions is further exacerbated by increasing global food demand, socially driven dietary habits, physical impacts of record droughts, record heat, floods that are already impacting agricultural yields, and the complex structure of global supply chains.

The good news is that there are concrete and cost-effective ways companies can accelerate the development and adoption of innovations that will help the sector reduce emissions in line with a 1.5°C future. There are a

wide range of existing practices, including regenerative agriculture practices aimed at increasing soil carbon emissions removals that companies can incentive in their supply chains. However, though these practices have many benefits for climate, water, and biodiversity, they alone will not be sufficient for sector-wide achievement of 1.5°C-aligned goals. **This report focuses on the innovative solutions that will help companies close the emissions gap as they near their target deadlines.**

This report is intended to help investors and companies understand the emerging solutions to reducing the main sources of agricultural emissions: enteric methane, manure management, rice cultivation, fertilizer use, fertilizer production, and on-farm energy use. Investors can use this information to inform their engagements with companies and assess whether corporate climate transition plans are sufficiently including plans to reduce these hard-to-abate emissions.

The report includes:

- A summary of strategies available to food companies to invest in innovations at various stages of development – from those that are still concepts in the discovery research phase to those that are commercially available but not yet widely adopted.
- A framework that illustrates how companies can prioritize what strategies to use based on available innovations for the large emissions sources in their supply chain.
- A menu of the available and emerging innovations for each of the key sources of agricultural emissions, including their mitigation potential and current innovation status

Why Investing in Agricultural Innovation is a Critical Component of Corporate Climate Transition Plans

As companies develop and disclose climate transition plans, it is critical that they consider existing and emerging technologies they will need to deploy in their supply chains to close the gap to their goals. As outlined in Ceres' Investor Guide to Climate Transition Plans in the U.S. Food Sector, a key first step is to identify the largest emissions drivers for the company. Based on this information, companies can then evaluate the actions they will take to address each of those sources of emissions and budget for research and development (R&D), capital expenditures, and other operational investments to reach their near- and long-term emissions reduction goals. However, it can be difficult to assess whether companies are prioritizing actions that will have the largest impact for their emissions footprint both in the near- and long-term, and whether companies' combined efforts will yield the emissions reductions needed for alignment with a lower emissions economy.

Emissions from agriculture are typically embedded in companies' supply chains, except for companies that own and operate direct agricultural operations, such as vertically integrated poultry processors. A common first step for companies to address hard-to-abate agricultural emissions is to engage suppliers through procurement teams or work within owned agricultural operations to adopt existing practices known to reduce on-farm emissions. While this is a much needed and effective way to mitigate supply chain emissions in the near-term, **companies will not achieve reductions in line with a 1.5°C future by relying on existing technologies and practices alone.**

To close the gap to achieving ambitious climate commitments, companies must also support the development and scaling of new and emerging technologies that may not yet be developed but have the potential to drive further emissions reductions. While these may not be cost-effective solutions today, early investment and testing will make it easier for companies to adopt these solutions when they need to address their remaining scope 3 emissions.

In addition, increased investment in emerging agricultural technologies can benefit companies' operational efficiency and supplier relationships while driving competitive advantages as the world transitions to a lower emissions economy.

Opportunities and benefits for companies include:

- **Mitigating systemic risks and adapting to physical impacts of climate change:** Many of the technologies and innovations targeted at emissions reductions have the added benefit of making farms more resilient to increased stress from variable and changing weather. Companies that invest in these innovations can help agricultural producers in their supply chains adapt to climate change. At the same time, these investments also help mitigate the systemic risk of climate change and can help reduce the worsening of climate-related impacts experienced by farmers.

- **Increasing agricultural productivity and stabilizing commodity prices:** Investments in agricultural technology are needed to increase productivity while maintaining the resilience of farmland and other assets in the face of population growth and changing weather patterns. Decreased yields can put economic strain on farmers and rural communities and can also raise the price of agricultural commodities, which can impact margins for food processors, manufacturers, retailers, and restaurants.

- **Incubating new business opportunities:** Some food companies are investing in early-stage technologies through their corporate venture capital arms. Others are supporting the scaling of innovation through pilots and trials, some are pursuing joint development agreements to co-create needed innovations, and still others are fully integrating new technologies through mergers and acquisitions. In any of these cases, companies can leverage investment in agricultural innovation to meet their strategic objectives and spur future business growth.

- **Attracting new forms of capital:** Companies are increasingly leveraging their emissions reduction efforts to attract capital in the form of equity and debt, including green bonds, sustainability-linked loans, and other financing tools.

STRATEGIES FOR CORPORATE INVESTMENT AND INNOVATION IN AGRICULTURAL EMISSIONS REDUCTIONS

To mitigate material financial risks associated with the worst impacts of climate change, it is critical that food companies support the adoption of existing, ready-to-deploy technologies and practices that are known to reduce agricultural emissions while simultaneously investing in the testing and development of those that will help the sector address the harder to abate emissions. While farmers and ranchers are also constantly innovating their practices, the purpose of this report is to highlight ways corporations can support innovations that are unlikely to be developed by farmers themselves. For example, it is typically not possible for a farmer to develop their own feed additives to reduce methane emissions from cattle. These innovations must be developed through public and private R&D processes and incentivized appropriately for farmers.

Companies have two main ways to invest in agricultural emissions reductions and make progress towards their scope 3 emissions reduction targets (Figure 1):

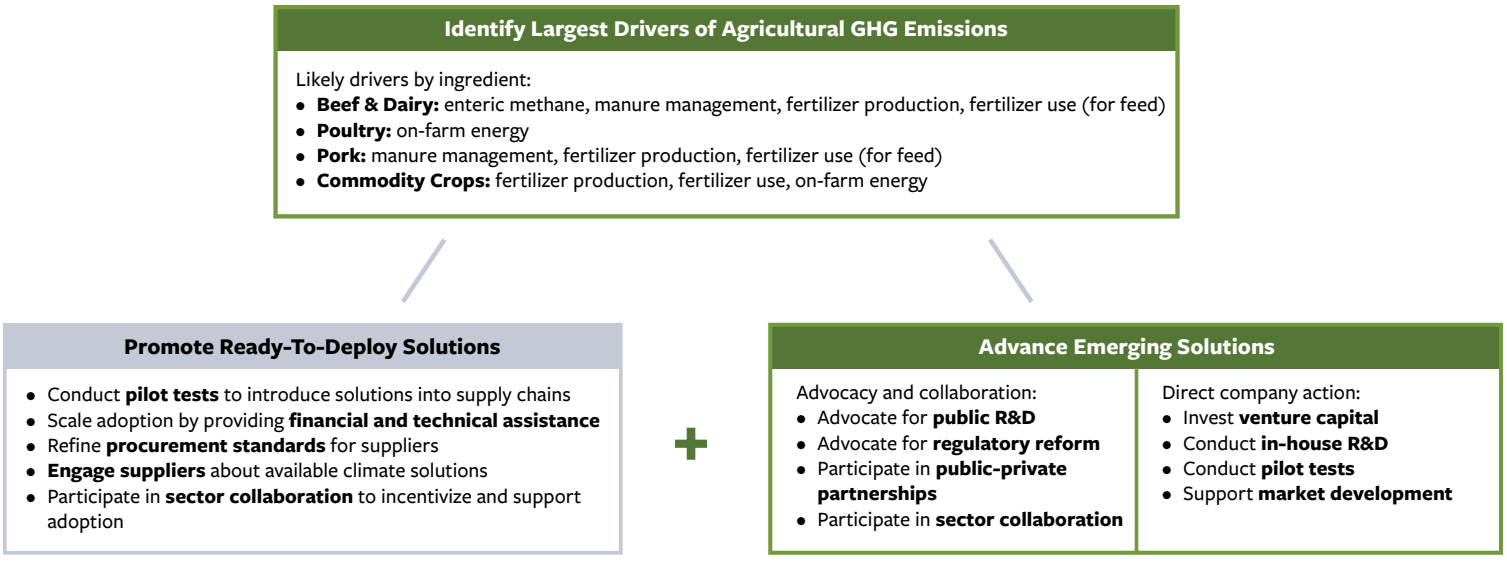
1. **Incentivize ready-to-deploy solutions:** There are many solutions that reduce agricultural emissions with proven and demonstrated impacts. For example, more efficient fertilizers and alternative manure management practices, such as manure composting, are proven solutions that do not have substantial regulatory barriers or remaining research needs. To incentivize the adoption of these solutions in their supply chains, companies can conduct pilot tests with farmers who have not yet adopted these practices, provide financial and technical assistance to scale the solutions, refine procurement standards and supplier expectations, and engage suppliers to incentivize adoption of these solutions in their supply chains.

2. **Advance emerging solutions:** Emerging solutions include technologies and practices that are in various stages of development, ranging from discovery phase to those that are commercially available on a limited basis. There are two main ways companies can advance these solutions:

a. **Advocacy and Collaboration:** Discovery and experimental research is often too early-stage and risky to attract company investment, as the timeframe for research can be too long, the research may be too expensive, and the benefits may be too uncertain. However, this research is critical, as it lays the groundwork for the development and delivery of innovative climate solutions, and it helps to ensure that new and improved solutions will continue to emerge. To support this type of research, companies can advocate for more funding for public research agencies, which are better positioned to conduct basic and high-risk research, participate in public-private partnerships, which allow companies to support and guide climate research with minimal risk, and reduce risks and barriers by advocating for efficient and safe regulatory processes. Companies can also participate in sector-wide collaborations to facilitate peer-to-peer learning, collaboration, and pooling of resources to support promising solutions.

a. **Direct Company Action:** There are some commercially available emerging solutions with limited market adoption that need additional research, development, and demonstration to evaluate and improve effectiveness, reduce costs, and produce at scale. Once technologies are farther along in the research and development phase, companies will be able to evaluate innovations based on their potential costs and benefits, impacts on animal and human health scalability, return on investment, and other factors that are important to the company. For promising innovations, companies can support continued research and development by investing venture capital, conducting in-house R&D, and participating in public-private partnerships. In addition, companies can also test, incubate and further develop technologies through pilot tests within their supply chains. Finally, companies also have a role to play in driving down costs and increasing demand for promising solutions by supporting market development.

