



# THE VIABILITY OF BIOMETHANE DIGESTERS IN VERMONT:

*Barriers and Solutions*

Middlebury College

Green Mountain Power

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## Guide to Acronyms

**ANR:** Agency of Natural Resources  
**ARRTA:** American Recovery and Reinvestment Tax Act  
**BMP:** Best Management Practices  
**CEDF:** Vermont Clean Energy Development Fund  
**CEP:** Comprehensive Energy Plan  
**CFR:** Code of Federal Regulations  
**CVPS:** Central Vermont Public Service  
**DAF:** Dissolved Air Flotation  
**DEC:** Department of Environmental Conservation  
**EPA:** Environmental Protection Agency  
**EQIP:** Environmental Quality Incentives Program  
**FIV:** Fertility Index Value  
**GIS:** Geographic Information Systems  
**GMP:** Green Mountain Power  
**HTC:** Hydrothermal Carbonization  
**kW:** kilowatt  
**kWh:** kilowatt hour  
**MACS:** Maryland Agricultural Water Quality Cost-Share Program  
**NPV:** Net Present Value  
**NRCS:** Natural Resources Conservation Service  
**P:** Phosphorus  
**PENNVEST:** Pennsylvania Infrastructure Investment Authority  
**PMT:** Phosphorus Management Tool  
**RGGI:** Regional Greenhouse Gas Initiative  
**SPEED:** Sustainably Priced Energy for Economic Development  
**TWh:** terawatt hour  
**TMDL:** Total Maximum Daily Load  
**USDA:** U.S. Department of Agriculture  
**VAAF:** Vermont Agency of Agriculture, Food & Markets  
**VEPP:** Vermont Electric Power Producers  
**VT:** Vermont  
**WWTF:** wastewater treatment facility  
**WWTP:** wastewater treatment plant

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## Executive Summary

With the right policies in place, biomethane digesters can provide key solutions to many of the environmental and economic challenges that Vermont currently faces. Anaerobic digesters convert raw manure into biogas, which can either be used for heat or combusted to generate electricity. The use of digesters can help Vermont reach its renewable energy goals, improve water quality, and diversify revenue for dairy farmers. We partnered with David Dunn from Green Mountain Power's Cow Power program to explore the potential for additional revenue streams and alternative models that would make digesters more feasible in Vermont. Biomethane digester operations require significant initial investments ranging from one to over two million dollars in Vermont. This is especially problematic for small farms with fewer than 200 cows, which make up 82% of Vermont's dairies. While federally-funded grant money available through the §1603 American Recovery and Reinvestment Tax Act (ARRTA) program initially allowed many dairy farmers to purchase biomethane digesters, this funding program expired in 2011. Although other sources of funding are available, investment in digester projects has stagnated since the expiration of the §1603 program. It is essential that this grant program be renewed to cover some of the upfront costs. However, this grant money should be used in conjunction with other models and revenue sources to increase the economic feasibility of digesters; we explore those alternative models and revenue sources in this report.

Although water quality regulations often create added pressure for farmers, a market-based approach to achieving Vermont's new Total Maximum Daily Load (TMDL) goals could incentivize digester owners by monetizing water quality benefits. If farmers use digesters as a way to process and divert phosphorus, they could potentially sell water quality benefits as part of a credit trading system. However, in order for a trading scheme to work, phase-in trading should be allowed in combination with a declining cap. Credit prices should also be predetermined, like they are in the Long Island Sound program, in order to increase certainty for farmers (Jones and Vossler, 2014). Lastly, the state should consider the feasibility of nonpoint to nonpoint credit trading and incorporate the demand from wastewater treatment facilities into its analysis. Vermont could also solve the problem of phosphorus loading by subsidizing the transportation of manure out of watersheds with high phosphorus concentrations. This will translate directly into more profits for digester owners because, based on the revenue from electricity sales, each ton of manure is already worth \$15.10 (Thompson, Wang, and Li, 2013). Maryland has been running a comparable manure transportation program for close to two decades now; Vermont could follow its example.

Beyond water quality credits and manure transportation, further revenue could potentially be derived from phosphorus itself as a product. Through various mechanical and chemical separation technologies, phosphorus can be extracted and incorporated into an array of products, including fertilizer and compost (Mayer, Baker, Boyer, Drechsel, Gifford, Hanjra, Parameswaran, Stotzfus, Westerhoff and Rittmann, 2016). However, further research is needed to identify additional market niches for reclaimed phosphorus. Currently, commercial sources of reclaimed phosphorus from livestock manure are not available on a large scale, and they cannot compete economically with fertilizer products containing phosphorus sourced from mines in Florida (J. Bingold, personal communication, November 29, 2016). While many reclamation technologies are viable for larger farms, it remains uncertain whether they can be applied to smaller farms in Vermont. While most farms rely on screw press separators to separate solids from liquids, and some of the phosphorus is inherently contained in the solids, one farm has

recently added a decanter centrifuge which has the capacity to reclaim even larger amounts of this nutrient (Native Energy, 2014 January). In order to increase the market potential of recycled phosphorus, further research and development supported by a state government sponsored competition for local phosphorus removal technology, as well as subsidies for recycled phosphorus, are advisable.

