**(11) Pathways for Mitigation**

 **Agriculture – Summary Statement (Ryan)**

The agricultural sector’s non-CO2 emissions account for 15.8 percent of Vermont’s greenhouse gas (GHG) emissions. The main mitigation options within the agricultural sector involve one or more of three strategies:[[1]](#footnote-2)

1. **prevention of emissions** to the atmosphere by conserving existing carbon pools in soils or vegetation **or by reducing emissions** of methane (CH4) and nitrous oxide (N2O) through management changes;
2. **sequestration**—increasing the size of existing carbon pools, and thereby extracting carbon dioxide (CO2) from the atmosphere; and
3. **substitution**—substituting biological products for fossil fuels or energy-intensive products, thereby reducing CO2 emissions.[[2]](#footnote-3)

Vermont farmers are motivated to be part of the climate change solutions and many already include climate mitigation as a major goal in managing their farm.[[3]](#footnote-4) Carbon sequestration in agricultural landscapes is the mitigation strategy for agriculture with the greatest co-benefits, the easiest to implement and the least equity concerns in Vermont, and which has received significant attention from global and scientific communities as an important mitigation strategy[[4]](#footnote-5). Enteric emission, manure management emissions and Feed supplement strategies to reduce methane in enteric emissions are associated with negative implications for herd health and reliance on imported feed supplements that may negatively impact communities elsewhere, though more research is needed on the extent to which forage management may impact enteric methane and simultaneously support animal health. Adjustments in manure management are also considered among the suite of strategies that may help mitigate agricultural emissions sources, yet practices like methane digesters may not be appropriate for small farms, and other manure management practices may have trade-offs for water quality. Our recommendations include elevating sequestration as a strategy to invest in with known benefits and wide appeal, while simultaneously exploring ways that other agricultural emissions sources can be mitigated with more careful consideration for tradeoffs and inequity.

Today, Vermont farmers mitigate on-farm GHG emissions through the extensive adoption of conservation practices. Importantly, many water-quality best management practices have co-benefits for climate mitigation, and implementation has increased dramatically in recent years. Through more widespread adoption of these conservation practices Vermont farmers have a realistic potential to sequester one million tons of CO2-e annually by increasing the organic matter content of Vermont’s agricultural soils. Agriculture is also highly vulnerable to climate change. Currently, the majority of crop losses reported in the Vermont are due to the weather extremes that have been increasing in intensity due to climate change[[5]](#footnote-6). Many agricultural practices that increase carbon sequestration also enhance a farm’s capacity to bounce back from climate impacts. In fact, the most common strategy that Vermont farmers already employ to address extreme weather impacts is soil health[[6]](#footnote-7). highlighting the importance of soil health as an important strategy to address climate mitigation and adaptation. The Agriculture & Ecosystems Subcommittee recommends incentivizing farming systems that help all farmers both mitigate the drivers of climate change and build resilience to its impacts.

Agriculture – and other associated natural and working lands – is a nexus for building a resilient future for Vermont in the face of climate change that centers priorities of:

1. Improving soils, water, and resilience of the working landscape to combat climate change;
2. Increasing sustainable economic development and creating good jobs in Vermont’s food and farm sector; and
3. Improving access to healthy local foods for all Vermonters.

The importance and focus on Vermont’s agricultural soils to address climate change in these action recommendations is foundational to catalyze a paradigm shift in how farmers are acknowledged and empowered to perform their essential roles of environmental stewardship while providing food and fiber. Where historic federal food policy and current international markets have driven agriculture to particular farming systems and methods that have historically externalized costs of production to water, land, and air – a focus on Vermont’s soils and investment in **ten key actions** can help catalyze enterprise-level changes, remove the barriers to transition, and leverage the impressive engagement and work farmers have recently undertaken to address Vermont’s water quality challenges and expand and capacitate all Vermont farmers to address climate change.

Leveraging the state’s existing water quality conservation programming is the first step to support agriculture in meeting the 2025 and 2030 emission reduction goals laid out in the GWSA. Here exists a robust multi-partner service-delivery mechanism for agriculture where Natural Climate Solutions (e.g. Cover crops, Nutrient management, Manure management, Reduced tillage, and riparian tree plantings) that have benefits for both water quality and GHG mitigation are already successfully being implemented by farmers across Vermont – over 300,000 acres of conservation practices have been implemented on Vermont farms since 2016.[[7]](#footnote-8) These Natural Climate Solutions can be delivered at below the social cost of carbon, deliver immediate GHG mitigation services, have long lasting effects, and provide multiple co-benefits that support adaptation, resilience, and food security goals for Vermont.

**Pathway A: Maintain and expand Vermont’s natural and working lands’ role in the mitigation of climate change through human interventions to reduce the sources and enhance the sinks of greenhouse gases.**

**Mitigation** in this section follows the GWSA 10 V.S.A. § 590(3) definition of ‘Mitigation’ which means: “reduction of anthropogenic greenhouse gas emissions, and preservation and enhancement of natural systems to sequester and store carbon, in order to stabilize and reduce greenhouse gases in the atmosphere.” This is consistent with the IPCC definition, “a human intervention to reduce the sources or enhance the sinks of greenhouse gases (GHGs)” (AR5).