Figure 1: How food companies can accelerate agricultural emissions reductions



Corporate Actions to Advance Emerging Technologies through Advocacy and Collaboration

Many of the promising technologies and innovations for reducing agricultural emissions are far from being ready for general adoption, and some may merely be the beginnings of ideas. To address research gaps, accelerate innovation, and make it more likely for these technologies to make it to market, it is critical that companies participate in public-private partnerships and pre-competitive collaborations while also engaging public policy to create an enabling regulatory environment.

Sector collaborations: Companies will not be able to reduce their scope 3 agricultural emissions through individual action alone. Pre-competitive collaborations allow companies within a sector to connect with other key stakeholders in their value chain, brainstorm solutions for sector-wide issues, aggregate and signal demand, and pool investments towards promising solutions to address key climate-related challenges. One example is Ceres' Climate-Smart Agriculture and Healthy Soil Working Group, a working group that brings together food, beverage, and clothing companies to engage in peer-to-peer learning and push for legislative and regulatory solutions to advance climate-smart agriculture practices in the U.S. Another is the SAI Platform, an industry-created organization that brings together over 170 companies and industry groups in the global food and agriculture sector to participate in on-the-ground sustainable agriculture projects around the world. Companies are also beginning to pool resources to support and accelerate the development of innovative startups working on technologies that will lead to sector-wide emissions reductions.

> **Example:** In 2018, Anheuser-Busch InBev, Coca-Cola, Colgate Palmolive, and Unilever came together to co-sponsor and launch the 100+ Accelerator. This collaborative project invests up to $100,000 in individual startup companies to pilot, test, and scale solutions for key challenges in the global food and packaged goods industries. The program also provides participating startups with access to remote programming and training. The goal is for startups to graduate to larger commercial contracts after completing the program. Key challenges the initiative is seeking startups to solve include sustainable agriculture, climate action, and biodiversity.

Public R&D advocacy: Government programs have historically been a source of funding for experimental agricultural R&D, but public investment has been on the decline, including in the U.S., where agricultural research spending has decreased in recent decades due to steep declines in state funding. More funding for public research programs at the state and federal levels would advance the development of a suite of solutions for agricultural GHG emissions, including early-stage innovations that are currently too high risk for private investment.

> **Example:** In the U.S., relevant programs include the Agricultural Research Service, Agriculture and Food Research Initiative (AFRI), and Agriculture Advanced Research and Development Authority—which fund basic, pre-competitive, or high-risk research that companies are ill-suited to support—and the Agricultural Genome to Phenome Initiative, a collaborative science engagement aimed at expanding knowledge of plants and animals' genomes and phenomes that would help in identifying traits for use in breeding lower emissions crop and livestock. Companies can advocate for higher discretionary funding levels for agricultural R&D, influence research program priorities by engaging directly with appropriate government departments, and match public R&D investments for ongoing federal research.

Public-private partnerships: Public-private partnerships are a low-risk opportunity for companies to support high-priority innovations. For example, in the U.S. companies can participate in partnerships such as the Foundation for Food and Agriculture Research (FFAR). FFAR's public-private partnerships fill critical research gaps in a number of focus areas, including developing next generation crops with environmental benefits. Globally, AIM for Climate, a joint initiative by the United States and the United Arab Emirates, is a collection of public-private partnerships seeking to address climate change. Planned innovation sprints with private and public actors include the Enteric Fermentation R+D Accelerator, which aims to accelerate development of methane mitigating technologies. There are also other programs companies can participate in to test and accelerate the adoption of technologies that are commercially available at a limited scale, as well as ready-to-deploy existing practices. Recent U.S. examples include the Partnerships for Climate-Smart Commodities program. These public programs allow companies to tap into government agencies' networks to connect with indirect suppliers and support their testing and adoption of innovative agricultural practices.

> **Example:** Archer Daniels Midland and Nestlé are founding members of the Greener Cattle Initiative, and JBS USA sits on the steering committee. The initiative is housed within FFAR, and consortium partners include the Innovation Center for U.S. Dairy and the New Zealand Agricultural Greenhouse Gas Research Center. The initiative conducts research for a wide variety of technological solutions to address methane emissions from livestock production particularly within beef and dairy supply chain, including methane-

inhibiting nutritional amendments for cattle feed, breeding cattle with genetic traits to emit less methane, and technologies for monitoring methane emissions. The first grants were awarded in 2023 to three projects in the U.S. focused on developing and testing new technologies.

Supporting regulatory reform: Some technologies that are not yet on the market require additional regulatory approval even for use in small-scale pilots. For example, in the U.S., methane-inhibiting feed additives that would reduce the amount of methane emitted by cow burps by adding certain chemical compounds to the feed consumed by cattle are currently subjected to the FDA's drug approval process. This can take up to 10 years and cost around $30 million. The U.S. could follow the lead of the European Union, which has an expedited approval process for products with high environmental potential benefit. Companies can help advocate for regulation reform to accelerate the approval process for different emissions mitigation strategies.

Corporate Actions to Advance Emerging Technologies through Direct Company Action

Some emerging technologies that can reduce agricultural GHG emissions, such as the methane-inhibiting feed additives, are further along in the innovation pipeline, with some options being commercially available at a limited scale. These technologies require additional research and testing to achieve wider market adoption so they can be incentivized within companies' supply chains like other ready-to-deploy solutions. To increase the economic viability of promising emissions-reducing innovations, there are several actions companies can take in their own operations and supply chains. Companies with a venture capital arm can also fund innovators on ideas that are still in initial stages.

In-house R&D investment: Food companies can invest in R&D to test the use of lower emission ingredients, such as crops bred to be grown with a lower emissions footprint, in their recipes. They can also test the performance of new technologies within their own supply chains. In addition, companies can also invest in R&D to create internal enabling environments to adopt agricultural innovations. Key examples include investigating infrastructural and process changes needed to incorporate new technologies within the business, developing alternative protein products, and testing new product formulations that use lower emitting crops.

> **Example:** Consumer goods companies such as General Mills and Patagonia have started using Kernza, a perennial wheat variety developed by The Land Institute, in their products. Perennial grains offer a host of environmental and economic benefits, including improving soil health, which helps sequester carbon and reduce runoff, and reducing the need for tillage and replanting. While Kernza is the first commercially viable perennial grain crop, more investment is needed to help improve yields to make it a more economically viable alternative to conventional annual grains. By testing the use of Kernza in their products, both for new products and as a replacement for traditional wheat in existing products, companies can help raise awareness for the crop and drive further investment towards its breeding program.

Market development and demand creation: Companies can develop and market new products that use a diverse set of ingredients with lower emissions than conventional ingredients. This not only helps the company reduce its scope 3 emissions, but also helps expand the market for diversified, climate-friendly ingredients. For example, many sustainable agriculture experts are calling for a system-wide shift to diversified row cropping systems that grow a variety of cereal grains and legumes rather than monocultures. Food companies can invest in the development of new food products that use alternative inputs, such as rye, oats, sorghum, and perennial versions of major crops like wheat to reduce the emissions impact of their products, while increasing the demand for such ingredients. Companies can also establish sustainable sourcing commitments that can serve as a guarantee for suppliers that low-emissions commodities will be procured by the company. This type of pre-payment offtake agreement can spur testing and innovation due to an established demand for commodities grown in a lower-emissions manner.

Pilot testing and proof of concept: By investing in pilot projects, companies can help establish proof of concept for emerging practices and technologies and help create trust and understanding among agricultural producers

in their supply chains. Corporate pilot projects allow farmers to test new practices or technologies with limited risk. Agriculture is often a word-of-mouth business. As farmers experience success with certain technologies, they may convince others to try things out for themselves. By taking some of the risk out of the initial adoption of a technology, providing technical assistance, and covering any up-front costs, companies can help increase awareness of certain emerging technologies. This also provides developers of the technology with critical data to improve their product.

> **Example:** Feed additives are nutritional amendments to livestock feed that can reduce the amount of methane produced by cows and emitted through their burps. One promising feed additive is Bovaer, which is being developed by dsm-firmenich, a Dutch multinational. Dutch dairy company Royal FrieslandCampina partnered with DSM and feed supplier Agrifirm to pilot Bovaer with 158 dairy farms in the Netherlands, in what is reported as being the world's first large-scale, on-farm use of this feed additive for cattle. The six-month pilot illustrated the efficacy of the product and the feasibility of implementation. The companies reported that the feed additive led to a 28% reduction in enteric methane emissions on average.

Corporate venture capital: Companies with a venture capital function can invest in emerging technologies that they may be able to adopt in their own supply chains in the future to make further progress towards emissions reduction targets. Venture capital investments and seed funding can be critical levers for companies to invest in technologies outside of their core business that are too risky or too far from commercial adoption to start developing or testing in-house at the present. Companies may also invest in solutions that are market-ready with the intent to scale production. Early investment in technologies can help companies gain a competitive advantage, as they will have earlier access to test and integrate the new technologies into their own supply chains and business models.

> **Example:** Tyson Foods' investment arm, Tyson Ventures, invests in and partners with promising innovators working across a wide range of areas, including alternative proteins, enabling technologies that support traceability and automation, and other solutions that support a more responsible food system. One of Tyson Ventures' portfolio companies, Athian, is developing a cloud-based platform that provides livestock producers with tools to benchmark their operational footprint and on-farm emissions reductions. Tyson Ventures' other portfolio companies include Upside Foods and Believer Meats–both focusing on cell-based and cultivated meat, which can divert demand and reduce emissions from livestock production.

