Cold Chain Optimization 2021

Efficiency Vermont R&D Project: GHG Reduction

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Introduction

PROJECT CONCEPT

The term *cold chain* comprises the processes and technologies that maintain products at cold temperatures, from harvest to retail end uses. Because agriculture is dependent on the cold chain, this Efficiency Vermont Research and Development (R&D) project has investigated two opportunities for reducing greenhouse gas emissions and improving energy and operational efficiency in that industry:

1. Optimizing cold chain emissions in dairy farm bulk tank storage
2. Reducing crop loss in diversified agriculture settings

ENVIRONMENTAL GAINS FROM BETTER COLD CHAIN ENERGY MANAGEMENT

Globally, the cold chain accounts for 11 percent of total electricity consumption.[1] Refrigeration in the food industry comprises 8 percent of that total.[2] Reducing carbon emissions from cold chain operations thus is an important objective for energy efficiency programs with a portfolio of commercial and industrial (C&I) customers that either use or are dependent on refrigeration for successful operations.

Experts expect the cold chain industry to grow at a compound annual rate of 14.8 percent between 2021 and 2028.[3] This growth is due to rising consumer demand for perishable goods, primarily dairy products, fruits and vegetables, and high-protein animal-based products.[4]

In agriculture, the cold chain begins when the product is harvested or produced, and involves the time it is stored on site, the time it is transported to and stored at a regional warehouse or distribution center, the time it is transported from that storage site to the retailer, and the time it is stored at the retailer until picked-up by the customer. For the purpose of this study, the cold chain ends once the product is delivered to the retailer at the appropriate storage temperature.

The Vermont Department of Environmental Conservation's Air Quality and Climate Division has reported that the state's agricultural sector was responsible for 16 percent of the total 2017

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[1] United Nations Industrial Development Organization, 2020. "Energy Efficient and Green Cold Chain," https://www.unido.org/our-focus-safeguarding-environment-implementation-multilateral-environmental-agreements-montreal-protocol/energy-efficient-and-green-cold-chain.

[2] Fan, Yun, Caroline de Kleuver, Sander de Leeuw, and Behzad Behdani, 2021. "Trading Off Cost, Emission, and Quality in Cold Chain Design: A Simulation Approach," *Computers & Industrial Engineering (158),* August, 107442. https://www.sciencedirect.com/science/article/pii/S0360835221003466.

[3] Grand View Research, 2021. "Cold Chain Market Size, Share & Trends Analysis Report by Type (Storage, Monitoring Components), by Equipment (Storage, Transportation), by Application (Fish, Meat & Seafood), by Packaging, and Segment Forecasts, 2021-2028. " https://www.grandviewresearch.com/industry-analysis/cold-chain-market.

[4] Markets and Markets, n.d. "Cold Chain Market by Application (Fruits & Vegetables, Dairy & Frozen Desserts, Fish, Meat & Seafood, Bakery & Confectionery), Temperature Type (Frozen, Chilled), Type (Refrigerated Transport, Refrigerated Warehousing), Region – Global Forecast to 2025." https://www.marketsandmarkets.com/Market-Reports/cold-chains-frozen-food-market-811.html.

greenhouse gas (GHG) emissions, or 1.4 million metric tons of CO_2 equivalent gases (CO_2e).[5] In the same year, transportation emissions from heavy-duty and diesel-powered vehicles accounted for 5 percent of the total GHG emissions, or 0.46 million metric tons of CO_2e.[6] The emissions sources for these values extend beyond the defined boundaries of the cold chain sector, but they give context to the significance of Vermont's agricultural industry in GHG accounting.

TWO PROJECT OPPORTUNITIES, ONE OBJECTIVE

This two-part R&D project—optimizing cold chain emissions in dairy farm bulk tank storage and reducing crop loss in diversified agriculture settings—describes and quantifies the energy efficiency and business value propositions for Efficiency Vermont cold chain projects among the state's dairy and produce farmers.

Improving cold chain processes and technologies offers financial and operations benefits for farmers and cooperatives. It also offers environmental benefits for the planet. Quantifying optimized cold chain processes can be challenging, because it considers the energy sector and the subsectors of the agriculture, transportation, and commercial industries.

The research results from this project could lead to changes in current practices, and thus directly affect the electricity consumption of equipment used in the cold chain system. Indirect effects from this research relate to lower GHG emissions from remediation of leaked refrigerants and from less use of gasoline- and diesel-powered transportation equipment associated with the cold chain system.

Dairy Farm Initiative

Milk haulers in Vermont typically pick up the contents of Vermont dairy farms' bulk storage tanks once or twice a day and bring the milk to a regional processing facility. If farms increased their on-farm milk storage capacity, they could reduce the milk pick-up frequency and benefit the farmer, the milk cooperative, the condition of local roads, and the environment. This research project investigated the energy, cost, and other business outcomes of changing the milk pick-up frequency from every day to every other day. The researchers calculated higher

[5] Vermont Department of Environmental Conservation (DEC), 2021. "Vermont Greenhouse Gas Emissions Inventory and Forecast / 1990-2017." State of Vermont, Agency of Natural Resources. . https://dec.vermont.gov/sites/dec/files/aqc/climate-change/documents/_Vermont_Greenhouse_Gas_Emissions_Inventory_Update_1990-2017_Final.pdf.

[6] Numbers are derived from the cited DEC inventory. The author used total transport / mobile emissions, 3.39 $MTCO_2e$ (p. 14), and applied the percent contribution from Table 4 (p. 17), from on-road gasoline and diesel emissions (85%) to the 3.39 $MTCO_2e$, to yield 2.88 $MTCO_2e$. Table 5 (p. 18) provided the percent contribution from heavy-duty gas, heavy-duty diesel, and light-duty diesel vehicles (16%), from which the total for heavy-duty and diesel-powered transport emissions could be derived: 0.46 $MTCO_2e$. Weighted against the 3.39 $MTCO_2e$ yields 5%.

milk storage capacity and / or refrigeration capacity, presuming the use of best-in-class milk cooling equipment.

BACKGROUND

Vermont has 124,000 milking cows on 610 dairy farms. Over the past decade, the number of dairy farms has decreased by 37 percent, whereas the total number of cows has decreased by less than 1 percent. In that same time period, the average herd size increased 30 percent, from 131 to 191 cows per farm.[7] The increased capacity on these dairy farms requires either new and expanded bulk tank storage, or more frequent milk pick-ups, to accommodate the increase in daily milk production.

Most Vermont dairy farmers are members of one of the two major cooperatives operating in Vermont: Agri-Mark Family Dairy Farms and Dairy Farmers of America (DFA). These two players are the result of co-op consolidation, too. That is, in the 1990s, Agri-Mark merged with Cabot Creamery Cooperative, and DFA merged in 2019 with St. Albans Cooperative Creamery. Agri-Mark's 133 member farms in Vermont produce approximately 78 million gallons of milk per year. DFA, which did not provide current production data, has 342 member-owners in Vermont. To inform its research and fill data gaps, the Efficiency Vermont project team has used publicly available information about the dairy industry, which represented 1.5 percent of the total state Gross Domestic Product in 2019.[8]

The dairy co-ops provide member farmers with risk management, financing, insurance, marketing, and enhanced market power services.[9] They also help the farmers bring their milk to market and negotiate a fair price. The co-ops sell some of the milk in its raw form and process much of it into butter, cheese, cream, and other value-added products. Agri-Mark has four plants in which it processes 80 percent of its members' milk: two plants are in Vermont, one is in upstate New York, and one is in central Massachusetts. DFA has production facilities throughout the United States, including five plants in New England, one of which is at the St. Albans Creamery. DFA processes 50 percent of its members' milk in regional facilities.

