Innovative Technologies and Practices for the Agriculture Innovation Agenda
Comments to the USDA from The Breakthrough Institute

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The Breakthrough Institute is a global research center that identifies and promotes technological solutions to environmental and human development challenges.

Summary

Most of agriculture's negative environmental impacts, including water and air pollution and greenhouse gas (GHG) emissions, derive from a few sources, namely livestock manure, enteric fermentation, fertilizers, and agricultural soils. Thankfully, there are commercially available innovations that effectively mitigate these impacts. They include anaerobic digesters, alternative manure management practices, feed additives, biofertilizers, nitrogen and urease inhibitors, variable rate application technologies, biochar, and enhanced rock weathering. These innovations mitigate environmental impacts directly — by better managing manure and fertilizers and reducing enteric fermentation, for example — and indirectly — by boosting productivity and providing added benefits like renewable energy production or food waste reduction.

These practices and technologies face several types of barriers to adoption, such as high costs, information gaps, and uncertainty. Existing USDA incentive, technical assistance, and research programs can help address these barriers, but the programs would benefit from additional funding. The USDA can also accelerate the adoption of environmentally beneficial innovations by directing its programs to prioritize manure management, enteric fermentation, fertilizer and nutrient management, and soil management solutions. Finally, the USDA can better facilitate the adoption of anaerobic digesters and alternative manure management practices by creating two new targeted programs — a manure transport program and an alternative manure management grant program.

Manure Management

Livestock manure produces several negative environmental impacts. Cattle, pig, and other livestock manure accounts for approximately 13 percent of total agricultural production greenhouse gas emissions in the US[1] and also generates numerous harmful water and air pollutants.[2] Thankfully, there are several cost-effective technologies and practices, which are currently underutilized, but could substantially reduce manure's environmental impacts. Anaerobic digesters and a suite of management practices generally referred to as "alternative manure management" are the most promising of ready-to-go manure innovations.

Anaerobic Digesters

There are multiple types of digesters including covered lagoon digesters, complete mix digesters, and plug flow digesters. Anaerobic digesters (ADs) reduce emissions and runoff by converting biodegradable materials like manure into biogas and digested solids. The methane-rich biogas can then be flared or used to produce renewable natural gas, electricity, or heat. Although they provide environmental and economic benefits, the adoption of anaerobic digesters remains stubbornly low — over 8,000 US dairy and swine farms could host ADs, but there are currently fewer than 300 in operation on US livestock farms.[3]

Increasing the deployment of ADs would help address several of the USDA's environmental goals, including GHG emissions mitigation. According to AgStar data, the 222 dairy AD projects currently operating or in construction are expected to reduce emissions by approximately 4.7 MMT CO_2e annually.[4] And according to an EPA estimate, if ADs become economically feasible for more farms, total mitigation potential could be as high as 55 MMT CO_2e/year.[5] ADs also generate other environmental benefits by reducing air and water pollution, accepting off-site food waste, and enabling the production of renewable natural gas, which has a carbon footprint at least 80% lower than gasoline.[6]

AD byproducts like biofuel, heat, electricity, organic nutrients, and animal bedding increase the productivity of farm operations. The economic benefits of producing AD biogas are especially large in states with low carbon fuel standards, like California. In California's San Joaquin Valley, Low Carbon Fuel Standard credits can increase the revenue of a standard 2,000 cow farm by 11%.[7]

A number of barriers are responsible for low adoption to date. ADs are complex, their construction is time consuming, they are expensive — with capital costs averaging around $1.5 million[8]— and they operate most efficiently on larger farms with at least 500 cows. Also, as is often the case with new practices and technologies, successful adoption requires education, training, and acknowledgment of potential cultural or personal barriers to adoption.[9]

Alternative Manure Management

Alternative manure management practices include processing manure into compost for fertilizer, using composted manure as bedding in barns, and separating solids, which can be dried and used as compost or bedding, from liquid manure.