TECHNOLOGIES AND INNOVATIONS TO DRIVE DOWN AGRICULTURAL GHG EMISSIONS

The major drivers of agricultural GHG emissions (figure 2) and the commodities that most significantly contribute to those emissions are:

- **Methane emissions**

  Enteric methane (dairy, beef)

  Manure management (dairy, pork, beef to a lesser extent)

  Rice cultivation (rice)

- **Nitrous oxide emissions**

  Fertilizer use (corn, including for animal feed, wheat, rice, fruits, and vegetables)

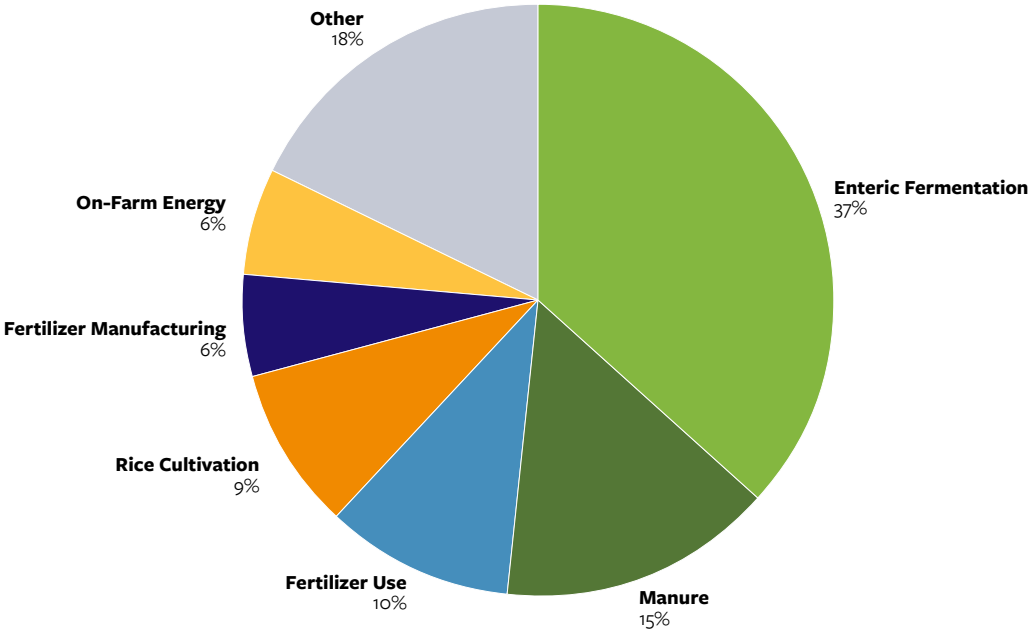
- **On-farm energy use emissions**

  Electricity and other energy use (all commodities, but particularly poultry, oilseeds, and grains)

- **Industrial emissions**

  Fertilizer manufacturing (corn, including for animal feed, wheat, rice, fruits, and vegetables)

Figure 2: Global emissions from agriculture in 2020, by source



Source: FAOSTAT. "Manure" includes CH_4 and N_2O from manure management and N_2O from manure left on pasture; "Fertilizer Use" includes N_2O from synthetic fertilizer use and manure applied to soils; "Fertilizer Manufacturing" includes CO_2 and N_2O; "On-Farm Energy" includes CO_2, N_2O, and CH_4; "Rice Cultivation" is CH_4; "Enteric Fermentation" is CH_4; and the "Other" category includes drained organic soils, savanna fires, crop residues, and burning crop residues.

The following pages describe promising technologies for each of the key drivers of agricultural GHG emissions. These technologies will help close the emissions gap to a 1.5°C future when implemented **in combination** with existing practices and technologies known to mitigate agricultural emissions, as well as an effort to curb the demand for beef, dairy, and other agricultural products with an inherently large emissions footprint. Companies can also invest in other indirect levers, such as reducing food waste, which will create efficiencies in the food system that will lead to additional emissions reductions.

As a company develops its innovation plan to address scope 3 emissions from agriculture, it should prioritize supporting and investing in innovations based on expected financial and environmental returns, emissions mitigation potentials, co-benefits, and scalability. There are often also complex tradeoffs between climate, environmental, economic, environmental justice, equity, and animal welfare impacts for several of the solutions. This report focuses on reducing GHG emissions, but companies and investors should carefully weigh tradeoffs and identify opportunities to mitigate negative side effects.

Addressing Livestock Emissions by Reducing Consumer Demand for Meat and Dairy

Food and beverage companies can avoid livestock methane emissions entirely by promoting alternatives to conventional meat and dairy products and curbing the demand for livestock production. Plant-based, cultivated, and fermentation-derived alternatives deliver proteins and the taste many people associate with conventional meat and dairy without the need for raising live animals—eliminating manure and enteric methane emissions. However, producing these alternatives can be energy intensive, so their emission reduction potential will grow with cleaner energy mixes, efficiency improvements, and continued innovation.

Innovations in the alternative protein space include:

- **Plant-based proteins:** Meat and dairy alternatives that are derived from protein-rich plants, such as legumes, grains, nuts, seeds, and vegetables. Numerous restaurant chains—including Carl's Jr., Burger King, and Chipotle—have added plant-based options to their menus, and food product manufacturers, such as Tyson and Nestlé, sell plant-based products. While many plant-based meat and dairy products are on the market, more research is needed for more widespread adoption of plant-based diets. Innovations in this area include breeding crops with increased protein content, quality, and nutritional function so consumers can more easily swap these products in for their meat counterparts.
- **Cultivated proteins:** Meat that is nearly identical to traditional meats and produced by growing animal cells in laboratories. The cultivated meat industry is still in its early stages. Singapore became the first country to sell cultivated meat when a company called Eat Just received approval to begin selling its cultivated chicken in 2020. In June 2023, Upside Foods and Eat Just became the first two companies to receive USDA approval to begin producing cell-based proteins in the U.S.
- **Fermentation-derived proteins:** Ingredients that are produced through microbial fermentation processes, typically using microorganisms like bacteria or yeast to convert plant-based substrates into protein-rich ingredients that can be used in cultivated and plant-based meats and in other food products. In recent years, dozens of new startups focused on using fermentation for alternative proteins have arrived on the scene and attracted investments. For example, Nestlé has partnered with Perfect Day, a company producing milk using precision fermentation.

Many food companies are investing directly in emerging alternative protein products through their venture capital arms, internal R&D functions, acquisitions of proven alternative protein companies, and procurement of commercially available products. Companies can also support the research, development, and delivery of novel alternative proteins still in development by supporting public R&D, investing in alternative protein companies, advocating for streamlined regulatory processes and fair labeling, and signaling demand for products that close-to-market. Companies should also actively engage consumers in a shift to the lower emissions offerings and create demand for alternative proteins through advertising, product packaging, labelling, product formulation, and other tactics.

Innovations to Mitigate Enteric Methane Emissions

Methane is a byproduct of enteric fermentation, a natural microbial process that occurs when cattle and other ruminant livestock digest feed. Enteric methane is responsible for around 37% of global agricultural GHG emissions. Beef and dairy cattle represent around 52% and 17% of these emissions, respectively, with goats, sheep, horses, swine, and other livestock accounting for the remaining 31%. In the U.S., beef and dairy are larger drivers, representing 71% and 25% of the country's enteric methane emissions, respectively. These emissions are significant drivers of scope 3 GHG emissions for food and beverage companies that source these commodities. For companies with company-owned agricultural operations, these emissions would appear within their scope 1 GHG inventories.

Ready-to-Deploy Enteric Methane Solutions

Several enteric methane mitigation solutions are already available to food companies and agricultural producers. Companies can support adoption of these solutions by sponsoring pilot projects and providing financial and technical assistance to producers. Because beef and dairy operations typically have low profit margins, practices and technologies must be at least cost-neutral for the farmer, so financial assistance and incentives will be critical.

Readily deployable enteric methane solutions include:

- **Breeding for Productivity:** Selecting genes for cattle that can yield more milk and meat on the same amount of feed can lower emissions intensity, reduce land use and other inputs, and improve farmer profits. Genomic breeding—an approach that maps an animal's entire genetic code to identify genes that impact desirable traits—can accelerate the rate of genetic change, but there is currently low uptake in non-dairy production systems.
- **Feed and Forage:** Providing cattle with more easily digestible feed and forage can reduce methane emissions. High fiber diets are correlated with greater emissions, but increasing fat content by adding lipids has been shown to reduce methane emissions. Studies have found that forage with a high tannin content, such as birdsfoot trefoil, sainfoin, and small burnet, can reduce enteric methane emissions. However, high concentrations of tannins may reduce protein digestibility and impact animal health, and some dietary lipids, such as cottonseed, may impact milk yield.

Emerging enteric methane solutions

New enteric methane solutions will continue to emerge, but currently the most promising enteric methane innovations in the research and development pipeline include rumen modifiers, enteric methane inhibitors, methane-capturing masks, vaccines, and breeding. When considering which solutions to support and invest in, it is critical that companies consider the animal welfare and human health and safety impacts of these new technologies.

Rumen modifiers are feed additives that can improve cattle feed use efficiency and reduce emissions by enhancing digestive processes. They include essential oil products, such as Agolin Ruminant (an essential oil blend) and Mootral (a combination of garlic powder and citrus extracts), as well as live yeast cultures like Yea-Sacc. In addition to reducing methane emissions, rumen modifiers may provide environmental and economic co-benefits, including improved animal health and productivity.

- **Mitigation Potential:** Rumen modifiers have the potential to substantially reduce enteric methane emissions, but they are less effective than several other mitigation strategies described in this section. Agolin Ruminant has been found to reduce methane yield by around 13% in dairy cattle, and, in an experiment with beef cattle, Mootral reduced methane yield by 23.2% after 12 weeks. Because strategies for effectively delivering rumen modifiers to grazing cattle have not yet been developed, feed additives have limited mitigation potential for beef cattle, which release most of their lifecycle emissions on pasture.
- **Innovation Status:** Several rumen modifiers are already commercially available or near-to-market in some countries. For example, Agolin Ruminant and Yea-Sacc are available in the U.S., UK, and other countries, and Mootral is being piloted on farms in the U.K. However, other products are in earlier stages of research and development. Additional research activities would help agricultural producers and food companies mitigate emissions more effectively and reliably. In addition, a safe and efficient process for regulatory approval will encourage investment and minimize delays.

