Vermont CAP

(11) Pathways for Mitigation

Agriculture – Summary Statement

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.[1] The agricultural sector's ~~non-carbon dioxide~~ emissions account for 15.8 percent of Vermont's greenhouse gas (GHG) emissions.[2] The main mitigation options within the agricultural sector involve one or more of three strategies:[3]

1. **Prevention of emissions** to the atmosphere by conserving existing carbon pools in soils and vegetation **or by reducing emissions** of methane (CH_4) and nitrous oxide (N_2O) through management changes;
2. **Sequestration**—increasing the size of existing carbon pools, and thereby extracting carbon dioxide (CO_2) from the atmosphere; and
3. **Substitution**—substituting biological products for fossil fuels or energy-intensive products, thereby reducing CO_2 emissions.[4]

Carbon sequestration in agricultural landscapes is the mitigation strategy for agriculture that yields the greatest co-benefits, is the easiest and most immediate to implement, has the fewest equity concerns in Vermont, and has received significant attention from the global and scientific communities as a critical mitigation strategy[5]. Feed supplement strategies to reduce methane in enteric emissions can be associated with negative implications for herd health[6] and reliance on imported feed supplements that may negatively impact communities elsewhere,

[1] White, A.C., Faulkner, J.W., Conner, D.S., Mendez, V.E., and M.T. Niles, M.T. "How can you put a price on the environment?" Farmer perspectives on stewardship and payment for ecosystem services. *Journal of Soil and Water Conservation* (in press).

[2] Agency of Natural Resources – Department of Environmental Conservation – Air Quality and Climate Division. "Vermont Greenhouse Gas Emissions Inventory and Forecast: 1990-2017." May 2021. https://dec.vermont.gov/sites/dec/files/aqc/climate-change/documents/_Vermont_Greenhouse_Gas_Emissions_Inventory_Update_1990-2017_Final.pdf.

[3] 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 at this time.

[4] Allwood J.M., V. Bosetti, N.K. Dubash, L. Gómez-Echeverri, and C. von Stechow, 2014: Glossary. In: *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_annex-i.pdf.

[5] 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 (April 2017): 59-86. https://doi.org/10.1016/j.geoderma.2017.01.002.

[6] U.S. Environmental Protection Agency. "Global Non-CO2 Greenhouse Gas Emission Projections & Marginal Abatement Cost Analysis: Methodology Documentation." September 2019.

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 scale appropriate for small farms, and other manure management practices may have tradeoffs with water quality. Recommendations below include elevating sequestration as a strategy to invest in, with known benefits and wide appeal, while simultaneously supporting proven technologies and exploring ways that other agricultural emissions sources can be mitigated with more careful consideration for tradeoffs and equity.

Today, Vermont farmers mitigate on-farm GHG emissions through the ~~extensive~~ adoption of conservation practices. Importantly, many water quality best management practices provide co-benefits for climate mitigation, and implementation has increased dramatically in recent years. Through more widespread adoption of these conservation practices, which increase the organic matter content of agricultural soils, Vermont farmers have a realistic potential to sequester one million tons of CO_2-e annually[7]. Today, Vermont's agricultural soils already store over an estimated 63 MMT CO_2-e[8].

The agriculture sector is also highly vulnerable to climate change. Currently, the majority of crop losses reported in Vermont are due to weather extremes that have been increasing in intensity and frequency due to climate change[9]. Fortunately, many agricultural practices that increase carbon sequestration also enhance a farm's resilience to a changing climate ~~capacity to bounce back from climate impacts~~. In fact, the most common strategy that Vermont farmers already employ to address extreme weather impacts is improving soil health[10], highlighting the importance of soil health as an important strategy to address both 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

[7] White, A.C. "Agricultural Greenhouse Gas Footprint in Vermont and Rough Quantification of Strategies to Meet Reduction Goals." Presentation to Agriculture & Ecosystems Subcommittee 5C Group. May 25, 2021.
[8] Galford, Gillian, Darby, Heather, Kosiba, Alexandra, and Hall, Frederick. "A Carbon Budget for Vermont: Task 2 in Support of the Development of Vermont's Climate Action Plan." September 2021.
[9] Vermont Climate Assessment. 2021. Due to be publicly released in Nov of this year. Lead authors are Galford, Faulkner & Dupigney-Giroux
[10] Vermont Climate Assessment. 2021. Due to be publicly released in Nov of this year. Lead authors are Galford, Faulkner & Dupigney-Giroux