Because the break-even prices for different technologies and management strategies vary widely from farm to farm, total climate mitigation potential increases with the number of mitigation options available.[10] Many of these alternative practices, such as compost production, compost bedding, and solid separation are more accessible to small, beginning, and tenant farmers than ADs.

Composting manure reduces bulk and makes it easier to handle.[11] The compost can be applied as fertilizer to fields or used as animal bedding. When applied as fertilizer, compost improves soil health and soil carbon content, thereby increasing agricultural productivity and carbon sequestration.

Solid separation entails partially separating solids from liquid manure, which can be accomplished using a variety of techniques. For example, producers can separate solids from liquids using settling basins, centrifuges, and separation screens.[12] Solid separation can improve water quality by removing much of the nitrogen, phosphorus, and other constituents from manure liquid.[13] Solid separation also reduces air pollution from ammonia, and it could reduce GHG emissions by almost 40%.[14]

Farms that adopt alternative manure management practices can also reap economic benefits, such as additional revenue from selling compost fertilizer and animal bedding, and generate economic benefits for their communities through job creation. However, as with ADs, cost and technical challenges are significant barriers preventing farmers from adopting manure management practices. Separation screens, for example, can cost anywhere from $26.33 to $73.41 per cow per year.[15]

The USDA has several programs that can address these challenges by providing financial and technical assistance (Table 1). Increased funding and a prioritization of manure management would improve these programs' capacity to assist farmers.

Table 1: Manure Management Innovations

Innovation	USDA Programs That Could Support Adoption
Anaerobic Digesters	Rural Energy for America Program (REAP)
Alternative Manure Management	Conservation Technical Assistance (CTA) NIFA Extension
Both	Environmental Quality Incentives Program (EQIP)

In addition to leveraging these existing USDA programs to promote AD deployment and alternative manure management adoption, the USDA could take the following steps:

1. Establish a manure transport program to help small farms access nearby digesters or participate in centralized digester clusters. A similar state-wide program in Maryland provides grants covering up to 87.5% of manure transportation and handling costs, or up to $18 per ton of manure transported.
2. Create a manure management grant program modeled after California's Alternative Manure Management Program (AMMP). AMMP is cost effective and beneficial — AMMP's average cost per MT of CO2e reduction is $49 over a five year period, and scaling up California's program would require around $170 million per year.

Both of these proposals are described in more detail in a Breakthrough Institute report.[16]

Enteric Fermentation

Enteric fermentation, part of the digestive process in ruminant animals such as cattle, produces methane as a byproduct and accounts for about 29% of US agricultural GHG emissions.[17] Emissions primarily come from beef cattle (~72%) and dairy cattle (~25%).[18] One of the most promising solutions for reducing enteric fermentation-induced emissions is providing livestock with feed additives.

Feed Additives

Livestock feed additives can improve livestock productivity and also reduce methane emissions. And while some feed additives are still in the early research stages, several are publicly available. Commercially available feed additives include Agolin (a blend of essential oils from clove and other herbs), Yea-Sacc (a yeast culture of *Saccharomyces cerevisiae*), and Enogen (corn that converts starch to useable sugars quickly and efficiently).[19] Mootral, a garlic and citric acid-based supplement, is being piloted in North America.[20]

Feed additives can reduce the livestock sector's environmental footprint in two ways: by directly inhibiting an animal's methane production (as Agolin Ruminant and Mootral do) or by increasing feed efficiency (as Yea-Sacc and Enogen do). Studies have demonstrated that Angolin Ruminant decreases methane production by 15 to 20% per kilogram of milk production[21] and 10% per animal,[22] and Mootral appears to reduce methane per kilogram of dry matter intake by around 23%.[23] Yea-Sacc reduces GHG per unit of product by improving gut microbiome health and increasing milk production per cow,[24] and Enogen could boost feed efficiency among dairy cows by over 10%.[25]

Agricultural producers are typically risk-averse and hesitant to adopt new inputs. There is also a lack of incentives for livestock producers to pursue enteric fermentation mitigation, unless the feed additive financially benefits producers through feed efficiency increases. Furthermore, there may be some wariness among producers, since the additives' methane claims have not been verified by the FDA.[26]

Several USDA programs (Table 2) are well positioned to address these information gaps and financial barriers. Education and technical assistance provided by NIFA Extension and CTA will help producers decide whether adoption is appropriate for them and their operations, and they can also help inform producers that EQIP provides financial assistance for feed management practices. These programs' impact would likely increase with additional funding.