Enteric methane inhibitors are feed additives that directly reduce the activity of methane-producing microorganisms in the rumen. Methane inhibitors include A. taxiformis, a type of red seaweed, and 3-NOP, a synthetic compound. Researchers are also testing synthetic bromoform, the active compound in A. taxiformis, and are working to identify other active compounds in red seaweed. While methane inhibitors are a promising climate solution, some products could pose health and safety risks. For example, bromoform is classified in the U.S. as a probable human carcinogen. It is critical that researchers confirm that methane inhibitors do not compromise meat and milk safety or pose risks to human and animal health.

- **Mitigation Potential:** Adding the red seaweed A. taxiformis to cattle feed has been found to reduce methane yield in dairy and beef cattle by up to 55% and 98%, respectively, and 3-NOP may decrease methane yield in dairy and beef cattle by up to 36% and 50%. As with rumen modifiers, methane inhibitors are not yet well suited for pasture systems. This restriction limits the scope of methane inhibitors' mitigation potential since beef cattle, even those finished in feedlots, spend most of their life grazing on pasture.

- **Innovation Status:** Methane inhibitor products are in various stages of development. A 3-NOP product called Bovaer has been approved for commercial use in Europe, Brazil, Chile, and Australia; SeaGraze, a red seaweed additive, is being piloted on farms in Wisconsin; and Lumen Bioscience is developing an additive from genetically engineered spirulina. Blue Ocean Barns' Brominata, a red seaweed product, has been approved by the California Department of Food and Agriculture, and Ben & Jerry's, Straus Family Creamery, and Clover Sonoma have signed deals to provide Brominata to dairy cows in their supply chains. Like rumen modifiers, methane inhibitors would benefit from additional trials and pilots, research on application in pasture settings, and safe and efficient regulatory processes.

Methane Masks have been developed by U.K.-based company. The device, ZELP, captures methane exhaled by cattle and converts it into water and CO_2, a less potent GHG. ZELP was developed with EU funding, and has recently attracted investments from Danone and the Bill & Melinda Gates Foundation. Because the masks track animal movement, feeding, rumination, and other activity data, ZELP can alert agricultural producers to potential animal welfare issues. However, little research has been conducted to assess whether wearing a mask could negatively impact animals' well-being.

- **Mitigation Potential:** According to the company, ZELP can reduce methane emissions by 53%, but these claims have yet to be confirmed in peer-reviewed studies.

- **Innovation Status:** In 2021, Cargill and ZELP announced a partnership, sharing that they would conduct additional testing at the Cargill Research and Development Center at Wageningen University and deliver the device to European dairy farmers in the second half of 2022. ZELP devices are currently available via subscription, which can be funded by corporations or farmers, but more research is needed to confirm ZELP's methane reduction potential and evaluate possible impacts on animal productivity and wellbeing.

Low methane breeding could reduce enteric methane emissions by genetically selecting for specific traits in cattle either through conventional breeding methods or gene editing and other novel techniques, such as CRISPR. Potential co-benefits and unintended consequences are still unclear. Experts disagree on whether breeding for low-methane traits could impact cattle growth rates, milk production, and welfare, and, if so, whether the impacts would be positive or negative.

- **Mitigation Potential:** Selective breeding can deliver permanent climate benefits, as future generations will retain the same low methane traits. In a recent study, low methane emitting cattle produced 22% less methane than high emitters on average, and researchers have determined that these traits can be passed down. Based on existing studies and estimates, it is likely that selective breeding could yield methane reductions between 20% and 30% by 2050.

- **Innovation Status:** At least one product—Semex, a low-methane genetic solution—is commercially available. However, its mitigation potential has not been verified through independent or peer-reviewed studies, and basic and experimental research gaps remain. Researchers have made progress identifying key differences

between low and high emitting cattle, but phenotyping and genotyping more livestock will be necessary to identify low-methane traits, and more research is needed to improve the accuracy of selective breeding and assess impacts on animal health and digestion.

Methane-inhibiting vaccines are designed to stimulate cattle's immune systems to produce antibodies that target and inhibit specific methane-producing microbes in an animal's digestive system. Impacts on animal productivity are currently unknown.

- **Mitigation Potential:** The effectiveness of methane vaccines is highly uncertain. Lab-based studies using cattle cells measured methane reductions of up to nearly 70%, but vaccines have not yet been demonstrated in live cattle. Studies conducted with live sheep have yielded mixed and temporary effects. Methane vaccines would be administrable to both grazing and feedlot cattle, making it a more versatile solution than feed additives, which are mostly appropriate for cattle in feedlot settings.
- **Innovation Timeline:** ArkeaBio, a company incubated by Breakthrough Energy Venture, is developing a vaccine to reduce methane emissions from cattle, sheep, goats, and other ruminant animals, but vaccine research is still in the discovery and experimental phases, and the timeline for commercial availability is uncertain. One study estimates that it could take five or more years before vaccines reach the market, while another study speculates that it could take seven to 10 years after the successful demonstration of a prototype, which has yet to occur.

SUMMARY OF EMERGING SOLUTIONS

Category (Innovation Timeline)	Solution	Mitigation Potential	Potential tradeoffs (-) / co-benefits (+)	Innovation Status
Rumen Modifiers (0-2 years) Currently limited to dairies and intensive systems	Agolin Ruminant	Dairy: around 13% reduction (methane yield*) Beef: unknown	(+) Potential for improved animal health; improved productivity and yield	Commercially available in the U.S., as well as in markets in Europe and Asia
	Mootral	Dairy: 20.7-38.3% reduction (methane concentration) Beef: Up to 23.3% reduction (methane yield)		Limited availability; on-farm pilot being conducted in the UK
	Yea-Sacc	Uncertain		Commercially available in the U.S.

SUMMARY OF EMERGING SOLUTIONS				
Category (Innovation Timeline)	**Solution**	**Mitigation Potential**	**Potential tradeoffs (-) / co-benefits (+)**	**Innovation Status**
Methane Inhibitors (3-5+ years) Currently limited to dairies and intensive systems	SeaGraze/ A. taxiformis	Dairy: up to 55% reduction (methane yield) Beef: up to 98% reduction (methane yield)	(-) Compound in A. taxiformis may cause tumors in animals and is classified in the U.S. as a probable human carcinogen. (It is unclear whether the compound could contaminate meat or milk, but most experts believe A. taxiformis is safe.) (+) Lumen Bioscience's spirulina product does not contaminate meat or milk	Commercially available in the U.S.; on-farm pilots being conducted in Wisconsin
	Brominata/ A. taxiformis	Unkown; likely similar to SeaGraze and other A. taxiformis additives		Approved by the California Department of Food and Agriculture; deals signed with Ben & Jerries and other companies
	Rumin8/ synthetic bromoform	>85% methane reduction according to company		Ongoing development and trials by company
	Bovaer/3-NOP	Dairy: up to 36% reduction (methane yield) Beef: up to 50% reduction (methane yield)		Approved for use and piloted in countries, including Europe, Brazil, Chile, and Australia; undergoing regulatory approval in the U.S.
	Lumen Bioscience (engineered spirulina)	Unknown, but company's lab tests have yielded promising results		Early stages of development; has not yet been tested in live cows; recently won the Wilkes Center Climate Prize
Methane Masks (0-2 years)	ZELP	53% methane emission reductions According to company	(-) Little research has been conducted to assess whether wearing a mask could negatively impact animals' wellbeing. (+) ZELP's tracking system can alert agricultural producers to potential animal welfare issues.	Limited commercial availability in Europe

SUMMARY OF EMERGING SOLUTIONS				
Category (Innovation Timeline)	**Solution**	**Mitigation Potential**	**Potential tradeoffs (-) / co-benefits (+)**	**Innovation Status**
Low-Methane Breeding (0-5+ years)	Semex	20-30% reduction by 2050 According to company	**Undetermined – more research needed to determine impact on cattle growth rates, milk production, and animal welfare.**	**Commercially available in the U.S.**
Methane Vaccines (5+ years)	Arkea Bio	**Uncertain**	**(+) Methane vaccines would be administrable to both grazing and feedlot cattle.**	**In development**

*Methane yield is calculated as methane emissions divided by dry matter intake

Ways Companies Can Accelerate Innovation Of Enteric Methane Solutions	
Advocacy and Collaboration	**Direct Company Action**
• Advocate for **public agricultural R&D**. Activities that would benefit from additional R&D funding include: development of feed additive strategies for pasture settings; multi-year feed additive trials; phenotyping and genotyping livestock; evaluation of breeding practices; rumen microbiome research; and in vivo vaccine demonstrations. • Participate in **public-private partnerships**, such as FFAR's Greener Cattle Initiative, whose priority research areas include the cattle microbiome, breeding practices, and feed additives. • Advocate for **regulatory reforms**, such as the Innovative FEED Act, which would regulate methane feed additives as "food additives," not "new animal drugs"	• Invest **venture capital** to fund development of early products (e.g. Arkea Bio's vaccine) and delivery of technologically ready products (e.g. ZELP) • Finance **trials** or conduct **in-house research** to evaluate impacts of products that have not been the subject of third-party, peer-reviewed research (e.g. ZELP and Semex) • Sponsor **on-farm pilots** of promising products that are not yet commercially available or not yet widely adopted (e.g. Mootral, SeaGraze, Bovaer, ZELP, and Semex)

Innovations to Mitigate Manure Emissions

Globally, methane and nitrous oxide emissions from manure management account for around 15% of agricultural emissions. Manure methane emissions vary by animal, diet, and manure management system. Methane producing bacteria thrive in wet conditions, so dairy cattle and pig manure, commonly handled in liquid form and stored in lagoons, ponds, tanks, and pits, generates more emissions than beef cattle manure, which is more often handled in solid form. In the U.S., dairy cattle and pigs account for 54% and 36% of total manure methane emission, respectively. Manure methane is a critical source of agricultural emissions and climate risk for companies sourcing dairy and pork products. To mitigate these risks and achieve 1.5°C-aligned targets, companies will need to develop strategies to support research and development of manure methane innovations.