The co-ops coordinate the collection and transportation of their members' milk by contracting with local milk haulers. Agri-Mark has external contracts with independent milk haulers throughout Vermont, whereas DFA primarily handles operations internally, using DFA Northeast Logistics, Inc.

The structure of this industry and the interactions between these entities are important factors in evaluating the effects of reducing milk pick-up frequency.

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[7] Pieciak, Michael S., 2021. "Act No. 129 (2020) Report: Vermont Dairy Industry Price Regulation: Assessment and Recommendations." Montpelier, VT: Vermont Department of Financial Regulation, January. https://legislature.vermont.gov/assets/Legislative-Reports/Act-129-DFR-Dairy-Pricing-Report.pdf.

[8] University of Arkansas System, 2019, "Vermont Economic Contribution and Impact Research." Economic Impact of Agriculture Division of Agriculture Research & Extension, Center for Agricultural and Rural Sustainability. https://economic-impact-of-ag.uada.edu/vermont/.

[9] Pieciak, "Vermont Dairy Industry Price Regulation," 2021.

RESEARCH

The methodological approach for this dairy farm initiative considered two primary questions:

- To what extent can expanded milk storage capacity on certain dairy farms create energy efficiency and GHG reduction opportunities?
- To what extent can the energy efficiency, transportation, and other product quality and financial effects of enhanced milk storage capacity be quantified?
  - To what extent do these effects provide value for dairy farms and co-ops?

Data Collection

This research combined qualitative and quantitative information to support the evaluation of the data in responding to these questions. Efficiency Vermont collected descriptive data through interviews with the University of Vermont (UVM) Extension; Agri-Mark; DFA; the Vermont Agency of Agriculture, Food and Markets (VAAFM); and field specialists. Agri-Mark shared numerical data on monthly milk production, frequency of milk pick-ups, and existing bulk tank storage capacity on each of its member farms.

Interviews with Agri-Mark and DFA provided an overview of the co-ops' structures; engagement among the co-ops, farmers, and milk haulers; existence and use of bulk tank programs; and high-level information on milk hauling routes. UVM Extension provided a broad, independent perspective of the opportunities in the dairy and milk hauling sector, using current research and that organizations' knowledge of innovative technologies.

Parallel to but independent of Efficiency Vermont's interviews on cold chain optimization, the VAAFM, Agri-Mark, DFA, ice cream manufacturer Ben & Jerry's, and the Agency of Transportation were engaged in discussions of the feasibility and interest in a heavy-duty electric milk hauling truck pilot. Collectively, these partners offered Efficiency Vermont some context for mapping the industry infrastructure, the relationships among the entities, the balance of priorities, the barriers to change, perceived inefficiencies, and how this effort could compliment industry opportunities for optimizing on-farm milk storage capacity and milk hauling routes.

Analysis Approach

Cold chain efficiency opportunities vary by farm size, location, and milk storage capacity. In general, opportunities to optimize bulk tank storage capacity fall into one of three categories: (1) new or additional bulk tank storage, (2) additional cooling capacity, or (3) investment supporting direct tanker loading.[10]

[10] A dairy farm whose milk volume is sufficiently large to fill a refrigerated milk tanker on site can directly chill and load its product without a bulk tank. Farms for which this is an economical alternative to bulk tanks typically have 700 or more cows. Biggers, Earl D., 2011. "Considerations for direct tanker loading on dairy farms." *Progressive Dairy*. https://www.progressivedairy.com/topics/management/considerations-for-direct-tanker-loading-on-dairy-farms.

To evaluate whether strategic milk storage capacity additions can increase cold chain system efficiency for Vermont's milk industry, the research followed this general structure (with research notes in parentheses):

1. Identify the cost per mile of milk trucks driven. (This was not successful due to lack of data.)
2. Identify the farms that have milk picked up every day and evaluate each farm's current milk storage capacity against daily milk production. (Agri-Mark supplied these data; DFA did not.)
3. Map each co-op's milk hauling routes and identify the farms with daily pick-ups along these routes. Ask the co-ops, field specialists, and milk haulers where streamlining opportunities might exist. (This was partially successful based on data availability.)
4. Evaluate opportunities to optimize milk trucking schedules at individual dairy farms:
    a. Increase bulk tank size(s)
    b. Increase refrigeration system capacity
    c. Upsize bulk tank outlet sizes from 1.5 inches to 2 or 3 inches in diameter
    d. Reduce on-farm milk transfer and truck idle time
    e. Move large farms to direct loading
5. Analyze the optimized routes for financial benefits to the co-op and the farmer.
6. Collaborate with stakeholders to highlight total system benefits, both on the farm and from road savings associated with potential system changes.

Evaluation of Methods

Agri-Mark supplied detailed production data for January 2021, which could reasonably be extrapolated to a full year.[11] Given the similar market characteristics of Agri-Mark and DFA, the primary researcher assumed that data from DFA, had it supplied the same level of information, would offer similar data on farm sizes, locations, frequency of milk pick-ups, and milk storage capacities. It is worth noting that an Agri-Mark spokesperson acknowledged that it and DFA share some farmer-members in common. This research did not obtain detailed information on instances of overlap on production or hauling routes.

Agri-Mark's independently contracted milk haulers set the milk hauling routes, and these haulers can optimize their routes for efficiency, profit, convenience, and trucking capacity. The co-op determines the number of farms allocated to each hauler, the price per hundredweight of milk, and the stop charges (per pick-up) that the farmers must pay to the milk hauler. Most of the dairy farms and milk haulers have been in the industry a long time, so their routes are well established. However, it should not be assumed that those routes are consistent from week to week.

This research assumed industry standard values, in the absence of local data for milk hauling routes, destination processing plants, average stop times, driving distances between farms, carrying capacity of straight trucks and trailer trucks, fleet sizes, average truck miles per gallon,

[11] Milk production does not vary significantly from month to month, thus making the January data a valid baseline for extrapolation.

average diesel fuel cost, and bulk tank outlet sizes. Future researchers will need to confirm these values with local market data before they can derive accurate economic models.

Interviews

This research involved phone or videoconferencing interviews with 10 industry professionals, representing four major organizations. Efficiency Vermont adapted the structure of each interview to each participant. Efficiency Vermont research staff for this project—Nicole Duquette, Cathy Reynolds, and Ethan Bellavance—have strong, longstanding working relationships with all the organizations and individuals listed in Table 1.

Table 1. Details of interviews for cold chain research project, 2021

Date	Organization	Name	Title
January 6	UVM Extension	Chris Callahan	Agricultural Engineer, Extension Associate Professor
February 2	UVM Extension	Mark Cannella Tony Kitsos	Farm Business Director Farm Business Educator
February 10	Agri-Mark / Cabot	Scott Werme Jed Davis Abby Snyder	Vice President, Membership, Agri-Mark Director of Sustainability, Cabot Sustainability Programs Specialist, Cabot
February 12	DFA	David Darr Kiersten Bourgeois	Senior Vice President, Chief Strategy & Sustainability Officer Manager, Communications and Industry Affairs
May 25	Agri-Mark	Jordan Clark Bob Fradette	Manager, Member Transportation Transportation Coordinator

RESULTS

Insights from the Interviews

The interviews helped validate the original thinking for this research. The highlights and lessons from the interviews are:

- The co-ops' fee structure offers financial savings to the dairy farmers, from economies of scale, particularly regarding milk hauling.
    - It costs milk haulers to transport air, and so they seek ways to avoid losses—that is, 1 cent per 1,000 pounds of air—from driving trucks that are not full. Sometimes haulers will stop every day at farms where they can top off their tanks to run a full truck and will not charge those farmers the stop fee.
    - Milk haulers' trailer-trucks have 80,000 gallons of capacity; straight trucks are more likely to have 40,000 gallons of capacity. The straight trucks are used only in the northern part of the state where some farms are not accessible to trailers.
- Addison County has the highest density of farms in the state, near Agri-Mark's Middlebury processing plant. These routes have already been optimized.