Table 2: Enteric Fermentation Innovations

Innovation	USDA Programs That Could Support Adoption
Feed Additives	NIFA Extension Conservation Technical Assistance (CTA) Environmental Quality Incentives Program (EQIP)

Fertilizers and Nutrient Management

US farmers apply over 26 billion pounds of nitrogen as synthetic fertilizer to crops each year, one-third of which is lost to water bodies or released into the atmosphere as nitrous oxide (N_2O), a potent GHG, and nitrogen oxides (NO_x).[27] Thankfully, there are many publicly available technologies and practices that reduce fertilizer use and mitigate its environmental impacts.

Biofertilizers

Biofertilizers contain various types of microorganisms, such as plant growth promoting rhizobacteria, endo- and ectomycorrhizal fungi, and cyanobacteria, that can help plants access nutrients, improve productivity, and reduce the need for inorganic chemical-based fertilizers.[28] The strains of microorganisms are packed into a carrier material, such as peat, clay, charcoal, soil, and paddy straw compost.

Biofertilizers could help producers significantly reduce mineral fertilizer use (and their associated air and water pollution and GHG emissions) without sacrificing crop productivity.[29]

Despite their affordability and benefits, biofertilizers have struggled to gain traction with retailers and farmers, and biofertilizer sales have only experienced minor growth in the past decade.[30] One reason for biofertilizers' limited adoption is the unpredictability of results,[31] paired with pressures for producers to cut input costs.

Nitrification and Urease Inhibitors

Among the most promising technical solutions for reducing Nitrogenous emissions are enhanced-efficiency fertilizers (EEFs) including those containing nitrification or urease inhibitors. Urease inhibitors, such as Agrotain and Limus, prevent urea from hydrolyzing and producing ammonia, which can then be lost to the atmosphere as gas.[32] Nitrification inhibitors, such as N-Serve, Instinct, and Centuro, protect against denitrification and leaching by preventing the conversion of ammonium into nitrite.[33]

Nitrification and urease inhibitors can reduce nitrogen losses beyond what farmers are likely able to achieve with improved nutrient management practices alone. Inhibitors can reduce emissions from fertilizer application on the order of 32-44%.[34,35] With adoption rates currently low, the mitigation potential of EEFs is large. Inhibitors also provide economic benefits by reducing the amount of nitrogen farmers need to apply and increasing yields by several percent.[36,37] EEFs can also effectively reduce nitrate leaching on many farms.[38]

Only around 13% of nitrogen fertilizer sales in 2017 were treated with or sold as EEFs.[39] This low adoption rate may be because farmers are not aware of EEFs or are unsure about what products and rates of application are appropriate for different contexts. Also, while EEFs benefit farmers on average, their effects are variable, so farmers might decide that EEFs' steep upfront costs are too risky.[40]

Variable Rate Input Applications

Variable-rate input application technologies (VRT) allow farmers to use GPS yield and soil maps to customize the application of fertilizer, chemicals, and pesticides. VRT can boost yields, prevent air and water pollution, and reduce GHG emissions by reducing fertilizer input. Despite these benefits, adoption of VRT has lagged behind that of some other precision agriculture technologies like GPS tractor guidance systems.[41]

Three main barriers have slowed the adoption of VRT. First, approximately 25% of farmers lack access to any form of internet service,[42] which is generally required to operate internet-connected machinery and use remote sensed data; second, a lack of information about the costs and benefits of VRT might slow farmer adoption; and third, VRT is expensive and is less likely to be adopted on small farms. On US corn farms of average size, VRT was found to raise both profit and net returns by just over 1%.[43]

The USDA has several programs (Table 3) that can encourage adoption of biofertilizers, nitrification and urease inhibitors, and VRT. EQIP, for example, can provide financial assistance to farmers adopting nutrient management innovations, and extension and technical assistance programs can help reduce risks, improve farmers' perceptions of new practices and technologies, and help farmers assess which practices are most appropriate for their operations. In addition to increasing funding for these programs, the USDA can direct the programs to make nutrient management a priority area.