Ready-to-Deploy Manure Management Solutions

Companies can promote adoption of several ready-to-deploy practices and technologies for reducing manure methane emissions by offering financial and technical assistance, sponsoring pilot projects, and investing in market development. Some of these solutions, such as anaerobic digestion, are better suited for large farms or third-party operation by municipalities or other entities, and others, such as composting, are best suited for manure with less liquid content or manure that has undergone solid-liquid separation. Companies should support a variety of manure management technologies and practices as appropriate for their supply chain.

Readily deployable manure management solutions include:

- **Anaerobic Digesters** (**ADs**): ADs reduce emissions by breaking down animal manure—as well as food waste and other organic matter—and capturing the methane. This trapped gas can be converted to biogas, a source of electricity, heating, or renewable natural gas. Other valuable byproducts include digested liquids, which can be applied as a fertilizer, and manure solids, which can be used as animal bedding or fertilizer. ADs can also prevent water pollution from nutrient run-off. In 2022, ADs in the U.S. reduced emissions by nearly 11 MMT CO_2e from manure, but there is still room for growth. Germany touts around 10,000 operational ADs compared to the U.S.'s 2,300. ADs are mostly operated on large farms, but the development of mini and micro-scale ADs would allow for adoption on smaller operations. Examples include models being developed by startups Bioelectric and BioFactory.
- **Manure Pasteurization:** Pasteurization involves raising the temperature of liquid manure in storage to reduce biological activity of microbes. One study showed that this can reduce methane emissions by more than 95% over a 78-day period. Pasteurization can also be used to improve the productivity of anaerobic digesters. While some research questions remain, including how the process could impact emissions of other GHGs and how its cost-effectiveness and on-farm feasibility could be improved, the strategy is ready for adoption, and pasteurization prior to use of anaerobic digesters is a common practice in Europe.
- **Alternative Manure Management:** Methane emissions can also be reduced with the adoption of other manure management practices, often referred to as alternative manure management. Practices that have been shown to reduce manure methane emissions include solid-liquid separation and composting. Separating solid particles from manure liquids can reduce methane emissions by decreasing the amount of manure in liquid form. Composting involves microorganisms decomposing manure that is stored in aerobic conditions, where oxygen is present, which means that composting reduces methane emissions relative to uncovered lagoons. However, both solid-liquid separation and composting may increase nitrous oxide emissions compared to conventional manure management systems.

Emerging manure management solutions

Emerging solutions to reduce manure methane emissions include manure acidification and plants and antibiotics that can be mixed into manure to reduce emissions. Both solutions have been tested and used to address other issues, but impacts on reducing methane emissions are still being studied.

Manure Acidification involves lowering pH levels by treating manure with chemical compounds, such as sulphuric, nitric, and hydrocholoric acids, or with digestible carbohydrates and other organic substances in an approach called bio-acidification. While acidification cannot be combined with anaerobic digestion, it is compatible with other manure management practices. By reducing ammonia emissions, acidification can improve animal and farmer welfare and increase nitrogen levels in manure fertilizer. However, if manure fertilizer application rates are not adjusted to account for increased nitrogen availability, increased nitrogen leaching may occur. Manure acidification may also increase hydrogen sulfide emissions, which can irritate eyes and induce headaches, and acidic compounds could pose health and safety risks if not handled appropriately.

- **Mitigation Potential:** Chemical acidifiers, such as sulphuric, nitric, and hydrochloric acid, could substantially reduce methane emissions from pig and cattle manure. Sulphuric acid and nitric acid could reduce methane emissions from liquid pig manure by more than 90%, though nitric acid can also increase nitrous oxide emissions. Organic substances like sugar, whey, or fruit juices are also a promising alternative

to chemical acidification. One study found that brewing sugar reduced methane emissions by between 87% to 99%, depending on temperature.

- **Innovation Status:** Acidification, most commonly practiced on poultry farms, has been used for years to reduce pathogens, pollution, and ammonia emissions. Sulphuric acid is one of the most thoroughly studied and adopted manure acidification techniques. However, researchers have only recently started evaluating using this process to reduce manure methane emissions. Most bio-acidification studies have been conducted in a laboratory environment. Additional studies and pilots are needed to evaluate acidification's effects on methane emissions and nitrous oxide emissions from acidified manure fertilizer.

Manure Methane Inhibitors include tannins (naturally occurring compounds found in plants), a red seaweed called A. taxiformis, and antibiotics like narasin and monensin. When directly added to manure, these can inhibit microbial or enzyme activities that create methane, and tannins have also been shown to reduce nitrous oxide emissions. Manure methane inhibitors are not suited to be used with anaerobic digesters, but they can be used with most other manure methane mitigation methods.

- **Mitigation Potential:** Initial findings have been mixed. One study found that A. taxiformis reduced methane production by 44%, and another reported that Narasin reduced methane emissions initially, but that its effects are reduced over time. In laboratory studies, tannins form the quebracho tree have been found to reduce methane emissions by over 90% for at least 28 days in pig manure and by up to 68.2% during a 14-day incubation period in dairy manure.

- **Innovation Status:** Several manure methane inhibitors, including narasin, quebracho tannins, and A. taxiformis, have been studied as feed additives, but research on their effects as manure additives is preliminary and mostly limited to laboratory-scale studies. Longer term, farm-scale trials and pilots will be necessary to confirm climate benefits and evaluate effective dosages.

SUMMARY OF EMERGING SOLUTIONS

Category / Innovation Timeline	Solution	Mitigation Potential	Potential tradeoffs (-) /co-benefits (+)	Innovation Status
Manure Acidification (0-2 years)	Sulphuric Acid	>90% methane emission reduction (mitigation potential may be higher in pig manure than in cattle manure)	(-) Increased nitrogen pollution if fertilizer application rates are not adjusted; potential for human health and safety risks if not handled appropriately. (+) Improved animal and farmer welfare; increased nitrogen levels in manure fertilizer.	Commonly used to treat manure in some countries (e.g. Denmark); more commonly used to treat swine manure—being evaluated on dairy farms
	Bio-acidification (sucrose, glucose, whey, fruit juices, etc.)	Up to 99% methane emission reduction from brewing sugar; promising results from sucrose, whey, citrus juices, and other substances.		Bio-acidification research has largely been limited to laboratory-scale studies

SUMMARY OF EMERGING SOLUTIONS				
Category / Innovation Timeline	**Solution**	**Mitigation Potential**	**Potential tradeoffs (-) /co-benefits (+)**	**Innovation Status**
Manure Additives (0-2+ years)	A. taxiformis	44% methane emission reduction	(-) Not suited for use with anaerobic digesters	Has been widely studied (but not yet approved) as a feed additive; few studies have investigated its potential is a manure additive
	Narasin	Unclear (study found initial reduction in pig manure with waning impacts; adding sugar could increase effects)		Already used as a feed additive—primarily for chicken and swine—in the U.S., Europe; being evaluated as a manure additive
	Quebracho Tannins	>90% methane emission reduction for at least 28 days of laboratory incubation of pig manure; Up to 68.2% methane emission reduction in laboratory incubation of dairy manure		Have been evaluated as feed and manure additives; research on manure methane effects have been limited to laboratory studies

Ways Companies can Accelerate Innovation of Manure Management Solutions	
Advocacy and Collaboration	**Direct Company Action**
• Advocate for **public agricultural R&D**. Activities that would benefit from additional R&D funding include field-scale studies of chemical treatments and manure additives; assessments of treatment and additives' environmental, safety, and health implications	• Finance **trials** or conduct **in-house research** to evaluate impacts of chemical treatments and manure additives, identify optimal doses, and evaluate products for safety, health, and environmental impacts • Sponsor **on-farm pilots** of promising products that are not yet widely adopted but have been studied and deemed safe • Invest **venture capital** to fund the development of mini and micro anaerobic digestion systems, such as Biolectric and BioFactory, since these could be adopted by small farmers

Innovations to Mitigate Fertilizer Use-Phase Emissions

On average, crops only take up around half of the fertilizer nitrogen that farmers apply during the growing season, and excess nitrogen is lost to the atmosphere in the form of nitrous oxide, a powerful GHG around 300 times as potent as CO_2. Globally, nitrogen fertilizer application accounts for 10% of total agricultural emissions. Fertilizer use varies widely by crop. For example, in the U.S. the most fertilizer per acre is applied to celery, cucumbers, carrots, and tomatoes; and corn, winter wheat, and spring wheat lead in total fertilizer use because of the extensive acreage these crops cover. For companies sourcing these crops, fertilizer nitrous oxide is a significant driver of their scope 3 emissions and a substantial source of climate risk.

The 4Rs—right source, right rate, right time, and right place—are the hallmark of proper fertilizer application. By choosing the appropriate nutrients, matching fertilizer application with crop uptake, providing fertilizer when crops require it, and delivering fertilizer to the root zone, farmers can reduce nitrogen loss, fertilizer runoff, and nitrous oxide emissions. Most of the ready-to-deploy and emerging technologies to mitigate use-phase fertilizer emissions are intended to optimize for the 4Rs.

Ready-to-Deploy Fertilizer Use Solutions

There are already several practices and technologies available to reduce emissions from fertilizer use. Companies can promote these fertilizer solutions through financial and technical assistance, pilot projects, and market development.

Readily deployable use-phase fertilizer solutions include:

- **Precision Agriculture:** Precision agriculture is a suite of technological innovations that use GPS, sensors, and other tools to apply agricultural inputs such as fertilizer more efficiently. This can reduce input costs, GHG emissions, and localized pollution while improving yields. For example, variable rate technology (VRT) allows farmers to adjust fertilizer application rates based on varying nutrient requirements as they move across their fields. Precision agriculture is more widely adopted on large farms, and other ready-to-deploy solutions may be better suited for smaller farms.