The strategy which provides the most immediate and cost-effective opportunities for mitigation from the agricultural sector is to:

**Leverage, expand, and adapt existing State of Vermont programs that support the agricultural sector’s mitigation of climate change through:**

1. **~~The p~~ Prevention—of emissions to the atmosphere by conserving existing carbon pools in soils or vegetation, or by reducing emissions of methane (CH4) and nitrous oxide (N2O);**
2. **Sequestration—by increasing the size of existing carbon pools, and thereby extracting carbon dioxide (CO2) from the atmosphere; and**
3. **Substitution—~~substituting~~of biological products for fossil fuels or energy-intensive products, thereby reducing CO2 emissions.**

The majority of conservation practices funded through various state programs aimed at improving water quality by reducing erosion and nutrient loss also mitigate climate change by reducing carbon transport, sequestering carbon in plants and soils and reducing nutrient losses. The specific impact of these conservation practices on climate mitigation are explained below. The state programs that support these climate mitigation practices should continue to be funded and expanded to increase adoption by farmers across the State. Current state programs coordinate with federal programs to ensure as seamless and complimentary delivery of services as possible. As explained below, other programs may need further enhancement and funding to focus on climate mitigation in addition to water quality.

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| **LEAD IMPLEMENTER Vermont Agency of Agriculture, Food & Markets (VAAFM)** |
| **a.** | **Action Details****Implement agronomic practices that reduce tillage and increase vegetative cover, e.g. no-till, cover crop**Practices that reduce tillage intensity, such as reduced tillage and no-till conservation practices, reduce the emissions of CO2 from the soil by reducing decomposition from less soil disturbance. Practices that increase *herbaceous* (non-woody) vegetative cover on crop fields, such as cover crop at the end of the growing season, or rotation of perennial hay crops with annual crops such as corn (crop rotation), sequester carbon as they grow. Thus, the more living plants on the field during the growing season the more carbon is sequestered. Vegetative cover, whether perennial (hay) or annual (cover crop) also reduce erosion and the loss of nutrients through runoff, and increase *albedo* effect, lowering ground temperatures. Practices that reduce tillage and increase vegetative cover not only have climate mitigation and water quality benefits but are also important for climate adaptation and resilience. These practices increase the organic matter content of the soil which increases infiltration (reduces runoff) and water storage, thereby reducing flooding and storing more water during times of drought.The Vermont Agency of Agriculture, Food and Markets (VAAFM) funds *Cover Crop*, *Conservation Tillage* (reduced tillage and no-till), and *Conservation Crop Rotation* through its Farm Agronomic Practices (FAP) program. | **Impact**In SFY21, VAAFM funded over 24,000 acres of cover crop and 2,700 acres of conservation tillage. Implementation of these practices has been increasingly steadily since SFY2016 and the rate of adoption has potential to continue to increase with sustained or expanded funding.In a Canadian study, cover crops were estimated to be the largest single source of mitigation potential from the agricultural sector with 26% of all potential agricultural mitigation coming from the adoption of cover crops. 12.5% of all considered Natural Climate Solution mitigation reductions in Canada were estimated to come from cover crops.[[8]](#footnote-9) |
| **Equity**Farms in good standing with VAAFM are eligible to apply and participate.  |
| **Cost-Effectiveness**High cost-effectiveness due to low cost of implementation and potential for scaling up adoption on farms.Literature suggests that the CO2e/yr potential mitigation for cover crop as a mitigation strategy is available at the following price points: 14% of total possible reduction at ≤ $10/MT CO2e; 46% of total possible reduction at ≤ $50/MT CO2e; 84% of total possible reduction at ≤ $100/MT CO2e.[[9]](#footnote-10)Literature suggests that the CO2e/yr potential mitigation for reduced tillage as a mitigation strategy is available at the following price points: 22% of total possible mitigation at ≤ $10/MT CO2e; 44% of total possible mitigation at ≤ $50/MT CO2e; 67% of total possible mitigation at ≤ $100/MT CO2e.[[10]](#footnote-11) |
| **Timeline to Implement:** 0-6 months. | **Co-Benefits*** Overall adaptation, resilience, and water quality benefits
* Reduced soil erosion
* Reduced nutrient runoff
* Increase on soil organic matter (soil health, infiltration, water storage)
* Reduced flooding
* Resilience to drought and extreme rain events
* Reduced nitrogen fertilizer if planting legumes
* Reduced ground temperatures due to albedo effect of plant cover
 |
| **Technical Feasibility:** Yes |