Table 3: Fertilizer & Nutrient Management Innovations

Innovation	USDA Programs That Could Support Adoption
Biofertilizers	NIFA Extension Conservation Technical Assistance (CTA)
Nitrification and Urease Inhibitors	NIFA Extension Conservation Technical Assistance (CTA)
Variable Rate Input Applications	Broadband ReConnect Program Rural Broadband Access Loan and Loan Guarantee Program
All	Environmental Quality Incentives Program (EQIP)

Soils and Carbon Sequestration

Healthy soil practices can promote carbon sequestration, increase yields, improve drought resistance, and strengthen soil resilience to climate change. There is a wide range of management practices and research areas that can sequester carbon. Below we describe two practices with large potential but low adoption rates.

Enhanced Rock Weathering

Rock weathering occurs when rain containing CO_2 from the atmosphere gradually breaks down rocks and forms bicarbonate. The bicarbonate either remains in the soil or is eventually washed into the ocean, where it can be stored permanently. Unfortunately, when rock weathering occurs naturally, the process can take millions of years. Enhanced rock weathering, which entails applying crushed silicate rocks to land, accelerates that process.

Crushing the silicate rocks increases the surface area through which the rocks can absorb CO_2. If applied annually on two-thirds of the world's most productive cropland, enhanced rock weathering could remove between 0.5 billion and 4 billion tonnes of CO_2 from the atmosphere each year by 2100.[44] To put that in perspective, in 2007 farms emitted 6 billion tonnes of greenhouse gases globally.[45] Applying silicate rocks to arable land also has the potential to boost yields — in sugarcane trials in Mauritius, crushed basalt increased yields by over 30% for five successive harvests.[46]

As with many of the other innovations described in this memo, cost is a major barrier to increased adoption of this method. Also, while it's clear that increased adoption of enhanced rock weathering could yield significant environmental benefits, there are potential negative impacts that require further examination. For example, silicate rock mining operations and the erosion of silicates into bodies of water could produce unintended consequences.[47] Enhanced rock weathering could also introduce metals and persistent organic compounds into environments.[48] Finally, even though small farms in Africa, Brazil, and Malaysia have applied silicate rocks for years,[49] many US farmers are simply uninformed about the practice, and enhanced rock weathering is not listed as an eligible EQIP practice.

Biochar

Biochar is plant matter such as crop residue or timber slash that has been turned into charcoal for application to cropland and other soils. When applied to crop or pastureland, biochar acts as a fertilizer, improves soil health, and increases soil carbon content. By improving soil health, biochar can also make crops or grasses more productive, thereby promoting additional soil carbon sequestration.

Recent studies have suggested that biochar could potentially sequester 95 MMT CO_2e/year if used across the US agricultural system,[50] but more research is needed to better understand the carbon sequestration potential, cost, and feasibility of large scale biochar use.[51,52] Research and field testing is also needed to minimize potential GHG emissions, namely methane, from the composting process.[53]

The major barriers to increased biochar adoption are information and cost. Many producers are not aware of biochar's potential benefits, and biochar can cost around $2,580 per ton.[54]

USDA programs (Table 4) can facilitate increased adoption of enhanced rock weathering and biochar by providing financial and technical support and funding additional research. Additional funding would improve these programs' ability to accelerate adoption of these promising practices.

Table 4: Soil & Carbon Sequestration Innovations

Innovation	USDA Programs That Could Support Adoption
Enhanced Rock Weathering	Agriculture and Food Research Initiative (AFRI) for further research into environmental impacts and best practices Regional Conservation Partnership Program (RCPP) to fund demonstration projects
Both	NIFA Extension Conservation Technical Assistance (CTA) Environmental Quality Incentives Program (EQIP)

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