- **Fertigation:** Fertigation is a practice that involves combining fertilizers and water and then delivering the mixture to crops through an irrigation system—commonly a drip or microsprinkler system. Compared with one-pass fertilization, where all nitrogen fertilizer is applied when crops are planted, appropriately timed fertigation can significantly reduce nitrous oxide emissions without decreasing crop productivity.

- **Enhanced-Efficiency Fertilizers (EEFs):** EEF refers to products and technologies that improve the timing and efficiency of fertilizer release and alter chemical reactions to minimize pollution. Categories of EEFs include nitrification inhibitors, which slow the conversion of ammonium to nitrate; urease inhibitors, which reduce ammonia volatilization; and slow-release fertilizers, which have a coating that gradually breaks down. According to one study, nitrification inhibitors can reduce on-farm nitrous oxide emissions by nearly 27% on average. However, high prices currently discourage adoption. In 2021, Bayer and CHS announced that they would pay up to $3 per acre to growers who participate in the Bayer Carbon Program and purchase EEFs. ESN is a well-researched, commercially available EEF which releases nutrients in response to changes in soil temperature.

- **Conservation Practices (often referred to as regenerative agriculture):** Conservation or regenerative agriculture often refers to a suite of existing practices with the potential to provide a variety of environmental benefits. These benefits can include reduced fertilizer requirements, prevented run-off, and potential soil carbon sequestration. However, the impact of these practices on nitrous oxide emissions is uncertain. Cover crops have been found to reduce these emissions in some studies and increase them in others. Crop rotation can enhance soil nutrient cycling, potentially reducing fertilizer requirements and nitrous oxide emissions; and reducing or eliminating tillage may reduce nitrous oxide emissions and minimize the disturbance of the soil microbial communities involved in nitrous oxide production, though findings have been mixed.

Emerging use-phase fertilizer solutions

The most promising technologies under research and development to reduce nitrous oxide emissions can be categorized as smart fertilizers, biofertilizers, and nanofertilizers, though there is overlap between these categories. When devising their innovation strategies, companies should prioritize mitigation strategies and products that have high mitigation potential and are scalable within their business.

Smart Enhanced-Efficiency Fertilizers improve the timing and release of nutrients by relying on the plants to activate fertilizer release. Smart fertilizer products include AgTec Innovation's Smart-N and Aqua-Yield's nano-smart fertilizer, which are both designed to release fertilizer nutrients when they come into contact with root exudates.

- **Mitigation Potential:** Smart fertilizers do not directly inhibit nitrous oxide production, but they do align fertilizer timing and rates with each plants' nutrient requirements, thereby potentially dramatically reducing nitrogen loss, nitrogen pollution, and nitrous oxide emissions.
- **Innovation Status:** Commercially available smart fertilizers like ESN typically respond to soil temperatures and may be less precise than emerging products such as Smart-N and Aqua-Yield's fertilizer, which interact with the organic compounds released by plant's roots. More research is needed in this area to optimize nutrient delivery to plants.

Nanofertilizers' small size and high surface area may improve plants' nutrient uptake through a variety of mechanisms. Nanofertilizers can be manufactured by processing bulk fertilizers; adding nanomaterials to bulk fertilizers; or coating fertilizers with nanomaterials that control nutrient release. There is overlap between nanofertilizers and other novel fertilizer categories. For example, bio-fertilizers can incorporate nano technologies, and nanomaterial coating can be applied to smart EEFs.

- **Mitigation Potential:** Nanofertilizers could reduce fertilizer application rates and nutrient loss by 20%, and existing studies have reported positive effects on plant growth, yield, and other traits. However, nanofertilizers' climate and environmental impacts are not fully understood, and some experts question whether nanofertilizers' high surface area, fast dissolution, and high solubility could lead to greater nitrogen losses. There are also concerns about potential health and environmental implications of bioaccumulation of nanoscale particles in food supply chains.
- **Innovation Status:** Nanofertilizer has attracted research investments by the public and private sectors. USDA's Agriculture and Food Research Initiative has funded research projects at universities and research stations to develop nanofertilizer technologies and evaluate food safety and plant health implications. Aqua-Yield's nano-smart-fertilizer was a winner of USDA's Next Gen Fertilizer Innovations Challenge.

Biofertilizers (also referred to as microbial inoculants and microbial-based fertilizers) are an innovative form of organic fertilizer that package strains of nitrogen-fixing bacteria and other microorganisms in materials like clay and charcoal. Products include Holganix LLC's BIO 800+, which contains over 800 species of soil microbes, kelp, and other ingredients; Pivot Bio's on-seed solution of nitrogen-fixing microbes; and several products developed by NewLeaf Symbiotic, Concentric, and Indigo Ag.

- **Mitigation Potential:** The research on biofertilizers' impact on GHG emissions is limited and studies related to their efficacy have variable results, but several existing studies have identified positive impacts. For example, when compared with urea fertilization, a micro-algae-based fertilizer substantially reduced nitrous oxide emissions from wheat production, and treating crops with a combination of synthetic and biofertilizers could reduce nitrous oxide emissions by up to 9.9%. Biofertilizers may also deliver critical co-benefits, improving crop yields, water uptake, and photosynthesis, and protecting against plant pathogens.

- **Innovation Status:** Numerous biofertilizer products are already available and affordable, but commercially available nitrogen biofertilizers are mostly limited to a few strains and are most suitable for legume crops. Areas of ongoing research and development include basic soil microbiome research, identification and field trials of new microbial strains, demonstration in non-leguminous crops, microencapsulation to extend shelf life, and bioengineering of microbial communities. Research trials to collect data are needed to further understand the efficacy of biofertilizers.

SUMMARY OF EMERGING SOLUTIONS				
Category / Innovation Timeline	**Solution**	**Mitigation Potential**	**Potential tradeoffs/co-benefits**	**Innovation Status**
Smart EEFs (0-5 years)	Smart-N (AgTec Innovations Inc.)	Unknown	(+) Lower levels of nitrogen pollution Potential health and environmental implications of bioaccumulation of nanoscale particles in the food supply chain	In development
	Aqua-Yield*	Unknown		In development
Nanofertilizer (0-5+ years)	Nanoferti**	Unknown	(+) Potential for improved crop yields and lower levels of nitrogen pollution (-) Potential health and environmental implications of bioaccumulation of nanoscale particles in the food supply chain	Commercially available
	The Nano-Ag Answer (Urth Ag)	Unknown		Commercially available
Biofertilizers (0-5+ years)	BIO 800+ (Holganix LLC)	10-30% reduction in fertilizer application (according to company)	(+) Potential for improved crop yields, water uptake, photosynthesis, and protecting against plant pathogens	Commercially available
	Pivot Bio	Higher yields and increased nitrogen uptake according to Pivot Bio's on-farm studies		Commercially available

*Aqua-Yield can also be classified as a nanofertilizer.

**Nanoferti can also be classified as a biofertilizer.

Ways Companies can Accelerate Innovation of Fertilizer Use Solutions	
Advocacy and Collaboration	**Direct Company Action**
• Advocate for additional **public agricultural R&D** funding. Activities that would benefit from additional R&D funding include: basic soil microbiome research; identification of new microbial strains for biofertilizers; development and trials of innovative fertilizer products; prize opportunities similar to USDA's Next Gen Fertilizers Innovation Challenge • Participate in **public-private partnerships**, such as FFAR's Efficient Fertilizer Consortium, funds applied research on novel fertilizer technologies	• Invest **venture capital** to fund the ongoing development of early and near-to-market products, such as Smart-N and Aqua-Yield • Conduct **in-house research** to evaluate impacts of fertilizer products that are near-to-market or commercially available, such as ESN and BIO 800+ • Sponsor **on-farm pilots** of promising products that are not yet commercialized or not yet widely adopted

Innovations to Mitigate Emissions from Nitrogen Fertilizer Manufacturing

Synthetic fertilizer production is a carbon-intensive process. Nitrogen fertilizer cannot be manufactured without ammonia, and ammonia production is energy intensive and releases large quantities of CO_2 as a byproduct. Globally, fertilizer manufacturing accounts for around 6% of total agricultural emissions.

Emissions from fertilizer production are a part of food companies' upstream scope 3 emissions from purchased goods and services. Strategies for addressing emissions from fertilizer manufacturing will play an important role in closing the gap to achieving 1.5°C-aligned emissions reduction targets. Companies that rely on fertilizer-intensive crops—such as corn, corn-fed livestock, wheat, tomatoes, and rice—are most exposed to climate risks from fertilizer production and could address the emissions from these products head-on.

Ready-to-Deploy Fertilizer Manufacturing Solutions

In addition to emerging green ammonia solutions, which rely on zero-emissions processes as described below, some food companies may also choose to include blue ammonia as part of their fertilizer mitigation strategy. Blue ammonia is essentially conventional fertilizer production with carbon capture. The CO_2 generated during ammonia production is stored and captured, but some emissions still remain. The main drawbacks to blue ammonia when compared to other fertilizer production solutions include:

- Blue ammonia is a low-carbon alternative to conventional ammonia; but some carbon is still emitted in the production process, and it requires reliable and permanent carbon storage, typically by injecting the carbon deep underground.
- Blue ammonia relies on natural gas as a feedstock and energy source, so blue ammonia does not address environmental impacts from natural gas extraction and transportation.
- There are no formal standards dictating the acceptable range of emissions for blue ammonia, so the blue ammonia label is no guarantee that a product is climate friendly.

Blue ammonia represents an immediately scalable mitigation strategy—the blue ammonia industry is fairly well developed, with several companies already manufacturing blue ammonia in the U.S. Encouraging farmers to purchase blue ammonia can be an interim measure to reduce supply chain emissions from fertilizer production as the infrastructure for carbon-free fertilizer develops.