| **b.** | **Action Details****Expand Capital Equipment Assistance Program (CEAP) program to extend beyond water quality and incorporate climate change criteria.**The VAAFM Capital Equipment Assistance Program (CEAP) funds financial support for farmers to purchase the equipment necessary to implement many of the climate mitigation practices listed in ‘Action a’, including no-till and cover crop, and various precision agriculture technologies that improve nutrient management. This program is an effective way to assist farmers to have the equipment available necessary to implement climate mitigation practices and thereby increase the rate of implementation and adoption across the state. CEAP primarily focuses on innovative equipment to improve water quality, which as mentioned also benefits climate mitigation, however, the program could be expanded to include equipment more specifically for climate mitigation, regardless of water quality benefits.  | **Impact**Over 50,000 acres of conservation practices have been implemented through CEAP since 2018 that have co-benefits for GHG mitigation from the agricultural sector (e.g. reduced tillage, cover crop seeding).USDA has modeled potential mitigation by agricultural management category and CO2 price level ($/MT CO2e) and has found that of the 120 MMT CO2e possible to be mitigated by US agriculture nationally, over 1/3 of potential reductions could come from reducing tillage intensity.[[11]](#footnote-12) USDA notes that “the mitigation benefits of reducing tillage intensity depend critically on reduced tillage practices being adopted in the long term. As CEAP supports the purchase of equipment for long term utilization, this program helps ensure long-term adoption and can help farmers overcome one of the largest barriers EPA has identified for agricultural adoption of reduced tillage practice which is initial capital costs.[[12]](#footnote-13)  |
| **Equity**Farms in good standing with VAAFM are eligible to apply and participate. |
| **Cost-Effectiveness**USDA has modeled that nationally, over 50% (21 MMT CO2e) of the total mitigation potential from the adoption of reduced tillage practices is available below $30 per MT CO2e. |
| **Timeline to Implement:** 0-6 months, implemented annually based on current funding appropriation. | **Co-Benefits** Co-benefits are numerous for CEAP. For reduced tillage, co-benefits include air (reduced dust from wind erosion), biodiversity (increased soil microbial biodiversity), soil (reduced soil erosion and redistribution maintaining soil depth and water retention), water (increased soil water conservation and crop water use efficiency; improved water quality and reduced sediment loads)[[13]](#footnote-14), and a moderate improvement for the energy efficiency of field operations as fewer tillage passes are taken and horsepower requirements are reduced for tractors.[[14]](#footnote-15) |
| **Technical Feasibility:** Yes |
| **c.** | **Action Details****Implement grazing practices that increase vegetative cover and forage quality, e.g. rotational grazing*****Herbaceous* vegetative cover** (non-woody plants) can be increased on pasture by reducing grazing pressure from livestock that can cause overgrazing, soil erosion and nutrient loss. Rotational grazing manages the amount of time livestock spend on a given pasture by rotating animals among various pastures and providing pastures sufficient time to regrow. Reseeding pastures increase vegetative cover in areas that may be denuded and can introduce more desirable species for forage. Nutrient management is also important on pastures to ensure plants have sufficient nutrients to grow and to avoid excess application of nutrients. Pasture management is also important for forage quality, which can reduce enteric emissions (discussed in action (j) below). VAAFM funds *Rotational Grazing* and *No Till Pasture and Hayland Renovation* (re-seeding) through the FAP program and various structural practices and management assistance to improve pasture quality through the *Pasture and Surface Water Fencing* (PSWF) program. | **Impact**EPA considers intensive grazing as an abatement measure for enteric fermentation and the mitigation of the release of CH4 from ruminant animals. Globally, EPA places a reduction efficiency -13.3% for beef cattle and -15.5% for dairy cattle from baseline CH4 levels when intensive grazing is applied.[[15]](#footnote-16)  |
| **Equity**Farms in good standing with VAAFM are eligible to apply and participate. |
| **Cost-Effectiveness**VAAFM’s FAP and PSWF programs seek to reduce the barriers to adoption for farmers to implement more intensive grazing programs through the provisioning of technical and financial assistance to support plan development, infrastructure design, water system layout, and infrastructure installation.While there are both technical barriers and capital startup costs, annual operation and maintenance costs for intensive grazing can represent a savings to farmers with EPA modeling an annual Operation & Maintenance Cost (in 2020 USD) of between -$180 to +$1 per head for maintenance of implemented intensive grazing practices globally.[[16]](#footnote-17) |
| **Timeline to Implement:** 0-6 months | **Co-Benefits**Multiple co-benefits are provided by farmers adopting management-intensive grazing on their farms. These include the reduction of nutrients transported to surface and groundwater through increases to plant vigor and uptake of nutrients. A slight to moderate improvement to terrestrial habitat for wildlife and invertebrates is noted as the improvement or maintenance of quantity and quality of forage for grazing and browsing animals’ health and productivity improve or maintain the quantity and quality or connectivity of food and/or cover available for wildlife. Benefits to reduce soil erosion, improve water utilization, improve plant condition, improve habitat for fish and wildlife, and other air quality benefits are noted.[[17]](#footnote-18) |
| **Technical Feasibility:** Yes |