Adding food scraps as feedstock can increase both the efficiency and cost-effectiveness of anaerobic digesters. Adding 10% food waste could potentially double the amount of energy produced (DSM Environmental Services, Inc., Tellus Institute, and Spencer, 2013). Co-digestion also helps stabilize the technology because it results in a more balanced pH and increased buffer capacity (Zhang, Xiao, Peng, Su, and Tan, 2013). However, food waste can introduce more nutrients and possible contaminants into the digestate, so farmers will need to adjust their nutrient management plans to avoid phosphorus loading. Effective communication with food waste providers and close inspection of the waste will also be essential to keep harmful material like plastic and pathogens out of digestate. Lastly, because most farms will not be able to process the food waste on site, waste processing facilities like Casella's pilot program in West Rutland should be developed in order to prepare the food scraps into a slurry that is ready for digestion (DSM Environmental Services, Inc. *et al.*, 2013).

In addition to alternative revenue sources, farmers should also explore the feasibility of co-owning a community digester. Such an investment is more affordable because the investment costs are shared. Currently, only 10% of all the manure produced on Vermont's dairies is processed through a digester system. Community digesters could capture the private and public benefits of digestion by incorporating more of this manure. In order to maximize the cost-effectiveness of such a digester, GIS analysis should be used to increase transportation efficiencies and to site optimal locations, paired with a wide adoption of truck models that are the most fuel-efficient, such as box trucks. Because Vermont's dairy industry includes so many small farms for which the initial start-up costs in digesters may not be feasible, we concluded that a communal digester model may make more sense in Vermont, especially in conjunction with other practices like establishing and taking part in a phosphorus market, engaging in water quality and carbon credit trading, and incorporating food waste into digesters.

# 1. Introduction: Vermont Digesters and Green Mountain Power

## 1.1 The Big Picture

Dairy is essential to Vermont's economic vitality and cultural heritage. Dairy accounts for approximately 70% of agricultural sales in Vermont, and no other state has a single commodity accounting for such a high percentage of its total agricultural sales (Vermont Dairy Promotion Council, 2015). More than 80% of the farmland in Vermont is used for dairy production, including the crops grown to feed the cows. Over the last several decades, the number of dairy farms in Vermont has been declining drastically, while the number of cows per farm has been increasing (M. Audet, personal communication, October 4, 2016). About 82% of dairy farms in the state have fewer than 200 cows, which is considered small by national standards (Vermont Dairy Promotion Council, 2015). Currently, Vermont farms are facing increased pressures from more stringent water quality regulations and volatile milk prices set by the government.

## 1.2 Energy Policies in Place

With the right policies in place, biomethane digesters can provide solutions to the environmental and economic challenges that Vermont faces. First of all, the adoption of these digesters fits in with Vermont's energy goals. In the past several years, Vermont has passed a series of legislative benchmarks establishing goals for the state's production and use of renewable energy. For example, the Standard Offer Program was established in 2009 as a part of the Sustainably Priced Energy for Economic Development (SPEED) program. The Standard Offer Program was the nation's first feed-in tariff program, which offers a long-term fixed price to renewable energy developers, thereby encouraging them to overcome economic instability and enter the market. More recently, Vermont passed legislation that included an updated version of the Comprehensive Energy Plan (CEP), which established the goal of achieving 90% of Vermont's energy from renewable sources by 2050 (State of Vermont Department of Public Service). The CEP estimates that Vermont has the capacity to triple biomethane digester use (U.S. Energy Information Administration).

Especially when paired with phosphorus-separating technology or other effective nutrient management plans, biomethane digesters can reduce the amount of phosphorus that runs off into Lake Champlain and other bodies of water. Excess phosphorus in lakes can result in eutrophication, causing ecologically harmful algal blooms (Dobbs, 2016). Furthermore, digesters have been shown to reduce odor and improve local community perception of the dairy industry. Lastly, given that Vermont's Universal Recycling Law must be fully implemented by 2020, digesters could help manage the increasing amount of food waste that must be diverted from landfills by transforming it into a renewable source of energy. The use of biomethane digesters on dairy farms not only advances Vermont's environmental goals, but it also has the potential to save money for dairy farmers, especially after they have paid back the initial investment costs, which will contribute to their future viability.