Emerging fertilizer manufacturing solutions

While most fertilizer lifecycle emissions—around 59%—are associated with fertilizer use rather than fertilizer production, eliminating emissions from fertilizer production will help food sector emissions align with a 1.5°C scenario while also reducing overall industrial demand for natural gas.

Green ammonia is a carbon-free ammonia alternative produced using water as a feedstock instead of natural gas and using renewable energy to power the process. As with conventional ammonia, this green alternative can be applied directly to the field in liquid form, or it can be upgraded into other nitrogen fertilizer products. Because it is chemically identical to conventionally produced ammonia, agricultural producers will not need to alter their farm management practices to adopt green fertilizer.

- **Mitigation Potential:** As long as green ammonia production is powered using renewable-sourced energy, it should be an emission-free process. In addition to slashing emissions from nitrogen fertilizer manufacturing, growing the green ammonia industry would reduce demand for natural gas, a source of price volatility and non-climate environmental impacts.
- **Innovation Status:** The green ammonia industry is nascent, but in recent years, several major fertilizer companies and startups have entered the space. The Norwegian chemical company Yara International is involved in developing a green ammonia pilot plant in Norway, and OCI N.V., a Dutch fertilizer producer, is using bio-methane to manufacture green ammonia in Europe. In the U.S., CF Industries, an agricultural input company, is planning to open the country's first commercial plant in 2023, and several experimental pilots are ongoing. While green ammonia is technologically ready, continued innovation could improve its affordability, efficiency, and accessibility. Several startups, such as Green Play Ammonia, are developing green ammonia plants for small-scale, distributed production.

Ways Companies can Accelerate Innovation of Fertilizer Manufacturing Solutions	
Advocacy and Collaboration	**Direct Company Action**
• Advocate for expansion of the U.S. DOE Hydrogen Hubs Program and the clean hydrogen tax credit • Advocate for additional government investments in **public R&D** for green ammonia projects. Currently, DOE is funding a next-generation green ammonia pilot at University of Minnesota	• **Develop the market** by committing to purchasing products grown with green fertilizer • Invest **venture capital** in green ammonia startups and other green ammonia manufacturing projects • Provide **financial incentives** to encourage producers to switch to green fertilizer

Innovations to Mitigate Rice Methane Emissions

Rice cultivation practices vary geographically, but they often involve flooding rice fields for extended periods. Flooding improves crop productivity and deters weeds and pests, but it also accounts for up to 43% of global irrigation water use and generates large quantities of methane emissions. Globally, rice methane is responsible for 9% of total farm gate emissions. In the U.S., rice's GHG footprint is smaller but still significant, with rice methane accounting for nearly 3% of total agricultural emissions.

Ready-to-Deploy Rice Methane Solutions

While this report covers the discovery and development of emerging innovations, there are already several practices and technologies available that companies can engage supply chain actors to adopt today. Readily deployable rice methane solutions include:

- Direct dry seeding: Traditionally, rice seedlings are grown in nurseries and then transplanted into flooding fields. Direct dry seeding is an alternative practice that involves sowing seeds directly into the field. While direct seeding conserves water and reduces methane emissions, it can also increase nitrous oxide emissions.
- Alternate wetting and drying: Also called controlled irrigation and intermittent irrigation, alternate wetting and drying involves alternately irrigating and drying rice fields. Alternate wetting and drying spares water and reduces methane emissions, but as with direct dry seeding, it can increase nitrous oxide emissions.
- Efficient fertilizer application: Nitrogen fertilizer encourages growth of methane-producing bacteria in rice fields, so adopting existing fertilizer reducing practices and technologies—such as precision agriculture and enhanced efficiency fertilizers—can reduce methane and nitrous oxide emissions. A meta-analysis found that controlled release fertilizer reduces methane emissions from rice cultivation by 18.33%, and another study found that nitrification inhibitors reduced methane emissions by 41.6% during the growing season and 76.9% in the fallow season.

Emerging rice methane solutions

Appropriate solutions for reducing methane emissions from rice cultivation vary by location, and much of the current research is being conducted in regions where rice consumption is more prevalent. Companies should consult with suppliers to gain an understanding of common rice cultivation practices in their supply chains and evaluate the potential use of the mitigation strategies described below. The most promising emerging solutions include varieties of rice that require less fertilizer and therefore also lead to less methane emissions, varieties that can be grown in the presence of oxygen throughout the growing season, and irrigation that reduces the need for flooding.

Perennial rice could improve environmental outcomes, reduce labor requirements, and decrease input costs. Because perennial crops do not need to be replanted each year, they typically require less frequent tillage and can promote healthier soils. A perennial rice breeding program at Yunnan University in China has successfully produced several cultivars, including Perennial Rice 23 (PR23), a hybrid of a domestic annual rice with a wild perennial relative.

- **Mitigation Potential:** The methane mitigation potential of PR23 and other perennial varieties is unknown, though experts anticipate that perennials will reduce methane emissions. A farm-scale study in China will evaluate emissions impacts after the experiment's sixth year. Results from the first five years revealed positive impacts for soil health, water retention, and yield. However, perennial rice may require additional herbicide treatments to keep weeds and pests at bay.
- **Innovation Status:** Researchers at Yunnan University, along with other partners, have developed several perennial rice cultivars. These include PR23, PR25, and PE107, which are commercially available in China. PR107 has also been released in Uganda, and PR23 is being tested in countries in Asia and Africa. These cultivars are best suited for irrigated fields, but researchers have begun developing varieties for rain-fed systems. Researchers are also working to enhance disease resistance and drought tolerance in the existing cultivars.

Breeding aerobic cultivars, or breeding rice varieties that are drought tolerant, would allow farmers to grow rice in aerobic conditions (in fields that are not flooded or saturated). This reduces methane emissions. As aerobic rice fields

tend to be lower yielding, researchers are breeding aerobic cultivars that combine drought tolerant traits of aerobic varieties with the high yields of flooded varieties.

- **Mitigation Potential:** Compared with conventional production, aerobic production can reduce water use by up to 50% and should reduce methane emissions by avoiding flooding and saturation. In studies, Louisiana State University's rice varieties have demonstrated high water-use efficiency and drought resistance. However, aerobically grown rice is more exposed to weeds and pests, and aerobic conditions may reduce nutrient availability and increase nitrous oxide emissions.
- **Innovation Status:** R&D efforts are ongoing to develop cultivars suited for aerobic conditions. Louisiana State University's Rice Research Station developed its aerobic rice cultivars by breeding Louisiana-bred Cocodrie rice with drought-tolerant Indian cultivars. Researchers are evaluating their potential in alternative irrigation systems and may incorporate the cultivars into the breeding pipeline for new varieties.

Drip irrigation is an alternative to traditional flooding practices that delivers water more directly to crop roots. Types of drip irrigation systems include surface drip, which entails distributing water from a drip line that is buried just beneath the soil surface, and sub-surface drip irrigation, which uses buried pipes to deliver water directly to the root zone. Several drip irrigation systems have been developed specifically for rice fields. These include systems from the companies Netafim and Jain Irrigation.

- **Mitigation Potential:** A field experiment found that drip irrigation systems increased yields, led to water savings of around 23%, and decreased emissions by nearly 44%. Netafim claims that its drip irrigation technology prevents nearly all rice methane emissions, and reduces water and fertilizer use by 70% and 30%, respectively. Drip irrigation has also been shown to promote deeper root systems, reduce soil evaporation, and boost overall productivity, and unlike many other methane reduction practices, drip irrigation may also decrease nitrous oxide emissions. However, the high upfront costs associated with purchasing and installing drip irrigation systems can be a barrier to farmers, especially smallholders.
- **Innovation Status:** Netafim, an Israeli irrigation equipment manufacturer, has developed a drip irrigation system for rice that they have piloted and commercialized in several countries. Other companies are exploring similar solutions. For example, Jain Irrigation began testing their drip irrigation system for rice in 2008, and the company has conducted field trials in India. More research is needed to optimize irrigation timing and quantity for rice and evaluate impacts on pests, diseases, and climate.

SUMMARY OF EMERGING SOLUTIONS

Category	Solution	Mitigation Potential	Potential tradeoffs/ co-benefits	Innovation Status
Perennial Rice (0-5+ years)	PR23	Unknown (study in process)	(+) Potential increase in soil health, water retention, and yield compared to annual varieties of rice	Commercially available in China; being tested in 17 countries in Asia and Africa
	PR25	Unknown		Commercially available in China
	PR107	Unknown		Commercially available in China and Uganda
Aerobic Cultivars (2-5+ years)	LSU's Cocodrie hybrid	Unknown, but reduced water use (up to 50%) should decrease methane emissions; could increase N_2O	(-) Lower yield; more exposed to weeds and pests; could increase nitrous oxide emissions (+) Drought resistance	In development

SUMMARY OF EMERGING SOLUTIONS				
Category	**Solution**	**Mitigation Potential**	**Potential tradeoffs/ co-benefits**	**Innovation Status**
Drip Irrigation (0-2+ years)	**Netafim's system**	**Nearly 100% reduction in methane emissions *According to Netafim**	**(-) Expensive and less accessible for smallholders (+) Reduces water and fertilizer use; increased productivity; potential reduction of nitrous oxide emissions**	**Commercially available in Turkey, India, Greece, and Italy**
	RICE WITH DRIP (Jain Irrigation Systems Ltd.)	**Unknown**		**In development; successfully tested across India**

Ways Companies can Accelerate Innovation of Rice Cultivation Solutions	
Advocacy and Collaboration	**Direct Company Action**
• Advocate for **public agricultural R&D**. Activities that would benefit from additional R&D funding include: continued improvements to plant breeding practices and technologies; development of new perennial and aerobic rice cultivars; and field trials of alternative irrigation practices • Participate in **multi-stakeholder alliances**, such as the Sustainable Rice Platform, or **public-private partnerships**, such as Aim for Climate. One of Aim for Climate's ongoing innovation sprints is the Climate Smart Rice Technology Project, and the project participants are the International Rice Research Institute, USAID, and Bayer Crop Science	• Invest **venture capital** to fund development of early and near-to-market products, such as RICE WITH DRIP or Natafilm's drip irrigation system, which is only available in a few countries. Companies can also invest in research collaborations, such as the perennial rice project, to support the development of new and improved cultivars. • Sponsor **on-farm pilots** of products that are not yet commercialized or not yet widely adopted, such as Netafilm's drip system and PR varieties.