| **d.** | **Action Details****Implement agroforestry and silvopasture practices that integrate woody vegetation in agricultural production*****Woody* vegetation** (trees and shrubs) also sequester carbon as they grow and store more carbon and for longer periods in their woody biomass. A*groforestry* or agriculture that incorporates the cultivation and conservation of trees thereby increases the amount of carbon sequestered and stored compared to agriculture without trees. Practices that add woody vegetation on cropland include *alley cropping*, which adds rows of trees or shrubs in between rows of crops. S*ilvopasture* is the deliberate and managed integration of trees and grazing livestock on the same land. USDA NRCS Vermont currently provides the bulk of technical and financial assistance for farmer adoption and implementation of agroforestry and silvopastoral practices. VAAFM will need to expand practice standards in its FAP and PSWF programs to provide technical and financial assistance for these conservation practices. | **Impact**Silvopasture systems are highly effective at mitigating GHG emissions from agriculture through the simultaneous management of tree crops, livestock grazing, and forage crops on the same unit of land. Canada estimates that tree intercropping and silvopasture system adoption represent 18% of the total annual mitigation potential from agricultural GHG mitigation pathways.[[18]](#footnote-19) High potential for climate mitigation Emission Reduction Coefficients from this practice is balanced against the need for enhanced technical assistance to ensure successful adoption and integration of this practice on Vermont farms. |
| **Equity** Farms in good standing with VAAFM would be eligible to apply and participate. |
| **Cost-Effectiveness**100% of the annual mitigation potential for the adoption silvopasture is available at ≤ $10/MT CO2e in Canada. The same study estimates that 100% of the annual mitigation potential for the adoption of tree intercropping is available at ≤ $50/MT CO2e.[[19]](#footnote-20) |
| **Timeline to Implement:** 1-2 years | **Co-Benefits** Co-benefits for the adoption of agroforestry and silvopasture practices are numerous and span benefits for air, biodiversity, soil, water quality, and social considerations. Increased biodiversity and abundance of native bees and other beneficial insects is important to note, also increased economic benefit from the diversification of farm product and revenue.[[20]](#footnote-21) |
| **Technical Feasibility:** Yes |
|  | **~~Action Details~~****~~Coordinate with federal NRCS cost-share programs to elevate climate mitigation practices in Vermont, e.g. silvopasture, alley cropping, forest farming~~**~~Agroforestry practices such as alley cropping and silvopasture are, at the time of this report, not funded in Vermont. However, these and other agroforestry practices, exist and are cost-shared federally by the United States Department of Agricultural (USDA) Natural Resources Conservation Service (NRCS). Coordination with NRCS is ongoing and needs to continue so that these agroforestry and other climate mitigation practices are eligible for landowners in Vermont and appropriately funded to increase adoption.~~ | **~~Impact~~** |
| **~~Equity~~** |
| **~~Cost-Effectiveness~~** |
| **~~Timeline to Implement~~** | **~~Co-Benefits~~** |
| **~~Technical Feasibility:~~** ~~Yes~~ |
| **e.** | **Action Details****Implement edge-of-field practices that increase herbaceous and woody vegetation, e.g. riparian forest buffer (e.g. CREP).** **Woody** vegetation can also be added to the edge of crop fields or pastures through practices such as forested riparian buffers, windbreaks, or other tree/shrub establishments. VAAFM and USDA Farm Service Agency (FSA) jointly fund the Conservation Reserve Enhancement Program (CREP) to establish riparian forested buffers along Vermont’s waterways. It is recommended that the payment rates for CREP be increased to incentivize further adoption across the state. **Herbaceous** vegetation can also be added to the edge of annual crop fields by expanding existing buffers or field boarders. VAAFM funds such plantings via *Filter Strip* and *Forage and Biomass Planting* practices through its Grassed Waterway and Filter Strip (GWFS) program. Trees and native plants also have many co-benefits for pollinators and wildlife.  | **Impact**High impact through the retirement of active cropland or enhancement of existing edge-of-field buffers to include herbaceous and woody species adjacent to surface waters. High impact of GHG mitigation potential through both cultivation of woody biomass and increases in soil organic carbon on a per-acre basis is limited to modest total impact by the scope of implementation – maintaining prime agricultural soils for crop production limits area of opportunity for implementation on a sharply increasing marginal abatement cost as foregone income and other opportunity costs are considered by farmers. Currently there are over 2,000 acres of CREP under contract, but many more acres of vegetated or riparian forest buffers are implemented in Vermont. |
| **Equity**Farms in good standing with VAAFM would be eligible to apply and participate. Farms also need to be eligible for USDA Farm Bill programs for CREP. |
| **Cost-Effectiveness**High cost per acre of implementation relative to other Natural Climate Solutions is noted for this action as there are multiple costs embedded in the per-acre rate, including: implementation of the conservation practice (e.g. tree planting) itself which is quite labor and material intensive as well as incentive payments to offset forgone income and recurring rental payments for the farmer. A study in Canada finds that 0.0 of the 0.7 MMT CO2e/yr annual mitigation potential from the practice of riparian tree planting is available for implementation ≤ $100/MT CO2e.[[21]](#footnote-22) The multiple conservation benefits outweighs the lower cost-effectiveness compared to other in-field conservation practices and elevates this program action to a high priority. |