In accordance with Vermont's energy goals and the potential environmental and economic benefits of digesters, Green Mountain Power, the state's primary utility company, started the Cow Power program to promote anaerobic digesters throughout the state. However,



digester adoption has greatly stagnated since funding from an initial series of grants ended in 2011. As shown in Table 1, there are currently eighteen digesters in Vermont on farms of sizes ranging from 45 to 2500 cows (EPA AgSTAR, 2016 May). Table 1 summarizes the type of digester, utility size, and herd size, among other important factors.

**Table 1.** List of operational digesters in Vermont, taken from AgSTAR Database of livestock digesters. Data was last updated May, 2016 (EPA AgSTAR, 2016 May).

Project Name	Project Type	City	County	State	Digester Type	Status	Year Operational	Animal Type	Population Feeding Digester	Co-Digestion	Biogas Generation (Standard Cubic Feet)	Biogas End Use(s)	System Design Engineer	System Designer	Receiving Utility	Methane Emission Reduction (Metric tons CO2E/yr)
Pleasant Valley Farms - Berkshire Cow Power, LLC	Farm Scale	Berkshire	Franklin	VT	Mixed Plug Flow	Operational	2006	Dairy	1,950	Dairy processing waste	220,000	Cogeneration	DVO, Inc. (formerly GHD, Inc.)	DVO, Inc. (formerly GHD, Inc.)	Green Mountain Power (GMP) Vermont Central Vermont Public Service (CVPS)	5,047
Maxwell Farm / Neighborhood Energy, LLC	Farm Scale	Coverly	Orleans	VT	Mixed Plug Flow	Operational	2008	Dairy	750	Fats, oils & grease		Cogeneration	DVO, Inc. (formerly GHD, Inc.)	DVO, Inc. (formerly GHD, Inc.)	Vermont Electric Cooperative	2,180
Four Hills Farm	Farm Scale	Bristol	Addison	VT	Mixed Plug Flow	Operational	2012	Dairy	1,200			Cogeneration	DVO, Inc. (formerly GHD, Inc.)	DVO, Inc. (formerly GHD, Inc.)	Green Mountain Power (GMP)	3,815
Kane's Scenic River Farms	Farm Scale	Enosburg Falls	Franklin	VT	Mixed Plug Flow	Operational	2011	Dairy	850			Cogeneration	DVO, Inc. (formerly GHD, Inc.)	DVO, Inc. (formerly GHD, Inc.)	Green Mountain Power (GMP) Vermont Central Vermont Public Service (CVPS)	2,289
Keewaydin Farm	Farm Scale	Stowe	Lamoille	VT	Modular Plug Flow	Operational	2011	Dairy	120		5,000	Cogeneration	Avaar Energy	Avaar Energy	Stowe Electric	235
Gebbie's Maplehurst Farm	Farm Scale	Greensboro	Orleans	VT	Complete Mix	Operational	2012	Dairy	450	Dairy processing waste		Cogeneration	RCM International LLC	RCM International LLC	Hardwick Electric Company	1,115
Riverview Farm	Farm Scale	Franklin	Franklin	VT	Complete Mix	Operational	2013	Dairy	450			Cogeneration	Bio-Methatech Canada, Inc.-LPP GmbH	Bio-Methatech Canada, Inc.-LPP GmbH	Green Mountain Power (GMP) Vermont Central Vermont Public Service (CVPS)	1,480
Vermont Technical College - Randolph Center	Farm Scale	Randolph Center	Orange	VT	Complete Mix	Operational	2015	Dairy	0	Food waste		Cogeneration			Green Mountain Power (GMP) Vermont Central Vermont Public Service (CVPS)	-
Jonslein Farm	Farm Scale	Hyde Park	Lamoille	VT	Complete Mix	Operational	2012	Dairy	350		33,450	Cogeneration	UEM Group	UEM Group	Vermont Electric Cooperative	666
Jasper Hill Farm	Farm Scale	Greensboro	Orleans	VT	Mixed Plug Flow	Operational	2014	Dairy	45	Dairy processing waste		Boiler/Furnace fuel	ECOSolutions	ECOSolutions		76