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 the importance of Vermont's soils to address climate change and investment in the following **ten key actions** can help catalyze enterprise-level changes, remove the barriers to transition, and leverage the impressive engagement and work farmers have recently begun to undertake to address Vermont's water quality challenges and expand and empower all Vermont farmers to adapt, build resilience to, and mitigate 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~~requirements established in the GWSA. Here exists a robust multi-partner service-delivery mechanism[11] for agriculture where natural climate solutions (NCS) (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 through state and federal programs.[12] These agricultural NCS can be delivered at a large scale, at cost-effective rates, yield immediate GHG mitigation benefits, have long lasting positive 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 incorporates 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

[11] Vermont Agricultural Water Quality Partnership. https://vtagcleanwater.org/.
[12] Clean Water Interactive Dashboard data presented in Vermont Clean Water Initiative 2020 Performance Report. January 15, 2021. https://app.powerbigov.us/view?r=eyJrIjoiNTI5Y2QxZDEtODY3Ni00ZmYwLThjZTAtNjdiNTM3YTQyZjRkIiwidCI6IjIwYjQ5MzNiLWJhYWQtNDMzYy05YzAyLTcwZWRjYzc1NTljNiJ9.

consistent with the IPCC definition, “a human intervention to reduce the sources or enhance the sinks of greenhouse gases (GHGs)”[13].

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:

- **i. Prevention of emissions to the atmosphere by conserving existing carbon pools in soils or vegetation, or by reducing emissions of methane (CH_4) and nitrous oxide (N_2O);**
- **ii. Sequestration —by increasing the size of existing carbon pools, and thereby extracting carbon dioxide (CO_2) from the atmosphere; and**
- **iii. Substitution of biological products for fossil fuels or energy-intensive products, thereby reducing CO_2 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. The specific impacts 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 Vermont farmers ~~across the State~~. Current state programs coordinate with federal programs to ensure as seamless and complementary a 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.

LEAD IMPLEMENTER Vermont Agency of Agriculture, Food & Markets (VAAFM)		
a.	**Action Details**	**Impact**
	Implement agronomic practices that reduce tillage and increase vegetative cover, e.g. no-till, cover crop	In 2021, VAAFM funded over 24,000 acres of cover crop and 2,700 acres of conservation tillage. Vermont has about 90,000 acres of land suitable for cover crop and conservation tillage in 2021.[14] Implementation of

[13] IPCC, 2014: Annex II: Glossary [Mach, K.J., S. Planton and C. von Stechow (eds.)]. In: *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, pp. 117-130. https://www.ipcc.ch/site/assets/uploads/2019/01/SYRAR5-Glossary_en.pdf.

[14] U.S. Department of Agriculture Farm Service Agency. “Crop Acreage Data – 2020 Crop Year.” https://www.fsa.usda.gov/news-room/efoia/electronic-reading-room/frequently-requested-information/crop-acreage-data/index

	Practices that reduce tillage intensity, such as reduced tillage and no-till conservation practices, reduce the emissions of CO_2 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	these practices has been steadily increasing since 2016 and the rate of adoption has potential to continue to increase with sustained or expanded funding. While implementation of these agronomic practices are currently being tracked by VAAFM, a protocol needs to be researched and developed to quantify GHG mitigation from these practices for Vermont. 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 NCS mitigation reductions in the study were estimated to come from cover crops.[15]
		Equity Jurisdictional RAP farms are eligible to apply for VAAFM programs. A comprehensive review for equity should be undertaken by state programs. Outreach regarding program eligibility and availability should be expanded.
		Cost-Effectiveness High cost-effectiveness due to low cost of implementation and potential for scaling up adoption on farms. Literature suggests that the CO_2e/yr potential mitigation for cover crop as a mitigation strategy can be available at the following price points: 14% of total possible reduction at ≤ $10/MT CO_2e; 46% of total