| **Timeline to Implement:** 0-6 months | **Co-Benefits**Air, biodiversity, soil, water, and social co-benefits are all enhanced from the implementation of edge-of-field conservation practices that increase herbaceous and woody vegetation. Benefits to aquatic and terrestrial habitats, as well as reduced runoff of sediment and nutrients from crop fields are major co-benefits of such practices. |
| **Technical Feasibility:** Yes |
| **f.** | **Action Details****Implement natural resource restoration practices that support climate mitigation and resilience, including river corridor easements, wetland restoration, and afforestation practices with consideration to agricultural land loss.**  Various natural resource practices, such as wetland restoration and afforestation (both which sequester and store carbon), support climate mitigation and resilience. Restorations can restore the performance of wetlands for example, and the benefits of afforestation on agricultural land are mentioned above. River corridor easements. However, it is imperative that landowners retain the choice to make these management and land use changes, and that the climate benefits consider and outweigh the costs of implementation and taking land out of agricultural production.VAAFM is authorized to administer the Agricultural Environmental Management (AEM) Program at 6 V.S.A. § 4830 which can approve payments for conservation easements, land acquisition, farm structure decommissioning, site reclamation, and in-lieu payments for benefits that would otherwise be unrealized through the implementation of existing agricultural conservation programs. The AEM program can help extend the effectiveness of existing state and federal programs that target the natural resource restoration projects and can help bridge the gap of opportunity cost that might otherwise preclude a farmer from participating in a conservation program. | **Impact**Impact of this action is mostly limited to restoration projects as any avoided conversion costs are negligible as state wetland and river corridor rules prohibit conversion of wetlands or conversion of river corridors without a permit from DEC. Wetland restoration projects have high marginal abatement costs with only 4% of total potential wetland restoration pathways coming from restoration projects as reported by a national Canadian study.[[22]](#footnote-23) 16% of the potential annual mitigation potential from freshwater mineral and peatland wetland restoration is available at less than ≤ $100/MT CO2e. Wetland restoration is a project area that many farms participate in and are the driving force behind the net gain of wetlands that Vermont is realizing today – over 398 acres of wetland were permanently restored by farms between 2011 and 2015.[[23]](#footnote-24) |
| **Equity** Farms in good standing with VAAFM would be eligible to apply and participate. |
| **Cost-Effectiveness**Cost-effectiveness of these projects are often less than in-field agronomic conservation practices. The total potential impact is also less than in-field agronomic conservation practices as the total potential wetland restoration area is much more limited than those acres used to grow food and crops in Vermont. Many state and federal partner organizations come together to often permanent easements to farms that wish to restore wetlands on their agricultural cropland or enroll their river corridors in permanent easements. These programs play a large role and the AEM program exists to bridge the gap where needed between opportunity cost for the farmer and natural resource restoration potential. |
| **Timeline to Implement:** 0-6 months | **Co-Benefits**Benefits to air, biodiversity, soil, water, as well as social considerations abound for these natural resource restoration projects. Ponding and flooding benefits are provided, wherein a restored wetland can provide temporary flood storage reducing flooding and ponding.[[24]](#footnote-25) |
| **Technical Feasibility:** Yes |
| **g.** | **Action Details****Implement Nutrient Management and Amendments (e.g. biochar, compost) on cropland and grazing land.**Nutrient management balances the appropriate nutrient applications for optimum plant growth while minimizing loss of nutrients to soil, water, and atmosphere. **Nitrogen** is the primary nutrient of concern, that, through various pathways, can be emitted to the atmosphere as nitrous oxide (N2O), a greenhouse gas 298 times more potent than CO2 over a 100-year time period. Even nitrogen in the soil and water can ultimately be emitted to the atmosphere through processes of volatilization, denitrification, and leaching. Any practice or management that reduces nitrogen utilization or loss to the environment reduces emissions, in addition to providing water quality benefits. Both organic (e.g. manure) and synthetic nitrogen fertilizer have the potential to be lost to the atmosphere, however the creation of synthetic nitrogen fertilizer is an energy-intensive process, thus the use of **manure** *instead* of synthetic fertilizer is also a climate mitigation strategy. Planting **legumes**, which naturally convert atmospheric nitrogen to plant available nitrogen, is another way to naturally supply nitrogen instead of synthetic fertilizer. Programs that facilitate nutrient management education and planning for farmers is important to continue and enhance. All farms per the VAAFM Required Agricultural Practices Rule (RAPs) are required to follow nutrient management guidelines and all large, medium and certified small farms are required to develop and implement a nutrient management plan to USDA NRCS standards. VAAFM also funds grants for technical service providers to educate and assist farmers with the upkeep of nutrient management plans. VAAFM has begun and seeks to bolster investment in research, application, and adoption of precision agricultural technologies and their use on farms in Vermont.There are also various **carbon**-rich amendments that can be added to agricultural fields, which add carbon to the soils. Animal **manure** itself contains carbon and thus adds carbon to the soil when applied to crop fields or added directly by grazing animals on pasture. **Compost**, soil like substance resulting from *biological* process in which aerobic microorganisms decay organic materials such as manure and bedding, creates a more stable form of carbon that can be added to fields. **Biochar** is an even more stable form of carbon similar to charcoal that is produced by pyrolysis of biomass in the absence of oxygen; however, the *thermochemical* process is energy-intensive and therefore the net climate impact needs to be confirmed and verified before marketing to farmers—and is often at cost-prohibitive. | **Impact**Both EPA and USDA consider nutrient management with a specific focus on the utilization of nitrogen fertilizers as an impactful strategy for agricultural GHG mitigation. Variable rate technology, the use of nitrogen inhibitors, and management planning which reduces overall fertilizer utilization are important management options for farms. Of the 40 MMT potential reduction potential from cropland management across the United States, USDA estimates that only about 10% of the total mitigation potential comes from nitrogen nutrient management.[[25]](#footnote-26) Whole farm nutrient management is an essential component of farm’s achievement of water quality – when paired with other actions outlined in this table, the planning steps taken in this nutrient management action can capacitate the substitution and crop management to further enhance nutrient management benefits. |
| **Equity**Farms are required to comply with state nutrient management standards. Nutrient management standards are farm-size based. |
| **Cost-Effectiveness**Technological costs can be high for the acquisition of variable rate technology or the use of inhibitors. Technical assistance and planning support is needed to assist with proper agronomic balancing. 90% of the annual mitigation potential is available at ≤ $100/MT CO2e though only 11% of the annual mitigation potential is available at ≤ $10/MT CO2e.[[26]](#footnote-27) |
| **Timeline to Implement:** 0-6 months | **Co-Benefits**Benefits for air, biodiversity, and water quality can be realized through the implementation of nutrient management planning and implementation. Social considerations include a potential benefit to farm operations wherein their operating costs can be reduced while maintaining similar levels of crop productivity. |
| **Technical Feasibility:** Yes |
| **h.** | **Action Details****Implement methane capture and energy generation on farms, e.g. anaerobic digesters, roofa~~, roofs~~ and covers.**Manure from livestock contain carbon and nitrogen, which can be lost to the atmosphere primarily as methane (CH4) but also nitrous oxide (N2O), both potent greenhouse gases—25 and 298 times more potent than CO2 over a 100-year period, respectively. Emissions from manure management are significantly affected by **storage type**, duration, temperature, moisture and manure composition. Storage of manure as a liquid has 4 times[[27]](#footnote-28) higher emissions compared to solid storage because more methane, which is more potent, is emitted from the *anaerobic* conditions of liquid storage, compared to more *aerobic* conditions of solid storage, which emits carbon dioxide (less potent). As such, switching from liquid storage (2.01) to solid storage (0.49), especially one that composts (0.28 MTCO2e/dairy cow/year), reduces emissions from manure storage (4-7 times)[[28]](#footnote-29). Furthermore, reducing the amount of **time** manure is stored by increasing **grazing** time, which deposits manure directly on pasture, reduces emissions from manure storage (e.g. switching from confinement to grazing half of the year reduces emissions by half). However, the winter climate in Vermont and water quality standards necessitates a certain amount of manure storage. Additionally, the growing trend in manure storage is expansion of liquid storage. However, there are technologies that reduce emission from manure stored as a liquid. **Covers** on liquid storage prevent emissions from being emitted to the atmosphere and the captured methane (the primary component of natural gas) can be used as a fuel source on the farm. **Anaerobic Digestors** utilize bacteria to break down organic matter—such as animal manure, wastewater biosolids, and food wastes—in the absence of oxygen to create methane, which can be used as a biogas. Capturing methane from the storage of manure is an effective way to reduce emissions and create a renewable fuel source. | **Impact** VAAFM, along with partners, have funded anaerobic digestors on 20 farms since 2005, which currently reduce emissions of nearly 16,000 animals, or 12% of dairy cow population in Vermont. This amounts to 27,000 MTCO2e reduced per year. Adding a digester to a liquid manure system can reduce methane emissions up to 90%[[29]](#footnote-30). Globally, EPA utilizes an 85% reduction efficiency across different digester types.[[30]](#footnote-31) The provision of Renewable Natural Gas from on-farm anerobic digester products can provide a substitution benefit compared to other Natural Gas sources while abating emissions from manure management on farms in an effective manner. |
| **Equity** High initial capital costs, and the need for long-term ongoing management of the systems provides a barrier to adoption for small to medium sized farms which have less farm staff and assets to offset initial startup as a system builds towards payback. |