- Farmers need to know the economic value proposition of expanding bulk tank storage, which will be unique to each farm, and derived from the farm's size, infrastructure requirements, and available cash.
- Agri-Mark has a 5-year bulk tank loan program to support the purchase of new tanks. Several years ago, it ran a bulk tank program to optimize transportation, reducing the hauling rate by 10 cents per hundredweight for three years if an expanded bulk tank was feasible and subsequently installed. Many farms took early advantage of this program, but none has used it in recent years. The interviewees did not know what efficiency opportunities might remain within the system.
- DFA runs incentive programs in which it subsidizes interest costs.
- The biggest opportunity rests with shifting pick-up schedules from daily to every other day, for farms with fewer than 200 cows; larger farms typically use direct loading or transport their own milk.
- Bigger bulk tanks require bigger physical infrastructure on site. The work requirements can involve expanding buildings and barn doors and pouring larger concrete pads.
- Newer bulk tanks have larger outlet sizes, a factor that results in time and labor savings. There appears to be little benefit to, and little interest in, expanding outlets on existing tanks.
- Benefits of expanded bulk tank storage and / or improved refrigeration capacity:
  - Reduced stop charges for farmers; Agri-Mark / Cabot stop charge structure:
    - Every-other-day pick-up: Stop charge paid to milk hauler averages $50 per day.
    - Daily pick-up: Stop charge averages $50 for Day 1, $25 for Day 2.
  - Reduced truck miles traveled for milk haulers because they are making fewer trips to the farms by going every other day.
  - Labor savings from reducing truck time on site, waiting for milk to cool in the tank before transfer to the truck, picking up warm milk, or having to dump milk.

Production Data

Agri-Mark provided the following production data:

- Number of producers
- Farm towns
- Monthly production total
- Number of stops per month
- Tank capacities

The research team processed the production data by associating each town with a ZIP Code and county, so they could map the general farm location. There are 133 Agri-Mark farms and 39 (or 29 percent) of those farms have daily pick-up. Table 2 offers a county breakdown of farms, showing the total number of farms and the frequency of their pick-ups. Addison County accounts for 44 percent of the total number of Agri-Mark farms with daily milk pick-up. Given these farms' proximity to the Middlebury plant, an energy efficiency initiative that offers incentives on opportunities outside Addison County would provide higher value.

Table 2. Characteristics of Agri-Mark farms, by county

County	Total farms	Farms with daily pick-up
Addison	22	17
Bennington	4	1
Caledonia	20	5
Chittenden	2	1
Essex	6	1
Franklin	11	3
Grand Isle	0	0
Lamoille	5	1
Orange	15	3
Orleans	16	1
Rutland	9	1
Washington	4	2
Windham	6	1
Windsor	13	2
TOTAL	133	39

There are 22 Agri-Mark farms outside Addison County that have milk picked up at least once per day. Table 3 shows the farm locations with daily milk pick-up, with the proximity to processing plants and the farms' respective drive times and distances from that plant. The researchers assumed that picked-up milk is hauled to the nearest processing plant and assumed the drive times and drive distances involve the most direct path from the farm to the plant, without stops at any other farm. Efficiency Vermont understands that these assumptions do not necessarily align with the actual routes that would be taken. Thus, the estimate of potential savings is conservative. In interviews, Agri-Mark and DFA confirmed that processing plant locations occasionally shift to accommodate fluctuating business priorities and supply and demand channels. These changes in processing plant destinations were opportunistic and did not pose a sufficient reason to alter our basic assumptions about the proximity of the processing plants to the farms.

Table 3. Agri-Mark farms with daily milk pick-up, excluding farms in Addison County

Farm	Farm county	Number of stops per month	Closest processing plant	Drive time from plant (minutes)	Distance from plant (miles)
1	Windsor	32	Cabot	87	65
2	Essex	62	Cabot	56	51
3	Orange	62	Cabot	56	51
4	Windsor	32	Middlebury	17	11
5	Orleans	31	Cabot	30	21
6	Washington	62	Cabot	21	15
7	Franklin	31	Chateaugay, NY	98	75

Farm	Farm county	Number of stops per month	Closest processing plant	Drive time from plant (minutes)	Distance from plant (miles)
8	Orange	62	Middlebury	21	15
9	Caledonia	31	Cabot	81	59
10	Caledonia	32	Cabot	24	14
11	Rutland	30	Middlebury	34	24
12	Orange	47	Middlebury	63	40
13	Chittenden	31	Middlebury	50	35
14	Bennington	31	Middlebury	88	62
15	Caledonia	31	Cabot	35	18
16	Caledonia	31	Cabot	35	18
17	Franklin	31	Chateaugay, NY	90	68
18	Lamoille	31	Cabot	49	34
19	Caledonia	31	Cabot	47	33
20	Franklin	31	Chateaugay, NY	73	57
21	Washington	32	Middlebury	50	35
22	Windham	62	Springfield, MA	76	80

The opportunity for calculating possible savings at each farm depended on the milk hauler's trucking route and the available trucking capacity, as well as the schedule of milk pick-ups, milk production, and milk storage capacities of the nearby farms that currently have every-other-day pick-up.

The researchers subsequently calculated the additional bulk tank capacity needed to move a farm from daily pick-up to an every-other-day pick up schedule. They used the two-day milk production values and subtracted the existing bulk tank capacity. Most of the farms investigated for this study have two bulk tanks, but it seemed evident that some of the farms used only one of the two tanks. This is likely reflected in the farms' data showing negative values for the additional capacity needed. Agri-Mark suggested that the negative values likely reflect the case where one of the two bulk tanks has failed, or is out of commission, and the farmer has not replaced or repaired it, thus effectively reducing the available bulk tank capacity. Learning if this is the case, via direct discussions with the farmers, would help future research determine additional needed capacity and enable a more accurate calculation of the potential energy savings opportunity. Table 4 shows the additional capacity that would be needed on each farm to provide sufficient storage for two days of milk production.

Table 4. Additional bulk tank capacity needed to store two days' worth of milk production

Farm	Farm county	Two-day production (pounds)	Additional bulk tank capacity needed (pounds)
1	Windsor	44,902	12,652
2	Essex	135,156	46,361
3	Orange	57,057	38,868
4	Windsor	91,426	35,565

Farm	Farm county	Two-day production (pounds)	Additional bulk tank capacity needed (pounds)
5	Orleans	72,542	31,434
6	Washington	168,531	98,699
7	Franklin	12,010	432
8	Orange	88,428	9,179
9	Caledonia	14,197	(12,979)
10	Caledonia	43,994	(16,206)
11	Rutland	16,007	(2,225)
12	Orange	51,510	15,390
13	Chittenden	68,928	25,240
14	Bennington	60,105	5,667
15	Caledonia	48,784	21,737
16	Caledonia	32,188	(9,177)
17	Franklin	10,429	1,977
18	Lamoille	33,525	(3,283)
19	Caledonia	129,607	40,812
20	Franklin	86,182	11,405
21	Washington	87,460	9,286
22	Windham	129,478	40,845

Opportunities for savings

The research team determined that cost savings would result from the reduction in diesel trucking fuel, milk hauler labor costs, and farm stop charges.

Fuel savings. Diesel fuel savings would accrue from reducing the number of milk hauling truck miles traveled. To estimate the time and mileage, researchers assumed that the milk hauling truck began the route at the farm and ended the route at the nearest processing facility, taking the shortest distance between the two locations, without stopping at any other farms. Using information from Agri-Mark about the fuel economy of straight trucks versus trailers, and empty trucks versus full trucks, Efficiency Vermont applied an average of 6.5 miles per gallon of fuel to the analysis. Using a cost of $3.00 per gallon for diesel fuel, researchers then calculated the fuel cost savings in dollars per year.