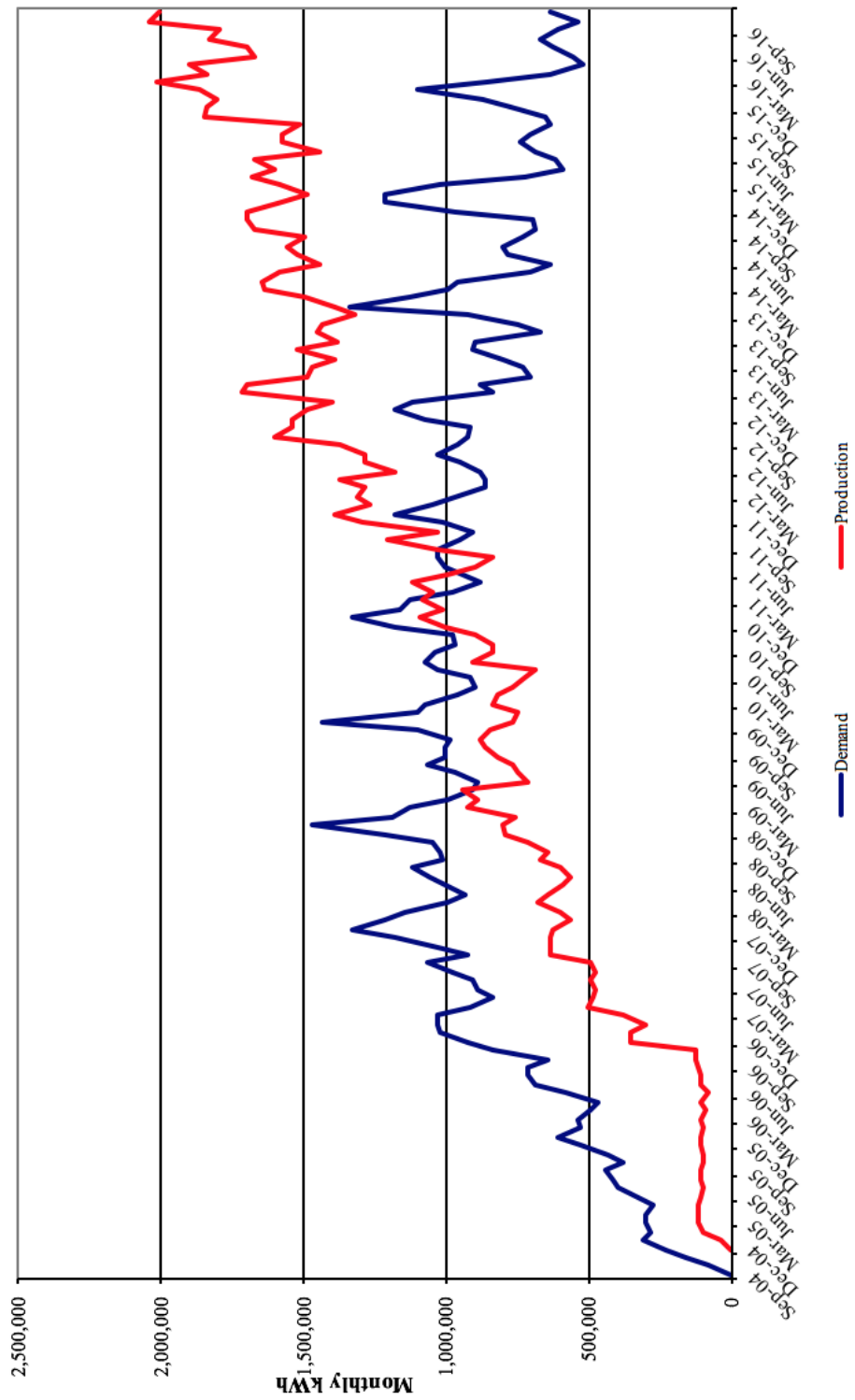
Project Name	Project Type	City	County	State	Digester Type	Status	Year Operational	Animal Type	Population Feeding Digester	Co-Digestion	Biogas Generation Estimate (cu ft/day)	Biogas End Use(s)	System Design Engineer	System Designer	Receiving Utility	Methane Emission Reductions (metric tons CO2E/yr)
Gervais Family Farm	Farm Scale	Bakersfield	Franklin	VT	Mixed Plug Flow	Operational	2009	Dairy	950	Dairy processing waste		Cogeneration	DVO, Inc. (formerly GHD, Inc.)	DVO, Inc. (formerly GHD, Inc.)	Enosburg Electric	1,911
Westminster Farms	Farm Scale	Putney	Windham	VT	Mixed Plug Flow	Operational	2009	Dairy	1,200	Ag residues; Fats, oils & grease		Cogeneration	DVO, Inc. (formerly GHD, Inc.)	DVO, Inc. (formerly GHD, Inc.)	Green Mountain Power	2,803
Chaput Family Farms	Farm Scale	North Troy	Orleans	VT	Complete Mix	Operational	2010	Dairy	1,700	Fats, oils & grease; Process water	111,114	Cogeneration	RCM International LLC	RCM International LLC	Vermont Electric Cooperative	9,226
Monument Farms	Farm Scale	Weybridge	Addison	VT	Mixed Plug Flow	Operational	2011	Dairy	500	Dairy processing waste; Fats, oils & grease		Cogeneration	DVO, Inc. (formerly GHD, Inc.)	DVO, Inc. (formerly GHD, Inc.)	Green Mountain Power (GMP) (formerly Central Vermont Public Service (CVPS))	1,230
Dubois Farm	Farm Scale	Vergennes	Addison	VT	Mixed Plug Flow	Operational	2010	Dairy	1,200			Cogeneration	DVO, Inc. (formerly GHD, Inc.)	DVO, Inc. (formerly GHD, Inc.)	Green Mountain Power (GMP) (formerly Central Vermont Public Service (CVPS))	7,443
Audet's Cow Power	Farm Scale	Bridport	Addison	VT	Mixed Plug Flow	Operational	2005	Dairy	2,500	Dairy processing waste		Cogeneration			Vermont Electric Cooperative	5,108
Green Mountain Dairy, LLC	Farm Scale	Sheldon	Franklin	VT	Mixed Plug Flow	Operational	2007	Dairy	1,050	Dairy processing waste	115,500	Cogeneration	DVO, Inc. (formerly GHD, Inc.)	DVO, Inc. (formerly GHD, Inc.)	Green Mountain Power (GMP) (formerly Central Vermont Public Service (CVPS))	2,668
Nelson Boys Dairy, LLC	Farm Scale	Swanton	Franklin	VT	Mixed Plug Flow	Operational	2007	Dairy	1,200		132,000	Cogeneration	DVO, Inc. (formerly GHD, Inc.)	DVO, Inc. (formerly GHD, Inc.)	Green Mountain Power (GMP) (formerly Central Vermont Public Service (CVPS))	2,659