| **Cost-Effectiveness**Methane capture and energy generation projects have high initial capital costs. An example project for an 800-cow dairy farm cost $1.8 million dollars to implement but has a 7-year payback timeframe based on electricity generated and sold as well as use of waste-heat by the farm. A recent project on a Vermont farm was brought online in 2021 and produces Renewable Natural Gas as a product of the digestion process. |
| **Timeline to Implement:** 1-2 Years | **Co-Benefits**Co-benefits for farm income and viability are an outcome of successfully implemented projects. Other co-benefits include the reduction of nutrients transported to surface water as management options for the farm are increased regarding storage, transport and application of wastes, proper field application of nutrients minimizes runoff losses.[[31]](#footnote-32) |
| **Technical Feasibility:** Yes |
| **i.** | **Action Details****Research into improved manure management and storage.**There may be additional methods or improvements to the manure storage strategies listed above that warrant additional research and development if proven to be effective. Emission from manure management represent 25% of the agriculture sector emissions in 2017 (DEC). It is important to consider equity of funding across all farm sizes when such technology is primarily feasible for large farms only. Other technologies may include acidification of manure or addition of biochar for example.[[32]](#footnote-33) VAAFM, through its Phosphorus Innovation Challenge (VPIC), is funding research and development of digestors, mobile composting units, and biochar which can have climate mitigation benefits. | **Impact**If the acidification of fresh manure slurries can replicate the impact of studies, it may be possible to reduce 64-99% of CH4 emissions over the summer manure storage season.[[33]](#footnote-34) Literature suggests that 90% of annual methane emissions can come through the summer months.[[34]](#footnote-35) A control treatment of treating manure could have significant impact for Vermont’s most common manure storage system type. |
| **Equity** Research will need to investigate equity considerations in development and implementation of manure storage and treatment technologies. |
| **Cost-Effectiveness**Cost-effectiveness will need to be considered against other NCS’ that can be implemented on agricultural operations. |
| **Timeline to Implement:** 1-2 years | **Co-Benefits** Reduction in emissions from manure storage can have co-benefits for air quality for this program.  |
| **Technical Feasibility:** Yes |
| **j.** | **Action Details****Research and develop a climate feed management program, including both feed amendments (e.g. seaweed, biochar) and feed quality (e.g. forage quality) to reduce enteric methane emissions; consider downstream impacts, sustainability and equity.*****Enteric fermentation*** is a biological process that occurs in the digestive system of animals, primarily ruminants (e.g. cows, sheep, goats) that produces methane, primarily through belching. With Vermont being a large dairy state, nearly 50% of the agriculture sector emissions in Vermont are from enteric emissions (DEC)[[35]](#footnote-36). However, enteric fermentation is a natural by-product of animals and thus has limited management options and minimal reduction potential (EPA).[[36]](#footnote-37) [Although methane from cows is *biogenic* (naturally produced), because livestock are raised by humans, it is considered an *anthropogenic* source of emissions subject to emission tracking.] Two approaches offer potential for reducing enteric fermentation emissions. **Feed amendments**, such as seaweed and biochar, have been documented to reduce enteric emissions. However, it is important to source these products sustainably and equitably to not cause negative impacts to humans, environment, or climate. Furthermore, feed amendments tend to be costly. A more local approach is to improve the **feed quality**, which reduces enteric emissions per unit of product (milk, meat). Further research is needed to appropriately develop these strategies for farms in Vermont.  | **Impact** EPA reports and models that improved feed conversion is an abatement measure for Enteric Fermentation and the release of CH4 globally. There is a range of reduction efficiencies that are reported that span from a decrease of 39.4% per head to an increase of 39.6% per head. Vermont agriculture currently has high productive capacity per cow and so the Vermont specific impact is unknown and requires further research. |
| **Equity** Methane emissions associated with enteric fermentation are ‘sticky’ and if analyzed without the context in which a cow is raised – the feedstocks that are grown to feed cows and the associated sequestration (net considerations) – there are limited pathways to reduce enteric fermentation rates. EPA publishes globally that with the application of reductions that are technically feasible but come with increasing costs that 91% of baseline emissions are residual and cannot be affected by management or technology by 2030.[[37]](#footnote-38) |
| **Cost-Effectiveness**The cost and cost-effectiveness of the implementation of a climate feed management strategy need to be researched and considered compared to other NCS that can be applied across a farm’s management area. The annual O&M costs estimated by EPA for improved feed conversion programs range from $25 - $295 per head per year.[[38]](#footnote-39) |
| **Timeline to Implement:** 1-2 years | **Co-Benefits** Certain feed management strategies – such as adoption management intensive grazing that increase forage uptake, availability, and quality for livestock – can have multiple co-benefits for farm profitability and associated air and water quality benefits associated with improved pasture management. |
| **Technical Feasibility:** Yes |