Labor savings. Labor savings would accrue from milk haulers' spending less time on the road and at each farm. The time spent on the farm includes testing the milk[12] and transferring it from the bulk tanks to the trucks. With input from Agri-Mark, Efficiency Vermont assumed that the milk hauler's average labor rate is $50 per hour, with an average 1-hour stop time at each farm. The labor cost savings associated with the hourly rate accrue to the dairy cooperative.

Reductions in stop fees. There is also a flat rate per stop, paid directly by the farmer to the milk hauler. The stop fees are set by the cooperative and vary geographically from $44-$50 per stop.

[12] Tests can involve ensuring cold milk temperature, absence of spoilage, and presence of antibiotics or other contaminants.

Farms near Middlebury averaged $44 per stop; remote farms in the northern and southern regions of the state averaged $50 per stop.

Carbon savings. The research team based carbon savings calculations from reduced diesel fuel consumption on an average fuel efficiency of 6.5 miles per gallon for the milk hauling trucks, an industry standard value. The team then converted the reduced number of truck miles traveled per year to annual gallons of diesel fuel saved per farm. The team multiplied the resulting fuel savings by the carbon dioxide equivalent emissions factor for diesel fuel, as published by the U.S. Energy Information Administration.

The value of all four types of potential savings. Table 5 shows Efficiency Vermont's calculated cost and carbon savings opportunity at each farm, with each assessed for lower fuel and labor costs accruing from the changes in milk pick-up frequency.

The researchers estimated the annual average cost savings per farm to be $29,800. The total cost savings that could be realized, if all 22 farms moved pick-up from every day to every other day, is over $655,000 per year. When converted to carbon savings, the average reduction of greenhouse gases is 11 metric tons (MT) of CO_2e per farm per year, with the total potential being over 250 metric tons (MT) of CO_2e across all 22 farms per year.

Table 5. Cost and carbon savings by farm, assuming a change in milk pick-up to an every-other-day cycle

Farm	Farm county	Diesel fuel savings (gal / year)	Labor savings (hrs / year)	Fuel cost savings ($ / year)	Labor cost savings ($ / year)	Stop fee savings ($ / year)	Total cost savings ($ / year)	CO_2e savings (MT CO_2e / year)
1	Windsor	1,825	447	$5,475	$22,356	$9,125	$36,956	19
2	Essex	1,432	353	$4,296	$17,642	$9,125	$31,062	15
3	Orange	1,432	353	$4,296	$17,642	$9,125	$31,062	15
4	Windsor	309	234	$927	$11,710	$9,125	$21,762	3
5	Orleans	590	274	$1,769	$13,688	$9,125	$24,581	6
6	Washington	421	246	$1,263	$12,319	$9,125	$22,707	4
7	Franklin	2,106	481	$6,317	$24,029	$9,125	$39,471	21
8	Orange	421	246	$1,263	$12,319	$9,125	$22,707	4
9	Caledonia	1,657	429	$4,970	$21,444	$9,125	$35,538	17
10	Caledonia	393	256	$1,179	$12,775	$9,125	$23,079	4
11	Rutland	674	286	$2,022	$14,296	$9,125	$25,442	7
12	Orange	1,123	374	$3,369	$18,706	$9,125	$31,200	11
13	Chittenden	983	335	$2,948	$16,729	$9,125	$28,802	10
14	Bennington	1,741	450	$5,222	$22,508	$9,125	$36,856	18
15	Caledonia	505	289	$1,516	$14,448	$9,125	$25,089	5
16	Caledonia	505	289	$1,516	$14,448	$9,125	$25,089	5
17	Franklin	1,909	456	$5,728	$22,813	$9,125	$37,665	19
18	Lamoille	955	332	$2,864	$16,577	$9,125	$28,566	10
19	Caledonia	927	325	$2,780	$16,273	$9,125	$28,178	9
20	Franklin	1,600	405	$4,801	$20,227	$9,125	$34,153	16
21	Washington	983	335	$2,948	$16,729	$9,125	$28,802	10

Farm	Farm county	Diesel fuel savings (gal / year)	Labor savings (hrs / year)	Fuel cost savings ($ / year)	Labor cost savings ($ / year)	Stop fee savings ($ / year)	Total cost savings ($ / year)	CO_2e savings (MT CO_2e / year)
22	Windham	2,246	414	$6,738	$20,683	$9,125	$36,547	23
Average savings				$3,373	$17,289	$9,125	$29,787	11
Total savings				$74,207	$380,360	$200,750	$655,318	252

Efficiency Vermont shared these results with Agri-Mark, and its leaders were in general agreement with the savings numbers. At Efficiency Vermont's request, Agri-Mark helped establish a line of communication to their field representatives to identify viable opportunities. The field reps are specialists who work directly with the farmers to give the farmers a voice and to provide on-site technical, logistical, and financial expertise. The Agri-Mark field reps subsequently presented two opportunities to Efficiency Vermont.

Efficiency Vermont does not know whether the milk haulers are willing to share hauling information; ultimately, these data will be critical for quantifying the energy efficiency and GHG savings.

Opportunities

Treadway Dairy

The first identified opportunity for greater operational efficiency and subsequent reductions in GHG from changes to milk hauling practices was with Treadway Dairy. Efficiency Vermont visited Brian Treadway at his farm in Shoreham on August 3, 2021. Treadway Dairy is a farm in Addison County that has 160 Holstein cows producing approximately 13,000 pounds of milk per day. The cows are milked twice a day, producing approximately 6,500 pounds per milking. The hauler picks up the milk every day, and Treadway pays a stop charge of $48 per day. The farm currently has one 1,600-gallon bulk tank (with a load capacity of 13,200 pounds of milk) that cools and stores the milk. The farm used to have a second tank that could hold about 800 gallons (7,000 pounds) of milk, but it is no longer in use because it is old and in need of repairs. Treadway wanted to double the capacity of his existing storage by purchasing a second 1,600-gallon tank. The second tank would allow him to have his milk picked up every other day. The proposed tank comes with a compressor to cool the milk, but Treadway preferred to have some operational redundancy. He therefore decided to purchase a second condensing unit for the new bulk tank. His existing tank has two condensing units with fully interlocked condenser fans. These provide some redundancy and allow the systems to run at lower head pressures.

The current infrastructure of the barn and the proposed location of the new bulk tank did not necessitate any modifications to the barn. At the time of Efficiency Vermont's visit, Treadway had not yet received a quotation for the project's cost, but he estimated that the new equipment, including the bulk tank and secondary condensing unit, would cost approximately $20,000, installed.

Looking at the direct cost savings to the farmer, the Efficiency Vermont researchers calculated the project's simple payback in terms of total project cost, divided by the savings from the reduced stop charges, paid every other day. The other cost savings rolled up to the milk hauler and to the dairy co-op. Although some of these savings might trickle down to the farmer, direct savings cannot be determined from these data.

The researchers found other opportunities for energy and operational efficiency at the farm during the site visit—opportunities that would offer direct savings for the farmer: expanding the milking parlor, installing an automatic feed pusher, and moving the bulk tank condensing units from inside to outside. Although Efficiency Vermont did not investigate the costs for these additional projects, the researchers estimated that the energy savings—or in other words, energy not used—from these measures could result in an additional 19 megawatt-hours (MWh) and 156 million British thermal units (MMBtu) per year. Applying average electricity and fuel rates, the research team determined that the direct cost savings from these projects to the farmer would be approximately $24,600 per year.

The economics shown in Table 6 reflect the energy and cost savings from installing a new bulk tank and moving the farm from daily pick-up to a pick-up schedule of every other day. This table does not reflect the estimated savings from the additional efficiency opportunities determined during the site visit.