[15] Drever, C Ronnie et al. "Natural Climate Solutions for Canada." *Science Advances* 7, 1 (June 2021). https://www.science.org/doi/10.1126/sciadv.abd6034.

	its Farm Agronomic Practices (FAP) program. USDA NRCS-VT funds additional implementation of these practices.	possible reduction at ≤ \$50/MT CO_2e; 84% of total possible reduction at ≤ \$100/MT CO_2e.[16] Literature suggests that the CO_2e/yr potential mitigation for reduced tillage as a mitigation strategy can be available at the following price points: 22% of total mitigation potential at ≤ \$10/MT CO_2e; 44% of total mitigation potential at ≤ \$50/MT CO_2e; 67% of total mitigation potential at ≤ \$100/MT CO_2e.[17]
	Timeline to Implement: 0-6 months.	**Co-Benefits** This suite of agronomic practices provides overall adaptation, resilience, and water quality benefits including: 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) provides financial support	**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). Farmers manage almost 530,000 acres of harvested cropland and pasture in Vermont[19] offering considerable opportunity for expanding adoption.

[16] Drever, C Ronnie et al. "Natural Climate Solutions for Canada." *Science Advances* 7, 1 (June 2021). https://www.science.org/doi/10.1126/sciadv.abd6034.
[17] Drever, C Ronnie et al. "Natural Climate Solutions for Canada." *Science Advances* 7, 1 (June 2021). https://www.science.org/doi/10.1126/sciadv.abd6034.
[19] U.S. Department of Agriculture National Agricultural Statistics Service. "2017 Census of Agriculture." https://www.nass.usda.gov/Publications/AgCensus/2017/index.php.

	for farmers to purchase the equipment necessary to implement many of the climate mitigation practices listed above 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 can have co-benefits for GHG mitigation, and the program currently can be used to increase mitigation by including equipment more specifically intended for climate mitigation[18]. Currently the program is funded through the Clean Water Fund, which focuses the program on clean water outcomes. Either an additional funding source or an agreement from the Clean Water Board to support climate focused practices is needed to expand the program beyond clean water practices.	While implementation of these agronomic practices are currently being tracked by VAAFM, a protocol needs to be researched and developed to quantify GHG mitigation from these practices for Vermont USDA has modeled potential mitigation by agricultural management category and CO_2 price level ($/MT CO_2e) and has found that of the 120 MMT CO_2e possible to be mitigated by US agriculture nationally, over one third of potential reductions could come from reducing tillage intensity.[20] 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 persistent 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.[21]
		Equity Jurisdictional RAP farms are eligible to apply for VAAFM programs. A comprehensive review for equity should be undertaken by state programs. Outreach regarding program eligibility and availability should be expanded.
		Cost-Effectiveness USDA has modeled that nationally, over 50% (21 MMT CO_2e) of the total mitigation potential from the

[18] 6 V.S.A. § 4828(a) "It is the purpose of this section to provide assistance to purchase or use innovative equipment that will aid in the reduction of surface runoff of agricultural wastes to State waters, improve water quality of State waters, reduce odors from manure application, separate phosphorus from manure, *decrease greenhouse gas emissions*, and reduce costs to farmers." Emphasis added.
[20] Pape, D., J. Lewandrowski, R. Steele, D. Man, M. Riley-Gilbert, K. Moffroid, and S. Kolansky, 2016. "Managing Agricultural Land for Greenhouse Gas Mitigation within the United States." Report prepared by ICF International under USDA Contract No. AG-3144-D-14-0292. July 2016. https://www.usda.gov/sites/default/files/documents/White_Paper_WEB_Final_v3.pdf (p.31)
[21] U.S. Environmental Protection Agency. "Global Non-CO2 Greenhouse Gas Emission Projections & Mitigation: 2015-2050." https://www.epa.gov/sites/default/files/2019-09/documents/epa_non-co2_greenhouse_gases_rpt-epa430r19010.pdf (p.60)

		adoption of reduced tillage practices is available below $30 per MT CO_2e.
	Timeline to Implement: 0-6 months	**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)[22], and a moderate improvement for the energy efficiency of field operations as fewer tillage passes are taken and horsepower requirements are reduced for tractors.[23]
		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	**Impact** Vermont has funded investment in improved grazing management on 11,500 acres since 2019[24]. Farmers report managing over 110,000 acres of permanent pasture in Vermont[25] offering considerable opportunity to expand adoption. While implementation of these agronomic and grazing practices are currently being tracked by VAAFM, a protocol needs to be researched and developed to quantify GHG mitigation from these practices for Vermont.