### 1.3 Project Overview and Methods

We partnered with David Dunn at Green Mountain Power to explore the viability of biomethane digesters on dairy farms in Vermont. We conducted over fifteen hours of interviews with nearly twenty primary and secondary stakeholders with a variety of backgrounds, including local Addison County farmers, digester investors in Massachusetts, environmental regulators, and Geographic Information Systems analysts. We conducted a thorough literature review and spoke with an array of experts in the field in order to thoroughly gauge the landscape and to provide helpful insights and recommendations for any and all stakeholders involved in the process.

While biomethane digesters provide a reliable source of renewable energy, the initial investments can be insurmountable, if not prohibitory. With over 850 dairy farms and 130,000 cows, Vermont seems to be an ideal site for anaerobic digesters, but the Environmental Protection Agency's AgSTAR program has identified 500 cows as the likely minimum dairy farm operation size to capture positive financial returns (Vermont Dairy Promotion Council, 2015; Lazarus, 2008). This 500-cow minimum is problematic because 82% of Vermont's dairy farms have fewer than 200 cows (Vermont Dairy Promotion Council, 2015). In order to make biomethane digesters a viable option for the Vermont landscape, it is therefore crucial to diversify digester revenue streams beyond electrical generation. Such diversification could stem from monetizing water quality benefits and greenhouse gas reductions via credit trading, engaging in phosphorus markets, and incorporating food waste. These revenue sources will become increasingly important for larger farms as well, given the recent volatile price of fossil fuels and lack of consumer demand for more expensive energy derived from special digester programs such as Green Mountain Power's Cow Power program.