Table 6: Treadway Farm project savings and economics from changing milk-hauling practices to an every-other-day pick-up schedule and adding one 1,600-gallon bulk tank

Benchmark	Metric
Milk production, in pounds per month	389,578
Milk hauler stops per month	31
Closest plant	Middlebury
Drive time to the plant, in minutes	20
Distance from the plant, in miles	11
2 days of milk production, in pounds	25,134
Capacity of Tank 1, in pounds of milk	13,244
Extra bulk tank capacity needed for 2 days of production, in pounds	11,890
Mileage savings per year	2,008
Diesel fuel savings, in gallons per year	309
Labor hour savings per year	243
Fuel cost savings per year (to milk hauler)	$927
Labor cost savings per year (to cooperative)	$12,167
Stop charge savings per year (to farmer)	$8,760
Total cost savings per year	$21,853
CO_2e savings, in MT CO_2e per year	3.2
Estimated project cost	$20,000
Direct cost savings to farmer (stop charge savings)	$8,760
Project simple payback, in years	2.3

Lucas Dairy / Lucas Family Farms

Efficiency Vermont visited Jon Lucas at his farm in Orwell (in Addison County) on August 25, 2021. Lucas Dairy has 280 Holstein cows producing approximately 22,700 pounds of milk per day. The milk is picked up every day, at $48 per pick-up. Currently, the farm has one 3,000-gallon bulk tank in operation, with a load capacity of 25,800 pounds. Like Treadway, Lucas had a second, smaller tank, but it had an internal leak in the refrigerant line and was not in use. Lucas also wanted to double his current capacity by purchasing a second 3,000-gallon tank. For that tank, he would need to purchase two new condensing units to handle the cooling loads. To make space for the larger tank, Lucas would need to expand the milking barn by bumping out one of the walls near the proposed bulk tank location. At the time of this report, Lucas had not yet received quotations for the work, but estimated the cost of these upgrades at $45,000—that is, for the bulk tank, two condensing units, infrastructure changes, and installation. In terms of stop charge savings only, the main opportunity for savings to the Lucas Dairy, the research team estimated the proposed project had a 5.1-year payback period.

The research team also considered other opportunities during its site visit to Lucas Dairy: moving the condensing units outside, installing compressor heat recovery for wash water preheat, and replacing the existing soft copper piping (soldered joints) with ACR copper, which is designated for air conditioning and refrigeration conditions and whose joints are brazed for greater reliability. These upgrades would have direct cost savings for the farmer by reducing the electricity, fuel, and refrigerant leaks associated with operating this equipment. Although Efficiency Vermont did not determine the cost of these additional projects, the team estimated that the extra measures, if installed, would save an additional 24 MWh, 72 MMBtu, and $5,000 per year.

The economics shown in Table 7 reflect the energy and cost savings from installing a new bulk tank and moving the farm from daily pick-up to a pick-up every other day. The project costs for these additional efficiency opportunities are unknown, so the additional savings from these opportunities are not included in this analysis.

Table 7. Lucas Family Farms project savings and economics from changing milk hauling practices to an every-other-day pick-up schedule and adding one 1,600-gallon bulk tank

Benchmark	Metric
Milk production, in pounds per month	389,578
Milk hauler stops per month	31
Closest plant	Middlebury
Drive time to the plant, in minutes	30
Miles from the plant	20
2 days of milk production, in pounds	45,316
Capacity of Tank 1, in pounds of milk	24,800
Extra bulk tank capacity needed for 2 days of production, in pounds	19,516
Mileage savings per year	3,650
Diesel fuel savings, in gallons per year	562
Labor hour savings per year	274
Fuel cost savings per year (to milk hauler)	$1,685
Labor cost savings per year (to cooperative)	$13,688

Stop charge savings per year (to farmer)	$8,760
Total cost savings per year	$24,132
CO_2e savings, in MT CO_2e per year	5.7
Estimated project cost	$45,000
Direct cost savings to farmer (stop charge savings)	$8,760
Project simple payback, in years	5.1

Opportunities for both farms

Although the additional efficiency opportunities for Lucas Dairy's and Treadway Dairy's investments are indirectly tied to the proposed bulk tank expansions, they could achieve energy and carbon reduction goals that are aligned with Efficiency Vermont's objectives and key initiatives (OKIs). Creating a pathway to supporting a farmer's decision to pursue these projects would strengthen the findings of this R&D project and provide Efficiency Vermont with a better understanding of Vermont's agricultural market.

DISCUSSION & NEXT STEPS

Savings and Opportunities for Efficiency Vermont

Looking at milk storage holistically can help quantify three other benefits:

- Benefits to the farm in reduced pick-up fees
- Benefits to the dairy cooperative in reduced transportation costs
- Benefits to Efficiency Vermont in finding ways to help customers and promote energy and non-energy GHG reduction (refrigeration leak repair and transportation savings)

This initiative has promoted Efficiency Vermont OKIs related to reducing GHG emissions, delivering greater customer experience through collaboration with state and local organizations, and evolving its services to advance geographic and social equity in service to customers across the state. Efficiency Vermont recognizes that it must try new ways to communicate such benefits to its dairy producer customers, so that these valuable energy efficiency projects are more attractive to them.

This type of project has uncovered possible added value from the opportunities identified by Efficiency Vermont staff when they have been on site at dairies. Thus, regulators and Efficiency Vermont might consider an opportunity to claim diesel savings through a total resource benefits (TRB) calculation.

Quantifying energy savings and carbon reduction opportunities through improvements in milk storage, between farm and processing plant, directly contributes to the metrics related to statewide GHG reduction targets. That is, improving milk cooling equipment at the farm, increasing a farm's milk storage capacity, and advancing complementary technologies will all result in electric energy savings. However, reducing the number of truck miles traveled, the time trucks spend idling during pick-up, and the number of stops at individual farms each month will result in GHG savings. New, enhanced bulk tanks present an opportunity for dairy producers to install high-efficiency condensing units to:

- More efficiently serve the cooling load
- Increase the bulk tank outlet size (to decrease the time it takes to transfer the milk from the bulk tank to the hauling truck)
- Move the farmer’s milk pick-up frequency from every day to every other day

New and upgraded bulk tanks are likely to use refrigerants that have a lower GWP than older equipment, effectively reducing the potential carbon impacts of leaked refrigerants.

Through this initiative, Efficiency Vermont has increased its collaboration with the UVM Extension and the VAAFM. The team has also cultivated new opportunities for supporting dairy farmers. Historically, the dairy sector has been underserved among Efficiency Vermont’s markets, relative to the potential, and this R&D pilot has provided a platform for engaging with the farmers and cooperatives at a deeper level.

Next Steps

The initial research shows that expanding the bulk tank capacity on these farms to allow storage of a larger quantity of milk can effectively reduce the frequency of milk pick-ups at each farm. In addition, each farm is likely to present more opportunities for savings in terms of energy efficiency, emissions reductions, and operational costs. More efficient milk cooling systems will allow the milk to cool faster and thus reduce the amount of time that the haulers might have to spend on site, waiting for the milk temperature to drop to safe levels for transporting to the processing plant. Because the opportunities available and appropriate to each producer will vary, each proposed project should be evaluated separately, with individual potential benefits to the program and the customer quantified.

To quantify the electric energy savings accurately, Efficiency Vermont would need to collect information on the size of the existing and proposed bulk tanks, the condensing unit configurations and model numbers, and the number of milkings and pounds of milk produced per day. Because the purpose of this study was to obtain information and not claim savings from the project, the researchers did not obtain those data for this study. However, Efficiency Vermont already supports and can quantify the benefits from the following relevant efficiency measures that constituted the additional opportunities the researchers observed for this study’s participating farms:

- Moving the condensing unit outside
- Installing high efficiency scroll compressors
- Installing multiple smaller compressors for capacity staging
- Installing modulating condenser fan motors and controls
- Installing floating head pressure controls.