Innovations to Mitigate Emissions from On-Farm Energy Use

On-farm energy use is a driver of GHG emissions—globally, on-farm energy use accounts for around 6% of agricultural emissions with the vast majority in the form of CO_2. These emissions largely come from fossil fuel combustion to heat on-farm buildings, cool storage facilities, run tractors and other equipment, and power irrigation systems. Regions with highly mechanized agricultural systems typically have greater energy requirements, and poultry products have especially high supply chain emissions from on-farm energy use.

Ready-To-Deploy On-Farm Energy Use Solutions

There are already several readily deployable practices and technologies that farmers can implement today to reduce on-farm energy use. In addition to supporting ongoing innovation of new and improved solutions, food companies can promote the following ready-to-deploy solutions by offering financial and technical assistance to agricultural producers. Readily deployable on-farm energy use solutions include:

- **Farm Energy Audits:** Energy audits provide assessments of energy consumption and identify opportunities for improved efficiency. Many private businesses conduct audits, and USDA's EQIP On-Farm Energy Initiative provides financial assistance for audits conducted by NRCS-certified providers. Some state agencies also conduct or finance farm energy audits.

- **On-Farm Renewable Energy:** By producing renewable energy with on-farm wind turbines and solar panels, farmers can reduce their carbon footprint and energy costs and diversify their revenue streams. Agrivoltaics, an innovative approach to incorporating solar on farms, is included as an emerging solution below.
- **Anaerobic Digesters (ADs):** When ADs process manure, food waste, and other organic materials, they create biogas as a byproduct, while also preventing the production of methane and CO_2 emissions from conventional waste disposal methods. Applications for biogas include generating electricity for on-farm equipment, providing heat, steam, or refrigeration, and creating natural gas to fuel farm vehicles.
- **Electric Heating and Irrigation Equipment:** By electrifying farm equipment and using clean or renewable electricity, producers can reduce their GHG footprint and improve their energy efficiency. Opportunities to electrify operations include installing electric water heaters and electric irrigation pumps. Electric pumps have been growing in popularity as an alternative to diesel pumps, but their high upfront costs may deter some producers.
- **Energy-Efficient Lighting:** Converting horticultural and livestock lighting to LED technology provides energy and cost savings. LED lighting is readily deployable, but the U.S. DOE is actively evaluating how to optimize LED lighting for improved plant growth and animal wellbeing.
- **Efficiency Improvements:** Agricultural producers can also reduce their energy footprints by improving the efficiency of their existing equipment. For example, producers can improve insulation of their water heater storage tanks and refrigerated cold storage areas, regularly maintain tractors and other equipment, and install insulation, circulatory fans, and efficient heaters, generators, and lighting in livestock housing.

Emerging on-farm energy use solutions

Currently, the most promising emission-reducing solutions in the research and development pipeline include agrivoltaics, electric tractors, and a hybrid approach to poultry production. Though ongoing innovation will occur mostly outside the food sector in university and public research labs or by agricultural equipment companies, food companies can still support the development of promising solutions by partnering with the product developers and testing innovations in their supply chains, for example.

Electric tractors are being developed to replace their conventional diesel-fueled counterparts. Companies manufacturing electric tractors include Monarch, Kubota, and Solectrac, and John Deere has plans to develop an all-electric tractor in the next few years. Due to limitations of battery technology, existing electric tractors are small and may have short run times, making them most suitable for small- and medium-sized farms and vineyards.

- **Mitigation Potential:** Electric farm vehicles could substantially reduce on-farm CO_2 emissions. A life cycle assessment found that the global warming potential of a battery electric tractor was 65% lower than a conventional system. According to Monarch, its electric tractor provides annual savings of 54 metric tons of CO_2e per tractor. Electric tractors also deliver financial benefits—Monarch's tractor could reduce farmers' annual operational expenditures by $18,000—and can reduce labor requirements and noise and air pollution.
- **Innovation Status:** In recent years, several manufacturers have released electric tractor models. Monarch launched the first commercially available autonomous electric tractor in 2022, and Solectrac unveiled several new electric models during the past few years. These tractors are most suitable for small farms, and their market presence is low but growing. Ongoing innovation to improve batteries or replace them with hydrogen fuel cells could lead to larger and longer running electric tractors. While more innovation is needed to expand electric tractors' applicability, food companies can begin promoting available models on small-and medium-sized farms in their supply chains.

Electrification of poultry production is critical, as on-farm energy use accounts for the majority of poultry emissions. Electricity is responsible for 85% of emissions on poultry breeder farms, and propane heating generates 68% of emissions on broiler and pullet farms. Researchers at the University of Melbourne, in partnership with two geothermal companies, are developing a hybrid system that will improve energy efficiency and reduce emissions by using geothermal and solar energy to supply heating, ventilation, and air conditioning. In addition to reducing poultry producers' carbon footprints, the hybrid system may also reduce energy costs by up to 90% compared to conventional systems.

- **Mitigation Potential:** Researchers developing the hybrid energy system at University of Melbourne estimate that 15%-20% uptake in Australia would reduce the country's poultry industry emissions by at least 10%, and full adoption could reduce Australia's poultry sector's emissions by around 55%.
- **Innovation Status:** In 2022, Ground Source Systems received funding from the Australian government to demonstrate the hybrid geothermal and solar system. Once the system is commercially available, high upfront costs could deter adoption, but one of the initiative's partners estimates that farmers will recover costs within three to six years.

Agrivoltaics is an experimental approach to producing on-farm renewable energy. It involves generating solar power and growing crops at the same time by planting crops beneath solar panels. Solar panels can also be incorporated into livestock pastures. In addition to providing farms with renewable energy, agrivoltaic systems can benefit crops and solar panel productivity—panel coverage reduces water evaporation from soils and may increase yields in some crops, and the cooling effect of plants' water vapor can increase solar panel efficiency. Crops that grow well under solar panels include tomatoes, beans, and broccoli.

- **Mitigation Potential:** If implemented on a large scale, the solar power generated by agrivoltaic systems could nearly eliminate agricultural producers' carbon dioxide emissions from on-farm energy use, especially if paired with electric tractors, heating, and irrigation equipment. By returning extra energy to the grid, farms with agrovoltaic systems can also support other sectors' transitions to green energy. For example, implementing agrivoltaics on just 1% of Canada's current agricultural land could satisfy up to more than a third of the country's total electrical energy needs.
- **Innovation Status:** Some solar companies now offer agrivoltaic services, and numerous agrivoltaic companies have entered the field in the U.S., France, and other countries. Several of these companies are conducting pilots and demonstration projects, and researchers are assessing different approaches to system design and implementation. In the U.S., the Department of Energy supports agrivoltaic research through InSPIRE, and recently introduced legislation would provide $15 million per year over five years to establish an agrivoltaic research and demonstration network within USDA's Agriculture Research Service.

SUMMARY OF EMERGING SOLUTIONS

Category / Innovation Timeline	Solution	Mitigation Potential	Potential tradeoffs/co-benefits	Innovation Status
Electric tractors and other farm vehicles (0-5+ years; up to 5+ for large tractors)	Solectrac	Unknown	(+) Farmer health benefits from quieter machinery; avoided pollution; lower operation costs (-) Not currently suitable for large farms; may have shorter run times	Several commercially available models
	Monarch MK-V	Annual savings of 54 metric tons CO_2e per tractor *According to Monarch		Commercially available/ accepting reservations

SUMMARY OF EMERGING SOLUTIONS				
Category / Innovation Timeline	**Solution**	**Mitigation Potential**	**Potential tradeoffs/co-benefits**	**Innovation Status**
Electrification of poultry production (0-3+ years)	Hybrid system (University of Melbourne collaboration)	Up to 55% reduction in poultry sector emissions *According to researcher's estimates for Australia	(+) Energy cost savings	Being piloted at a commercial broiler facility in New South Wales
Agrivoltaics (0-2+ years)	SolAgra Farming	Mitigation potential depends on the scale and efficiency of solar panel arrays.	(+) Lower water requirements; increased solar panel efficiency; crop protection against frost and excessive heat; energy cost savings and new income (+/-) Higher or lower crop yields, depending on the crop type and system specifications	Contracted to build agrivoltaic systems at two University of Delaware campuses
	SunAgri			Installing demonstration systems on vineyards, fruit, and vegetable farms in France

Ways Companies Can Accelerate Innovation of On-Farm Energy Use Solutions	
Advocacy and Collaboration	**Direct Company Action**
• Advocate for **public agricultural R&D** and **technical assistance** funding. Companies can test and deploy electric tractors (a USDA Conservation Innovation Grant program funded a project testing Monarch's tractor in blueberry fields at a farm in Oregon), support for energy audits, and pilots of hybrid poultry systems. • Advocate for the beneficial **legislation**, such as the Agrivoltaics Research and Demonstration Act, which would provide $15 million per year for five years toward research and demonstration • Advocate for new **state and federal incentive programs** and the expansion of existing ones, such as California's rebate program for electric tractors or USDA's guaranteed loan and grant program for renewable energy systems and energy efficiency improvements. Companies can also advocate for simpler forms of incentives, such as tax credits, to make funding more accessible to small farms. • Partner with universities—including those using electric tractors—to sponsor additional development and testing of new technologies.	• Invest **venture capital** to fund development and deployment of electric tractors and other innovations. • Conduct **in-house research** to test new approaches to poultry production, such as the hybrid system being developed by the University of Melbourne, Ground Source Systems, and other partners. • Sponsor **on-farm pilots** of electric tractors and other energy efficiency improvements. • Provide **financial assistance** to producers for energy audits and equipment upgrades.