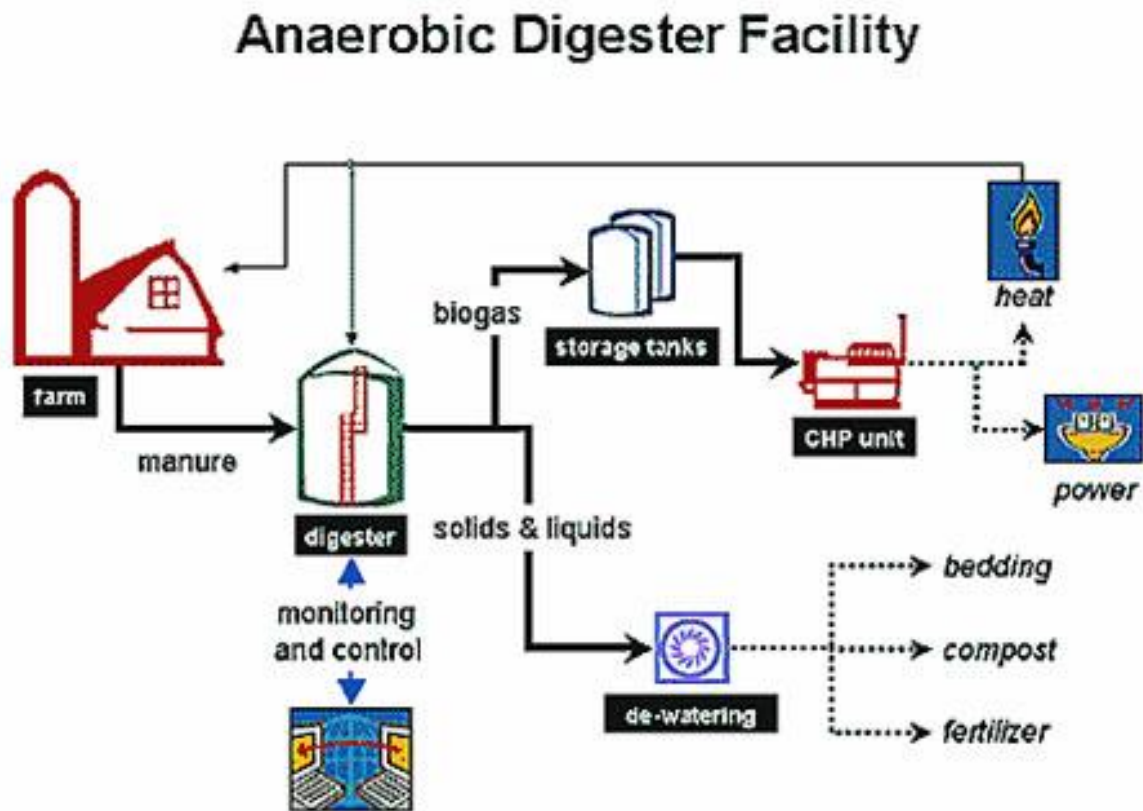
Cow Power is a customer-based premium program to motivate biomethane digester investment in Vermont. Customers pay 4 cents per kilowatt-hour for electricity generation, a premium which is then directly handed over to farmers in exchange for the renewable attributes of the energy they produce. Customers can elect to pay this premium for 100%, 50% or 25% of their electricity bill (Green Mountain Power, "Sign up", 2016). While demand surpassed supply up through late 2011, slower customer enrollment has put digester energy generation well above monthly Cow Power customer demand (see Figure 1). In order to fill this void, Green Mountain Power has explored the value of carbon offsets to supplement renewable energy credits that are sold on the regional market for those farms producing in excess of customer subscription. However, carbon is a relatively new market and this market is currently primarily based in California; further research is needed to secure additional potential revenue streams.



**Figure 1.** Green Mountain Power (GMP) Cow Power™ production versus demand for energy sourced from anaerobic digesters (D. Dunn, personal communication, 2016).

## 1.4 Types of Digesters and System Overview

The two most widely propagated digester models in Vermont are mixed plug flow and complete mix (Table 1). Mixed plug flow digesters are the most expensive to install; however, they also produce the highest quality fibers and have comparable or lower operation costs in relation to complete mix systems (Informa Economics, 2013). As shown in Table 1, most digesters in Vermont are of the plug flow variety. Plug flow anaerobic digesters break down raw dairy manure, producing biogas in the form of methane, which can be used for hot water and space heating on the farm or transformed into electricity (Wang, Thompson, Parsons, Rogers, and Dunn, 2011). Figure 2 outlines this process. The generated electricity is then used on the farm or put on the grid, depending on contractual agreements with the utility. Unlike wind and solar energy, biomethane digesters can provide a constant stream of energy, so they are arguably more reliable than these other renewable energy sources (Wisconsin Biogas Initiative, 2011). The solid and liquid byproducts are separated upon completion of the digestion process, which typically takes between twenty to forty days. The solids are commonly separated using a screw press, and the separated solids, also known as fibers, are most often utilized as fertilizer, compost, or animal bedding (Wang *et al.*, 2011). Beyond the economies for these solid byproducts, many studies and practices have explored the potential revenue streams from separated nutrients, most notably phosphorus, which we explore later in this report.



**Figure 2.** Overview of plug flow anaerobic digestion on a dairy farm. Image taken from <http://www.plugflowdigester.com>