Other opportunities for savings to customers, energy savings, and GHG reductions

Other significant measures can add quantifiable value to a comprehensive cold chain program, if one were to be put in place at Efficiency Vermont. Plate coolers, which are well water heater exchangers that use cold well water to pre-cool milk, can further reduce milk cooling energy requirements by reducing water heating energy requirements. This technology helps Efficiency Vermont and the farmer accrue fuel savings. Efficiency Vermont will quantify these benefits with its approved analysis tools. Participating farms would need to provide information only about the bulk tank size, hot water wash temperatures, and wash sink sanitizing cycles.

As this report has already mentioned, GHG savings will result from reducing the amount of diesel fuel consumed by the milk hauling trucks via fewer miles traveled in a year, and less time spent idling at each stop. In addition, by reducing the number of stops workers will spend fewer hours traveling to each site.

Although the groundwork has been laid for a well-informed, comprehensive cold chain program for Efficiency Vermont, the researchers recognize the need for a few more points of information.

First, it will be important to talk to the milk haulers, to understand their exact truck hauling routes, hauling distances, truck types used for collection, specific farm locations along routes, milk pick-up times, and their contract structures and fees. This and other related information will be essential in fully estimating the several types of savings from a program, while also balancing the priorities of the milk haulers.

VAAFM's recent advocacy of heavy-duty electric vehicles (EVs) is well aligned with the dairy market's participation in this cold chain R&D project. Agri-Mark, DFA, Cabot, and Ben & Jerry's have already begun talking to VAAFM, which invited Efficiency Vermont to their kick-off meeting. That meeting articulated a general awareness of the importance and future potential of moving milk hauling trucks toward electrification. The participants also recognized that the technology and equipment are not yet sufficiently in the market for rapid adoption.

Recommendations

Promoting heavy-duty EVs for dairy. Efficiency Vermont, with its partners and stakeholders, should continue to explore heavy-duty EVs as a future incentive opportunity in this sector. EVs are an appropriate complement to the optimization of diesel-truck milk hauling routes—while also supporting the economic and environmental interests of the State, the dairy industry, and Efficiency Vermont.

Balancing heavy-duty EV use and diesel truck use. Efficiency Vermont believes that heavy-duty EVs will likely be optimized for shorter routes (for example, within Addison County), and diesel trucks are likely to continue to be the preferred option for longer hauls (in the northern and southern regions, for example). Engagement with state agencies, policymakers, and dairy industry stakeholders is something that Efficiency Vermont should continue to pursue and promote in the coming years.

Ongoing Efficiency Vermont support for the dairy sector. In 2022, Efficiency Vermont will continue to work with Agri-Mark and DFA to create energy-saving and GHG-reducing opportunities that support cooperatives, farmers, and milk haulers. Efficiency Vermont will coordinate and perform site visits, identify appropriate measures for projects, and evaluate proposed project savings and economics, customized for each farm.

An additional objective of this support will be to expand relationships and build trust with the milk haulers. It is important for Efficiency Vermont to promote their interests and business priorities as it designs cold chain programs to support the optimization of on-farm milk storage. The Cold Chain Optimization R&D project has uncovered this under-explored feature of what could become a well-organized and supported, valuable initiative.

Diversified Agriculture Initiative

Hundreds of small agriculture farms cultivate perishable crops that require appropriate temperature and humidity control, post-harvest, before they reach the market. Without proper cold chain infrastructure to support the washing, processing, and storing of these products, the product quality can quickly degrade and thus reduce farmers' profits.

What is the extent of Vermont's crop loss in diversified agriculture? Where are those products lost along the food supply chain? And how could cold chain improvements extend product life and quality?

After researching on-site post-harvest production processes, Efficiency Vermont has created a foundational structure that outlines the existing post-harvest cold chain infrastructure and the proposed benefits of improving the efficiency of this equipment. To successfully implement a cold chain calculator or toolkit to help farmers, cooperatives, and distribution partners improve the efficiency of refrigeration equipment, additional research is needed.

The initiative that became part of the Cold Chain Optimization R&D project at Efficiency Vermont has investigated the extent of food loss from this agriculture subsector and offers solutions through appropriate management of energy-efficient cold chain technologies.

BACKGROUND

Not all crops grown for human consumption are consumed. According to the Food and Agriculture Organization of the United Nations, approximately 1.3 billion tons of food are lost or wasted each year. On a global scale, this represents one-third of all the food that is grown.[13] The global food supply chain is a complex system that involves coordination of many entities, sectors, and resources. Food is lost for many reasons, and food loss occurs at many different

[13] Food and Agriculture Organization of the United Nations, 2022. "Food Loss and Waste Facts." https://www.fao.org/resources/infographics/infographics-details/en/c/317265/.

points along this chain. In Vermont, an estimated 16 percent of all fruits and vegetables grown in the state and coming from the diversified agriculture sector is lost.[14]

It is important to understand the difference between food loss and food waste, even though they collectively refer to produced food the consumer does not use.

- *Food loss* refers to crops that are damaged in the field—by animals, insects, disease, or weather—and to crops that are damaged in storage or during transportation. For this latter category, inadequate refrigeration or improper handling are likely in play.
- *Food waste* refers to produce that is blemished and cannot be sold, food whose sell-by dates have expired prior to being sold or consumed, and food that is thrown away at the retail or consumer level.

Efficiency Vermont researchers have considered both food loss and food waste for this study, given that both occur in the pre-retail stage of the food supply chain. For ease of understanding, the researchers are collectively referring to them as *crop losses.*

This portion of the Cold Chain Optimization R&D project involves diversified agriculture farms that are primarily growing food for human consumption. This report uses the terms *crop* and *food* interchangeably. The project involved farms that are predominantly growing fruits and / or vegetables. Collectively, the report refers to these consumables as *produce*.

Farms in Vermont—whether for livestock, poultry, or crops—generated a market value of $781 million in 2015. Crops, in this context, included fruits and vegetables, as well as grains, nursery plantings, cultivated trees, hay, and other items. Within this category, fruits and vegetables comprised 5.6 percent of the total annual sales, or about $44 million.[15] In total, Vermont has an estimated 6,800 farms in operation. Of those, farms specializing in fruits and vegetables make up 10.4 percent, or approximately 700 farms.[16]

Mitigating fruit and vegetable loss on farms is especially challenging because these foods are highly perishable. Temperature and humidity control are two of the most important factors affecting the quality and market value of these products. Cold chain infrastructure preserves these products throughout the supply chain, especially in the context of in-field harvest, washing, processing, storage, transport, and distribution. The initiative on which this R&D project was based has sought to understand the equipment and systems that contribute to improved product quality and longevity at those points along the supply chain.

Gathering consistent and reliable data to estimate crop losses is ongoing. This industry is characterized by highly diverse crops, across multiple regions and growing seasons, from growers, producers, and distributors. For this reason, Vermont's potential energy, cost, and

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[14] Snow, Theresa, and Elana Dean, 2016. "Food Loss in Vermont: Estimating Annual Vegetable & Berry Loss." Morrisville, Vermont: Salvation Farms. https://salvationfarms.org/VT_Food_Loss_Study_2016.pdf.
[15] "State Profile: Vermont," 2017. Census of Agriculture. Washington, DC: USDA National Agricultural Statistics Service. https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/County_Profiles/Vermont/cp99050.pdf.
[16] "Farm to Plate 2019 Annual Report," 2019. Montpelier, Vermont: Vermont Sustainable Jobs Fund. https://www.vtfarmtoplate.com/assets/resource/files/VT-Farm-to-Plate-Annual-Report-2019_Interactive.pdf.

carbon savings from crop losses have not been adequately studied. This project has sought to quantify reductions specifically in food waste by improving on-farm refrigeration and cold chain processing systems.

RESEARCH

The two purposes of this project were to identify the extent to which farms need to reduce food waste and to evaluate whether there is a business proposition for harvesting and storing additional food.