1. While demand-side measures (e.g. reducing losses and wastes of food) may also play a also play a role in mitigation of climate change, these recommendations are not in-scope of the Agriculture & Ecosystems Subcommittee. [↑](#footnote-ref-2)
2. <https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_annex-i.pdf> [↑](#footnote-ref-3)
3. White, A.C., Faulkner, J.W., Conner, D.S., Mendez, V.E., and M.T. Niles, M.T. (in press) “How can you put a price on the environment?” Farmer perspectives on stewardship and payment for ecosystem services. *Journal of Soil and Water Conservation.* [↑](#footnote-ref-4)
4. Minasny, Budiman, Brendan P. Malone, Alex B. McBratney, Denis A. Angers, Dominique Arrouays, Adam Chambers, Vincent Chaplot et al. "Soil carbon 4 per mille." *Geoderma* 292 (2017): 59-86. [↑](#footnote-ref-5)
5. Vermont Climate Assessment. 2021. Due to be publicly released in Nov of this year. Lead authors are Galford, Faulkner & Dupigney-Giroux [↑](#footnote-ref-6)
6. Vermont Climate Assessment. 2021. Due to be publicly released in Nov of this year. Lead authors are Galford, Faulkner & Dupigney-Giroux [↑](#footnote-ref-7)
7. <https://dec.vermont.gov/sites/dec/files/wsm/erp/docs/2021-01-15_CleanWaterPerformanceReport_SFY2020-FINA-PDF-A.pdf> [↑](#footnote-ref-8)
8. <https://www.science.org/doi/10.1126/sciadv.abd6034> [↑](#footnote-ref-9)
9. C Ronnie Drever et al., Natural Climate Solutions for Canada, 7 Science Advances 1 (2021) [↑](#footnote-ref-10)
10. C Ronnie Drever et al., Natural Climate Solutions for Canada, 7 Science Advances 1 (2021) [↑](#footnote-ref-11)
11. <https://www.usda.gov/sites/default/files/documents/White_Paper_WEB_Final_v3.pdf> (p.31) [↑](#footnote-ref-12)
12. <https://www.epa.gov/sites/default/files/2019-09/documents/epa_non-co2_greenhouse_gases_rpt-epa430r19010.pdf> (p.60) [↑](#footnote-ref-13)
13. <https://www.science.org/doi/suppl/10.1126/sciadv.abd6034/suppl_file/abd6034_sm.pdf> (Table S1) [↑](#footnote-ref-14)
14. USDA CPPE [↑](#footnote-ref-15)
15. <https://www.epa.gov/sites/default/files/2019-09/documents/nonco2_methodology_report.pdf> (p.S5-P168) [↑](#footnote-ref-16)
16. ibid [↑](#footnote-ref-17)
17. USDA CPPE [↑](#footnote-ref-18)
18. <https://www.science.org/doi/10.1126/sciadv.abd6034> [↑](#footnote-ref-19)
19. <https://www.science.org/doi/10.1126/sciadv.abd6034> [↑](#footnote-ref-20)
20. <https://www.science.org/doi/10.1126/sciadv.abd6034> (p.70) [↑](#footnote-ref-21)
21. <https://www.science.org/doi/10.1126/sciadv.abd6034> [↑](#footnote-ref-22)
22. <https://www.science.org/doi/10.1126/sciadv.abd6034> [↑](#footnote-ref-23)
23. [https://legislature.vermont.gov/Documents/2020/WorkGroups/Wetlands/Documents%20and%20Testimony/W~Laura%20LaPierre~Memo%20to%20Legislative%20Study%20Committee%20on%20October%209,%202019%20meeting%20requested%20materials~10-9-2019.pdf](https://legislature.vermont.gov/Documents/2020/WorkGroups/Wetlands/Documents%20and%20Testimony/W~Laura%20LaPierre~Memo%20to%20Legislative%20Study%20Committee%20on%20October%209%2C%202019%20meeting%20requested%20materials~10-9-2019.pdf) [↑](#footnote-ref-24)
24. USDA NRCS CPPE [↑](#footnote-ref-25)
25. <https://www.usda.gov/sites/default/files/documents/White_Paper_WEB_Final_v3.pdf> (p.31) [↑](#footnote-ref-26)
26. <https://www.science.org/doi/10.1126/sciadv.abd6034> [↑](#footnote-ref-27)
27. Food and Agriculture Organization of the United Nations (FAO) Ex-Ante Carbon Balance Tool (EX-ACT) [↑](#footnote-ref-28)
28. Ibid [↑](#footnote-ref-29)
29. Ibid [↑](#footnote-ref-30)
30. <https://www.epa.gov/sites/default/files/2019-09/documents/nonco2_methodology_report.pdf> [↑](#footnote-ref-31)
31. USDA NRCS CPPE [↑](#footnote-ref-32)
32. S. O. Petersen, A. J. Andersen, J. Eriksen, Effects of cattle slurry acidification on ammonia and methane evolution during storage. J. Environ. Qual. 41, 88–94 (2012).; <https://www.science.org/doi/10.1126/sciadv.abd6034> [↑](#footnote-ref-33)
33. C Ronnie Drever et al., Natural Climate Solutions for Canada, 7 Science Advances 1 (2021) [↑](#footnote-ref-34)
34. H. Baldé, A. C. VanderZaag, S. Burtt, L. Evans, C. Wagner-Riddle, R. L. Desjardins, J. D. MacDonald, Measured versus modeled methane emissions from separated liquid dairy manure show large model underestimates. Agric. Ecosyst. Environ. 230, 261–270 (2016). [↑](#footnote-ref-35)
35. DEC Emission Inventory 2017 [↑](#footnote-ref-36)
36. <https://www.epa.gov/sites/default/files/2019-09/documents/epa_non-co2_greenhouse_gases_rpt-epa430r19010.pdf> [↑](#footnote-ref-37)
37. <https://www.epa.gov/sites/default/files/2019-09/documents/epa_non-co2_greenhouse_gases_rpt-epa430r19010.pdf> (p.53) [↑](#footnote-ref-38)
38. <https://www.epa.gov/sites/default/files/2019-09/documents/nonco2_methodology_report.pdf> (S.5, P.167) [↑](#footnote-ref-39)