## 2. Overview of Digester Economics

### 2.1 Hurdles to Investment

Individual biomethane digester operations require significant initial investments averaging between 1.35 and 2.44 million dollars in the state of Vermont, depending on the digester size (Wang, Valchuis, Thompson and Parsons, 2016). However, the total investment goes well beyond the costs of initial infrastructure. Management and general operational expenses continue to accrue throughout the lifespan of a digester, which is estimated to be 20 years (CVPS Cow Power). Bob James of Monument Farms in Weybridge, VT, spoke to the high expense of each individual part that must be replaced, which is unlike other mechanical operations involved in the dairy industry due to the smaller economy of scale for digesters in general (B. James, personal communication, October 28, 2016). Additionally, anaerobic digestion processes are highly corrosive and prone to cause wear to pipework due to all of the hydrogen sulfide filtering through the system (Haghighatafshar, 2012). Although it was hard to say whether Monument Farms was turning a profit in its digester operation, involving payoff of a 10-year loan, Bob James cited their ability to continue to pay for repairs as a good indicator (personal communication, October 28, 2016). Initial investment costs include engineering and design concept work, construction labor and materials, grid interconnection, permits and other various capital expenses (Wang *et al.*, 2011). Annual costs also include registration fees for criteria pollutants and toxics if the engine-generator's emissions exceed a certain amount. For Marie Audet of Blue Spruce Farm in Bridport, VT, this results in around \$6000 in fees per year from the state for her farm of over 2,100 cows (J. Hollingsworth, personal communication, December 12, 2016).

Average total initial investment for Vermont farms with 501 to 2,100 cows is estimated to be around \$2.44 million, while the average for herd sizes ranging from 75 to 500 is around \$1.35 million (Wang *et al.*, 2016). Estimates released by the EPA provide further insight into these costs. Although cost-size relationships are difficult to gauge given numerous operation variables including differing designs and small overall economy of scale, the EPA AgSTAR program extrapolated the initial capital costs per cow to range from \$3,116 for a herd of 100 to \$371 for a herd size of 2,000 (Lazarus, 2008). This tremendous difference is illustrative of why the AgSTAR program identified 500 cows as a necessary baseline for positive financial return.

Farmers have traditionally paid for these investments through a complex series of grants, loans, and owner equity. Possible grant sources include the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) and the Vermont Agency of Agriculture, Food and Markets (Wang *et al.*, 2011). Wang *et al.* (2011) writes that of the average total project investment, in this case around \$2 million, 34.7% came from grants, 53.6% came from loans and 11.7% was owner's equity. This puts farmers at the whim of banks to secure funding. With few digesters built in recent years, Bob James spoke to the importance of the initial grant framework (personal communication, October 28, 2016). Without an extensive grant framework, farmers struggle even more to adopt biomethane digesters, especially in a variable interest rate environment. Even if the digesters could play a pivotal role in diversifying revenue streams for future generations, farmers may not have the necessary credit to secure loans. This initial barrier is problematic even if the system would ultimately pay for itself in the long run.

## 2.2 Income and Payoff

Once built, farmers hope to compensate for their initial investments and ultimately obtain a positive Net Present Value (NPV). A positive NPV results when the discounted sum of the financial returns is more than the cost of the initial capital investment. Once again, the traditional sources of revenue (or savings) are derived from electricity production and various fiber markets including end uses in both animal bedding and compost. According to Wang *et al.* (2011), electricity sales through Central Vermont Public Service’s (now GMP’s) Cow Power program accounted for approximately 64.6% of project income. Electricity generation is a major benefit as articulated by Bob James, who talked about farms potentially receiving monthly checks upwards of \$30,000-\$40,000 for their energy production for a herd of roughly 1,500 milking cows (personal communication, October 28, 2016). However, as shown in Table 2, this farm is on the high end in terms total return given its relatively large herd size. Annual electrical generation is upwards of \$350 per cow for a herd size of 1450, while for a herd size of 375, total annual return is downwards of \$150. This is especially concerning for small farmers looking to invest in this technology given the upfront initial investment per cow at upwards of \$4,000. Relying on energy returns alone, in a purely undiscounted scenario, it would take more than thirty years to justify this investment. Although this is not discounted, this is well beyond the average 20-year lifespan of such a system in the first place.

**Table 2.** Total initial investment and energy returns for plug flow anaerobic digesters in Vermont.

<b>Herd Size<sup>1</sup></b>	<b>Annual Energy Income (including RECs)<sup>2</sup></b>	<b>Average Monthly Energy Income</b>	<b>Annual Energy Income Per Cow</b>	<b>Total Initial Investment<sup>3</sup></b>	<b>Total Initial Investment Per Cow</b>
<b>1,450</b>	\$534,445	\$44,537	\$368.58	\$3,013,722	\$2,078.43
<b>1,200</b>	\$312,204	\$26,017	\$260.17	\$2,611,810	\$2,176.51
<b>500</b>	\$110,739	\$9,228	\$221.48	\$2,397,372	\$4,794.74
<b>375</b>	\$51,172	\$4,264	\$136.46	\$1,612,966	\$4,301.24

<sup>1</sup> Herd sizes of four individual farms in Vermont  
<sup>1,2,3</sup> Individual herd size, annual energy income and total initial investment data provided Wang et al. (2016).