Research Question

The primary research question this project has sought to answer is:

- To what extent can food waste economics be used to justify cost-effective investments in new or enhanced refrigeration systems on small / seasonal produce farms?

Data Collection

This research collected and analyzed qualitative data to support evaluation for and response to the research question. Researchers collected descriptive data through interviews with UVM Extension, Salvation Farms, and individual farms. The research was intended to help identify the energy and GHG opportunities for the agricultural industry and evaluate whether there was a value proposition for farms.

The initial conversations with UVM Extension and Salvation Farms provided context for the interviews with farmers. Those organizations' collective experience, technical knowledge, and level of engagement within the agriculture industry provided the foundational knowledge to guide this part of the project. Salvation Farms had already published and shared quantifiable data regarding Vermont crop losses on farms in a report, but no one had previously studied the connection to the potential for reducing those losses.

The research team therefore sought to identify and quantify energy efficiency opportunities, resource availability, and economic drivers that would support actions to reduce crop losses. It was clear that energy efficiency measures, if farmers chose to adopt them, would need to be scoped and installed individually to each farm. The analysis would consider the type of crops harvested, available labor, current infrastructure, operational practices, and market distribution support.

The researchers strove to collect relevant information from structured interviews with the individual farms. The research team sought information on the types of crops they grew, what the existing cold chain infrastructure was, the farmers' perceptions regarding crop losses and whether the farm tracked this information, and the opportunities for improving operational and energy efficiency. The team used the qualitative data from these conversations to evaluate whether the benefits of efficiency improvements would be sufficiently cost-effective to the farmers in reducing their crop losses.

The research evaluated several types of refrigeration technologies, ranging from CoolBot systems for the smallest growers to vacuum cooling systems for the largest ones. The researchers have assumed that Efficiency Vermont's existing technical and financial assistance programs could be used to support appropriate energy-efficient equipment that helped to increase crop volume and the resilience of the state's cold chain.

Analysis

To evaluate whether strategic refrigeration and process equipment upgrades can increase product quality and retention on farms, the research team followed this general outline:

1. Understand whether there is a perceived need to reduce food waste on farms
    - Technical or social drivers
    - Refrigeration systems used for harvesting, washing, processing, storing, or transporting products
    - Infrastructure, cost, program, or market barriers
    - Why the crops are lost
    - Is there a benefit to farms?
    - What is needed to help producers understand their options?
2. Create a calculator that highlights the value of lost product and identifies energy use and farm product savings potential, available to farmers and the Efficiency Vermont small and medium-sized businesses team. This calculator should account for:
    - The cost of crop losses—in terms of environmental, social, and economic costs
    - The market value of the lost crops
    - The benefits and detriments for farms to harvest the potential crops
        - Evaluate potential TRB savings: water conservation, soil health, carbon sequestration, etc.
    - The barriers to reducing the losses
    - Can the financial benefits of reducing crop losses justify cost-effective investments in new or enhanced refrigeration systems?
3. Identify and quantify project economics and total energy impacts of refrigerated storage options to help farms reduce crop losses
    - Refrigeration systems—consider traditional or hybrid systems, temporary or permanent installation, owned or leased equipment, temperature, insulation requirements, controllability. This might involve pricing and impacts of refrigeration technologies such as CoolBot, controlled walk-in refrigeration units, storage pallets using phase change materials (PCM), cold plate or insulation box storage solutions, and vacuum refrigeration systems.

Interviews

Efficiency Vermont conducted interviews with three industry professionals and six farm organizations. Salvation Farms recommended the farms for their industry expertise, their willingness to converse and share information, and their interest in moving the industry toward sustainability practices.

Table 8 presents this project's scope of interviews.

Table 8. Diversified agriculture interviews

2021 date	Organization / farm	Interviewee	Title
January 6	UVM Extension	Chris Callahan	Agricultural Engineer, Extension Associate Professor
February 12	Salvation Farms	Theresa Snow	Executive Director
February 19	Mighty Food Farm	Lisa MacDougall	Owner/Farmer
February 26	Jericho Settlers Farm	Christa Alexander	Owner/Farmer
March 5	Dog River Farm	George Gross	Owner/Farmer
March 8	Foote Brook Farm	Tony Lehouillier	Owner/Farmer
March 11	Intervale Community Farm	Andy Jones	Farm Manager
March 18	Intervale Center	Sam Smith	Farm Business Director
April 28	UVM Extension, Center for Sustainable Agriculture	Eric Garza	Lecturer, Rubenstein School

RESULTS

Crop losses exist all along the food supply chain. Many factors influence growers' and distributors' decisions regarding these losses. These typically involve product quality, marketability, price volatility, labor cost and availability, refrigeration infrastructure, and transportation and distribution access.

Each action taken to reduce crop losses comes at an additional cost that farmers must weigh against the market value of the product. These costs involve environmental, social, and economic factors. Direct costs to the farmers and distributors are time, labor, energy, water, packaging materials, and transportation costs.

Cold chain infrastructure supports the removal of field heat at the time of harvest; cold-water washing and crash-cooling of products before they are packed and stored; and refrigeration systems for storage, transportation, and distribution. The equipment that serves these functions varies by farm type and size, crop type being grown, and product shelf life. The specific equipment that researchers evaluated as part of this project were direct expansion (DX) refrigeration systems, CoolBot control technologies, ice machines, vacuum-cooling and washing systems, walk-in cooler construction, and refrigerated transport vehicles.

Insights from the Interviews

The interviews with UVM Extension, Salvation Farms, and individual farms resulted in the following observations and insights.

- Farmers assume some crop loss is inevitable.
    - Most farms do not have accurate or consistent records for tracking and measuring crop loss, making it difficult to quantify the effects of those losses.
- Significant amounts of labor and resources go into harvesting and washing produce.
    - Lack of time and lack of available labor are the biggest contributors to food being left in the field or not being moved into storage in a timely way.

- The value proposition for the farmer to harvest and wash more produce is specific to each farm and to the type and quantity of crop being harvested.
- A large percentage of product lost is because it is not sufficiently economical for the farms to sell lower-quality products. Farmers want and need to know they will be able to sell the product at full price; otherwise, it is more economical to leave it in the field.
    - When left in the field, farmers mainly turn the crops back into the soil
- There is a win-win opportunity at the confluence of refrigeration system efficiency and food safety, which could help reduce waste.
    - When farmers lose product from infrastructure failures, it is primarily because the farms do not have enough storage with the proper temperature and humidity levels, not because the refrigeration systems are deficient.
    - More refrigeration doesn't necessarily change the condition of the crop; some loss is unavoidable, because of natural and environmental factors.
    - Farms use CoolBot controls and traditional direct expansion (DX) refrigeration systems[17] for product storage. CoolBots are good for long-term storage where stable product temperatures are maintained but are inadequate for pull-down temperature applications, where heat needs to be removed from products over a short time span.[18] Farms would largely prefer to use DX systems, but they are expensive to install. Most farms do not operate their coolers all 12 months of the year, which makes the economics of the DX systems harder to justify.
    - Improved humidity control during product storage provides the greatest opportunity for increased food preservation, quality, and safety.
    - Vacuum cooling, hydro cooling, and forced air cooling, which remove field heat more quickly from products, provide the greatest opportunities for increased product longevity.
    - Carbon calculators can be used to help farmers understand cost and resource allocation against total yield to help better track crop losses. These calculations exist, but they are prohibitively complex for farmers to apply effectively.
    - The following technologies require additional research or testing for appropriate application:
        - High humidity evaporators
        - Digital thermostats
        - Dual-suction head systems
        - Distributed storage systems for surplus production

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[17] "In DX cooling equipment, a refrigerant coil is placed directly in the supply air stream. As the refrigerant evaporates and expands, it removes energy, lowering the temperature of the supply air stream." "Cooling Equipment Type," n.d. Energy Code Richland, Washington: Pacific Northwest National Laboratory, https://energycode.pnl.gov/COMcheckWeb/robohelp/Cooling_Equipment_Type.htm.