[22] Drever, C Ronnie et al. "Supplementary Materials for Natural Climate Solutions for Canada." *Science Advances* 7, 1 (June 2021). https://www.science.org/doi/suppl/10.1126/sciadv.abd6034/suppl_file/abd6034_sm.pdf (Table S1)

[23] U.S. Department of Agriculture Natural Resources Conservation Service. "Conservation Practice Physical Effects on Soil, Water, Air, Plants, Animals, Energy, People; National Summary Tool FY2021." Technical Resources. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/econ/tools/?cid=nrcs143_009740.

[24] USDA NRCS-VT currently provides the majority of financial assistance programing with over 1,300 acres of prescribed grazing applied in 2019.

[25] U.S. Department of Agriculture National Agricultural Statistics Service. "2017 Census of Agriculture." https://www.nass.usda.gov/Publications/AgCensus/2017/index.php.

	rotating animals among various pastures and providing pastures sufficient time to regrow. Reseeding pastures increases 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.	EPA considers intensive grazing as an abatement measure for enteric fermentation and the mitigation of the release of CH_4 from ruminant animals. Globally, EPA places a reduction efficiency of -13.3% for beef cattle and -15.5% for dairy cattle from baseline CH_4 levels when intensive grazing is applied.[26]
		Equity Jurisdictional RAP farms are eligible to apply for VAAFM programs. A comprehensive review for equity should be undertaken by state programs. Outreach regarding program eligibility and availability should be expanded.
		Cost-Effectiveness VAAFM's FAP and PSWF programs seek to reduce the barriers to adoption for farmers to implement more management intensive grazing programs through technical and financial assistance to support plan development and water and fencing infrastructure design and installation. While there are both technical barriers and capital startup costs, annual operation and maintenance costs for management intensive grazing can represent a savings to farmers with EPA modeling an annual Operation & Maintenance Cost (in 2020 USD) between -\$180 to +\$1 per head for maintenance of implemented management intensive grazing practices globally.[27]
	Timeline to Implement: 0-6 months	**Co-Benefits**

[26] U.S. Environmental Protection Agency. "Global Non-CO2 Greenhouse Gas Emission Projections & Marginal Abatement Cost Analysis: Methodology Documentation." September 2019. https://www.epa.gov/sites/default/files/2019-09/documents/nonco2_methodology_report.pdf (p.S5-P168)
[27] Ibid

		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.[28]
		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 compared to herbaceous vegetation. Agroforestry or agriculture that incorporates the cultivation and conservation of trees thereby increases the amount of carbon sequestered and stored compared to agriculture	**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.[29] High potential for long-lasting climate mitigation from this practice is balanced against the need for near-term enhanced technical assistance to ensure successful adoption and integration of this practice on Vermont farms. **Equity**

[28] U.S. Department of Agriculture Natural Resources Conservation Service. "Conservation Practice Physical Effects on Soil, Water, Air, Plants, Animals, Energy, People; National Summary Tool FY2021." Technical Resources. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/econ/tools/?cid=nrcs143_009740.
[29] Drever, C Ronnie et al. "Natural Climate Solutions for Canada." *Science Advances* 7, 1 (June 2021). https://www.science.org/doi/10.1126/sciadv.abd6034.

	without trees. Practices that add woody vegetation on cropland include alley cropping, which adds rows of trees or shrubs in between rows of crops. Silvopasture 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.	Jurisdictional RAP farms are eligible to apply for VAAFM programs. A comprehensive review for equity should be undertaken by state programs. Outreach regarding program eligibility and availability should be expanded. **Cost-Effectiveness** 100% of the annual mitigation potential for the adoption silvopasture is available at ≤ \$10/MT CO_2e in Canada. The same study estimates that 100% of the annual mitigation potential for the adoption of tree intercropping is available at ≤ \$50/MT CO_2e.[30]
	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.[31] **Technical Feasibility:** Yes
e.	**Action Details** **Implement edge-of-field practices that increase herbaceous and woody vegetation, e.g. CREP riparian forest buffer**	**Impact** Currently there are over 2,000 acres of CREP under contract, but many more acres of vegetated or forested riparian buffers are implemented in Vermont.