[18] Pull-down temperature application refers to a "commercial refrigerator with doors that, when fully loaded with 12 ounce beverage cans at 90 degrees F, can cool those beverages to an average stable temperature of 38 degrees F in 12 hours or less." 42 United States Code, § 6311(9). https://www.law.cornell.edu/definitions/uscode.php?width=840&height=800&iframe=true&def_id=42-USC-1431166546-1218270378&term_occur=999&term_src=title:42:chapter:77:subchapter:III:part:A%E2%80%931:section:6311#:~:text=(D)%20The%20term%20%E2%80%9Cpull,in%2012%20hours%20or%20less.

    - Vacuum cooling
- Supply chain supports to identify and connect farmers to markets are needed to make the financial model work Farmers need to know they will be able to sell the harvested crops and turn a profit; otherwise, it's more economical to leave the crops in the field
- Gleaning and charitable organizations help to reduce crop losses, but there are not enough of them when they are needed. Farm surplus management programs are needed to aggregate surplus product, for charity and for institutional meals (schools and prisons) and explore opportunities to incentivize farmers to donate food that would otherwise be lost.
    - There is an opportunity to establish markets for blemished or misshapen produce and value-added products. This would help to bridge the gap for the farmer between turning a full profit or donating the produce.
    - Programs can consider dehydrated or canned foods as an additional alternative to frozen foods, which have a high process energy intensity.
- At present, there is no Vermont-specific data on soil carbon sequestration and its applicable benefits, however UVM Extension is currently assessing this potential.

Food Waste Data

Theresa Snow and Elana Dean's *Food Loss in Vermont* report[19] provided essential Vermont-specific data on estimated annual vegetable and berry loss. Their report counts crop loss in terms of crops that are considered edible, but left unpicked in the field, and crops that are harvested but neither sold nor donated.

According to the report, of the 88.8 million pounds of edible produce grown in Vermont each year, an estimated 14.3 million pounds of produce are lost. which is approximately 16 percent of the total yield.

The lost produce comprises two categories. A total of 4.6 million pounds of produce is lost in the field (5 percent of the total grown), and 9.7 million pounds of harvested produce are neither purchased nor donated (11 percent of total grown).

Together, the Vermont Gleaning Collective and the Vermont Foodbank Gleaning Program picked up 0.62 million pounds of produce in 2015. Although this amount represents less than 5 percent of the total food lost, it demonstrates that there is a significant opportunity to decrease food waste through increased support for gleaning programs.[20]

Carbon Accounting Course

As part of this initiative, Efficiency Vermont researcher Nicole Duquette enrolled in and completed a carbon accounting course offered by the GHG Management Institute – a U.S. nonprofit that addresses climate change through education. The course covered GHG accounting principles; organizational and operational boundaries for creating GHG inventories;

[19] Snow and Dean, "Food Loss in Vermont." 2016.
[20] (Snow, 2016)

and the tracking, calculating, reporting, and management of GHG emissions and sources. The course has given Efficiency Vermont a perspective into quantifying carbon within the specific boundaries of an industry or organization.

Direct farming activity accounts for approximately 13 to 15 percent of global GHG emissions, but accurately quantifying local effects from direct farming is difficult. Estimating CO_2e emissions for specific agricultural operations and supply chains is challenging because of the high number of variables to be considered, and how they change by geographic area. The more a model can contain assumptions, inputs, and tracked data, the more useful those models can be. This undertaking can be especially challenging for small, independent farms that do not have protocols for maintaining accurate or consistent records.

Nevertheless, many valid and reliable carbon calculators are available. Among them is COMET-Farm, which calculates carbon trade-offs based on externally derived shifts between fuel or electricity sources. That tool uses a localized grid profile and U.S. Environmental Protection Agency standards for the fuels. Other relevant calculators are the Farm Carbon Toolkit, Agricultural Resource Efficiency Calculator (Agrecalc), and Unified Livestock Industry and Crop Emissions Estimation System (ULICEES). Each has its own attributes for specific farm uses, but few Vermont farms have been motivated to purchase them.

NEXT STEPS

The diversified-agriculture segment of this R&D project could benefit from further research. The Efficiency Vermont research team identified a need to change farmer and policy maker perceptions of crop loss and expand the industry's understanding and acceptance of how and why food is wasted.

The collected data indicate there is no widespread perceived need to reduce food waste on farms. Estimates about crop losses show that a significant opportunity exists for efficiencies that would lower both detriments to a farm's bottom line provided that the demand for the lost crops is realized in the market.

The research team has further noted the importance of recognizing the broader, more compelling connection between carbon emissions and food systems—with energy use associated with the cold chain as a significant factor. Food is relatively cheap because it externalizes many of the resources and carbon emissions associated with these agricultural industries. Strategies for carbon reduction and better accounting require the internalization of resources. They also require policy, regulations, and programs to support an integrated model for more effective agricultural energy use. These requirements present an opportunity to look more holistically at making food systems more operationally efficient and to expand the area of influence to include energy sources, water conservation, soil health, nutrient application, and transportation fuels.

It is the research team's opinion that Vermont must find new ways to help farms stay in business, by implementing more sustainable practices and designing programs that support investments in agricultural infrastructure. Efficiency Vermont is in an excellent position to explore opportunities that support the shift to lower-carbon crops, regenerative agriculture, precision agriculture tools, no-till farming, and/or a shortened supply chain. Regenerative agriculture, which is a conservation and rehabilitation approach to food and farming systems, is more labor intensive than it is mechanically intensive, so it relies on farms' ability to find and retain labor. This labor market is already struggling in Vermont. However, finding ways to strengthen workforce development programs, to advertise job opportunities, and to bring more labor-ready people into the state could support this objective. Helping farmers create their own brands and their ability to do more direct marketing—in the context of supporting cold chain objectives and farmer objectives for reducing energy use—could work to shorten the supply chain and increase farmers' profits.

There is an opportunity to improve refrigeration systems, integrate humidity controls, and build supply chain and food system resilience in Vermont. The proposed next steps of this project would be to:

- Continuing talking to farmers about their priorities
- Working with UVM Extension to pilot new technologies and services
- Cultivating relationships with state and local agencies to promote policy and financing support for cold chain optimization

Improving these connections and systems will offer direct savings for farmers in reducing energy costs, improving product quality and longevity, conserving resources, reducing on-farm time and labor, and reducing embedded carbon emissions. The connection to and the impacts on reducing food waste are not sufficiently clear to chart a new course, and therefore should be explored further.

Conclusion

This research supports an Efficiency Vermont effort to continue to help dairy and diversified small-scale agriculture become more energy efficient, environmentally sustainable and financially viable. The dairy research puts Efficiency Vermont in a position to quantify carbon emissions savings and to support operational strategies that offer economic benefits to Vermont cooperatives and dairy farms. The small-scale diversified agriculture research helps advocate for and identify ways to reduce the annual 14.3 million pounds of lost, unmarketable produce in Vermont. In addition to helping farmers increase revenue, working with industry partners could help address Vermonters' food insecurity and their ability to access locally grown foods.

Improving cold chain infrastructure can increase the efficiency of the supply chain and allow Vermont's food systems to feed more people. It can improve the profitability and quality of markets, so that Vermont and its farmers can continue to invest in sustainable practices.

Efficiency Vermont needs to continue to work for and listen to the needs of its ratepayer-customers. The research team sees strong growth in diversified agriculture, and a strong need to improve operating margins within the dairy sector. Efficiency Vermont's hope is that this R&D project will allow the team to better understand and respond to the state's agricultural landscape so that its agricultural customers can thrive in the marketplace.