[30] Drever, C Ronnie et al. "Natural Climate Solutions for Canada." *Science Advances* 7, 1 (June 2021). https://www.science.org/doi/10.1126/sciadv.abd6034.
[31] Drever, C Ronnie et al. "Natural Climate Solutions for Canada." *Science Advances* 7, 1 (June 2021). https://www.science.org/doi/10.1126/sciadv.abd6034. (p.70)

	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 borders. VAAFM funds such plantings via Filter Strip and Forage and Biomass Planting practices through its Grassed Waterway and Filter Strip (GWFS) program.	While implementation of these agronomic practices are currently being tracked by VAAFM, a protocol needs to be researched and developed to quantify GHG mitigation from these practices for Vermont. 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.
		Equity Jurisdictional RAP farms are eligible to apply for VAAFM programs. ~~.~~Farms also need to be eligible for USDA Farm Bill programs for CREP. A comprehensive review for equity should be undertaken by state programs. Outreach regarding program eligibility and availability should be expanded.
		Cost-Effectiveness High cost per acre of implementation relative to other NCS 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 relatively 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 none of the 0.7 MMT CO_2e/yr annual mitigation potential from the practice of riparian tree planting is available for implementation ≤ \$100/MT CO_2e.[32] 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. Increasing vegetation along waterways also reduces erosion and stabilizes banks during high precipitation events, improving water quality through reduced nutrient deposition. Trees and native plants also have many co-benefits for pollinators and wildlife.
		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.**	**Impact** Various natural resource practices, such as wetland restoration and afforestation (both which sequester and store carbon), support climate mitigation and resilience. Restoration projects can increase the wetland acreage as well as restore wetland performance, and the benefits of afforestation on agricultural land are

[32] Drever, C Ronnie et al. "Natural Climate Solutions for Canada." *Science Advances* 7, 1 (June 2021). https://www.science.org/doi/10.1126/sciadv.abd6034.

	A network of state, federal, and non-profit partners offer and implement natural resource protection and restoration projects with willing landowners throughout Vermont. Whether paired with permanent farmland conservation easement or implemented separately, these restoration projects can leverage and enhance natural resource benefit on farms. Examples of these natural resource restoration programs include the DEC River Corridor Easement program, the USDA NRCS Wetland Reserve Enhancement Program, the USDA FSA Conservation Reserve Enhancement Program, among other site-specific practice enhancement programs administered by DEC or USDA NRCS. Natural resource restoration projects provide climate mitigation, adaptation, and resilience benefits – among significant co-benefits for water quality, aquatic and terrestrial habitat, and biodiversity. 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	mentioned above. River corridor easements permanently protect dynamic streambanks, allowing for extensive climate resilience benefits and permanent forested buffers. Farmers in Vermont has conserved over 5,000 acres of wetlands through 68 permanent wetland easements with USDA NRCS.[33] All mapped wetlands and water bodies in Vermont have been identified to store 57 MMT CO_2-e with an annual sequestration of -0.01 MMT CO_2-e /yr.[34]
		Equity Farmers, as the owners and managers of the lands involved in this conservation area, are decision makers that need to be directly involved when considering equity outcomes. Robust farmer participation in natural resource conservation programs is occurring throughout Vermont because programs are responsive to farmer goals and priorities and sufficient technical assistance and financial assistance can support planning over multiple years to achieve implementation.
		Cost-Effectiveness As a means of mitigation for agriculture, natural resource restoration projects do not rank as highly on a cost per ton of CO_2 equivalent basis compared to agronomic practices applied to cropland, as an example. From a climate adaption and resilience perspective these natural resource restoration programs

[33] Jim Eikenberry, USDA NRCS VT Wetlands Specialist. Personal Communication.

[34] Galford, Gillian, Darby, Heather, Kosiba, Alexandra, and Hall, Frederick. "A Carbon Budget for Vermont: Task 2 in Support of the Development of Vermont's Climate Action Plan." September 2021. https://outside.vermont.gov/agency/anr/climatecouncil/Shared%20Documents/Carbon%20Budget%20for%20Vermont%20Sept%202021.pdf

	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.	and practices are highly cost-effective. Taken together, these natural resource restoration programs are ranked high for both impact, cost effectiveness, and prioritization.
	Timeline to Implement: 0-6 months	**Co-Benefits** Benefits to air, soil, water, biodiversity, wildlife habitat, flood resilience, as well as social considerations abound for these natural resource restoration projects. Ponding and flooding benefits are provided, wherein a restored wetland can provide flood storage during rainfall events.
		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 (N_2O), a greenhouse gas 298 times more potent than	**Impact** Both EPA and USDA consider nutrient management with a specific focus on the efficient utilization of nitrogen fertilizers as a strategy for agricultural GHG mitigation. Of the 40 MMT reduction potential from cropland management across the United States, USDA estimates that about 10% of the total mitigation potential comes from nitrogen nutrient management.[35]
		Equity Farms are required to comply with state nutrient management standards. Nutrient management standards are farm-size based.
		Cost-Effectiveness

[35] Pape, D., J. Lewandrowski, R. Steele, D. Man, M. Riley-Gilbert, K. Moffroid, and S. Kolansky, 2016. "Managing Agricultural Land for Greenhouse Gas Mitigation within the United States." Report prepared by ICF International under USDA Contract No. AG-3144-D-14-0292. July 2016. https://www.usda.gov/sites/default/files/documents/White_Paper_WEB_Final_v3.pdf (p.31)

	CO_2 over a 100-year time period. Even nitrogen in the soil and water can ultimately be emitted to the atmosphere through processes of volatilization, runoff and leaching. Any practice or management that increases utilization or reduces loss of nitrogen to the environment reduces emissions, in addition to providing water quality benefits. Examples include precision agriculture, variable rate technologies for applying nutrients, and nitrogen inhibitors for improved fertilizer use efficiency, in addition to general nutrient application management. 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 are 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	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 CO_2e though only 11% of the annual mitigation potential is available at ≤ $10/MT CO_2e in the United States per a USDA study.[36]

[36] Ibid

	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**, a soil like substance resulting from a *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 cost-prohibitive.	
	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 and covers.** Manure from livestock contain carbon and nitrogen, which can be lost to the atmosphere primarily as methane (CH_4) but also nitrous oxide (N_2O), both potent greenhouse gases—25 and 298 times more potent than CO_2 over a 100-year period[37], respectively. Emissions from manure management are significantly affected by **storage type**, duration, temperature, moisture and manure composition. Storage of manure as a liquid has four times[38] 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	**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 $MTCO_2e$ reduced per year. Adding a digester to a liquid manure system can reduce methane emissions up to 90%[40]. Globally, EPA utilizes an 85% reduction efficiency across different digester or capture and flare systems .[41] The provision of Renewable Natural Gas (RNG) 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. The destruction of CH_4 and conversion to CO_2 is a permanent climate benefit and is the only climate mitigation practice currently quantified in the Vermont GHG Emission Inventory.
		Equity High initial capital costs and the need for long-term ongoing management of the systems provides a barrier

[37] Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland, 2007: Changes in Atmospheric Constituents and in Radiative Forcing. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg1-chapter2-1.pdf.

[38] Food and Agriculture Organization of the United Nations (FAO) Ex-Ante Carbon Balance Tool (EX-ACT). https://www.fao.org/in-action/epic/ex-act-tool/suite-of-tools/ex-act/en/.

[40] Food and Agriculture Organization of the United Nations (FAO) Ex-Ante Carbon Balance Tool (EX-ACT). https://www.fao.org/in-action/epic/ex-act-tool/suite-of-tools/ex-act/en/

[41] U.S. Environmental Protection Agency. "Global Non-CO2 Greenhouse Gas Emission Projections & Marginal Abatement Cost Analysis: Methodology Documentation." September 2019. https://www.epa.gov/sites/default/files/2019-09/documents/nonco2_methodology_report.pdf

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<td rowspan="2">emits carbon dioxide (less potent). As such, switching from liquid storage (2.01) to solid storage (0.49), especially one that composts (0.28 $MTCO_2e$/dairy cow/year), reduces emissions from manure storage (4-7 times)[39]. 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.</td>
<td>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.</td>
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<td>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. While these systems have high-cost effective ratios, farmers themselves face significant upfront costs and ongoing maintenance for a project to be implemented successfully.</td>
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[39] Ibid

	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.[42]
		Technical Feasibility: Yes
i.	**Action Details** **Research and pilot ~~into~~ improved manure management and storage programs.** 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[43]. 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[44] or addition of	**Impact** If the acidification of fresh manure slurries can replicate the impact of studies, it may be possible to reduce 64-99% of CH_4 emissions over the summer manure storage season.[46] Literature suggests that 90% of annual methane emissions can come through the summer months.[47] 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**

[42] U.S. Department of Agriculture Natural Resources Conservation Service. "Conservation Practice Physical Effects on Soil, Water, Air, Plants, Animals, Energy, People; National Summary Tool FY2021." Technical Resources. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/econ/tools/?cid=nrcs143_009740.

[43] Agency of Natural Resources – Department of Environmental Conservation – Air Quality and Climate Division. "Vermont Greenhouse Gas Emissions Inventory and Forecast: 1990-2017." May 2021. https://dec.vermont.gov/sites/dec/files/aqc/climate-change/documents/_Vermont_Greenhouse_Gas_Emissions_Inventory_Update_1990-2017_Final.pdf

[44] S. O. Petersen, A. J. Andersen, J. Eriksen. "Effects of cattle slurry acidification on ammonia and methane evolution during storage." Journal of Environmental Quality 41 (2012): 88–94 (2012).

[46] Drever, C Ronnie et al. "Natural Climate Solutions for Canada." *Science Advances* 7, 1 (June 2021). https://www.science.org/doi/10.1126/sciadv.abd6034.

[47] 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." Agriciculture, Ecosystems Environment 230 (2016): 261–270.

	biochar[45] for example. 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.	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.**	**Impact** EPA reports and models that improved feed conversion is an abatement measure for enteric fermentation and the release of CH_4 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.
	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[48]. However, enteric fermentation is a	**Equity** Research will need to investigate equity considerations in development and implementation of climate feed management program.
		Cost-Effectiveness The cost and cost-effectiveness of the implementation of a climate feed management strategy needs to be

[45] Drever, C Ronnie et al. "Natural Climate Solutions for Canada." *Science Advances* 7, 1 (June 2021). https://www.science.org/doi/10.1126/sciadv.abd6034.
[48] Agency of Natural Resources – Department of Environmental Conservation – Air Quality and Climate Division. "Vermont Greenhouse Gas Emissions Inventory and Forecast: 1990-2017." May 2021. https://dec.vermont.gov/sites/dec/files/aqc/climate-change/documents/_Vermont_Greenhouse_Gas_Emissions_Inventory_Update_1990-2017_Final.pdf

	natural by-product of animals and thus has limited management options and minimal reduction potential[49]. [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.	researched and considered compared to other NCS that can be applied across a farm's management area. The annual operation and maintenance costs estimated by the EPA for improved feed conversion programs range from \$25 - \$295 per head per year.[50]
	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

[49] U.S. Environmental Protection Agency. "Global Non-CO2 Greenhouse Gas Emission Projections & Mitigation: 2015-2050." https://www.epa.gov/sites/default/files/2019-09/documents/epa_non-co2_greenhouse_gases_rpt-epa430r19010.pdf

[50] U.S. Environmental Protection Agency. "Global Non-CO2 Greenhouse Gas Emission Projections & Marginal Abatement Cost Analysis: Methodology Documentation." September 2019. https://www.epa.gov/sites/default/files/2019-09/documents/nonco2_methodology_report.pdf. (S.5, P.167)