Since Monument Farms is one of the three net-metered farms in Vermont, the energy produced from the Monument Farms digester compensates for what would normally be a \$10,000-12,000 monthly electricity bill. Furthermore, through a local partnership with a tractor dealership in Middlebury, the farm receives additional revenues, in the form of actual electricity bill payment, from the dealership’s consumption of the farm’s excess electricity (B. James, personal communication, October 28, 2016).

Beyond energy production, the liquid and solid byproducts also have economic viability. While electricity accounted for 64.6% of total income, bedding contributed 31.6% to this total (Wang *et al.*, 2011). After the manure is put through the digester, the resultant pathogen-free “slurry” is put through a screw press separator. A screw press contains a large auger screw, which puts pressure on the manure. These solids can then be used as animal bedding, replacing traditionally purchased sawdust material. Wang *et al.* (2011) estimates a 2008 value of \$13 a

cubic meter retail cost for this bedding, much less than the \$26 a cubic meter this study references for traditional sawdust sources. The lower estimate of \$13 is due to the short timespan in which farmers have to turn the product before the fibers break down through natural composting (Wang *et al.*, 2011). Averaging four different farms, Wang *et al.* (2011) estimates that a herd size of 1,212 cows producing 23.3 m<sup>3</sup> of fiber per day would result in an average daily revenue of \$305 from both avoided bedding costs and revenues from fiber sales. To put this byproduct revenue stream in perspective, this is about one third of the average electricity revenue of these four farms of around \$958 per day (Wang *et al.*, 2011). However, it should be noted that information on the overall market for selling excess bedding is quite limited, so there is no widely determined market price (Wang *et al.*, 2016). Wang *et al.* (2016) extrapolated an average combined savings and income from bedding of around \$78,000 per year for large farms and \$16,000 for farms with fewer than 500 cows.

The importance of this solid material for bedding cannot be underplayed. In fact, Marie Audet expressed that the bedding was what she liked best about her farm's digester operation. She is able to sell half of the bedding to three other farms, providing a constant revenue stream. She stated, "Our success as a dairy farm lies squarely on the care of our cows. Proper, ample bedding is a critical component for cow health. Supplying ourselves with our own bedding provides us with peace of mind and simultaneously contributes to maintaining the high quality of our milk" (personal communication, October 4, 2016 and January 24, 2017). Bob James echoed this sentiment, emphasizing that this bedding material was one of his farm's primary motivations for investing in a digester (personal communication, October 28, 2016).

Whereas logging operations used to actively seek farmers to take away the sawdust that was building up in their area, wood chip manufacturers now consume a large portion of that market. Monument Farms ultimately ended up sourcing its sawdust from Canada for around \$4000 a month and was still never guaranteed a steady supply (B. James, personal communication, October 28, 2016). The digester provides a steady, closed loop supply of bedding to remedy this uncertainty, and, as noted, this was one of their main motivations to invest in this equipment. While the requirements of every farm are different, many farms have leftover fibers to sell in various forms. Beyond the use of separated fibers for animal bedding, several markets have been established both locally and nationally for this product as compost. Blue Spruce Farm sells this separated solid as a compost product on site, while other farms have turned to national vendors to market these products. Jensen *et al.* (2016) notes that various composting methods exist, including aerated static piles, turned windrows, and rotating drum composters. Composting products can also be approved as organic which results in higher revenues. Additionally, as peat moss has become increasingly expensive, these solids have been targeted as a suitable replacement for greenhouse and nursery plant growth due to their high fiber content (Jensen *et al.*, 2016). These fibers allow for generous aeration, have high water retention rates and contain nitrogen, phosphorus, and potassium, nutrients unavailable in traditionally sourced peat moss. This market is relatively new, however, and as of July 2015 only a few companies were active (Jensen *et al.*, 2016). Replacing peat moss with digested fibers can also avoid 5.8 million metric tons of greenhouse gases from being released (Quantis, 2013). According to Jensen *et al.* (2016), this end use of fibers could generate around \$10.50 to \$17 a cubic yard in bulk for digester operators, assuming that wholesalers pay for any transportation involved before reselling in retail markets. However, Jensen *et al.* (2016) notes that these prices could increase with further market penetration. Relative potential revenues compared to bedding use are outlined in Table 3. If farmers were able to penetrate these peat moss markets, they could



potentially make a little more margin from the separated fibers, depending on the proportion of fibers they had in excess beyond intrinsic bedding requirements.

**Table 3.** Potential annual revenue streams from peat moss markets. Peat moss prices noted in Jensen *et al.* (2016) as having potential to range from \$10.50 to \$17.00 per yd<sup>3</sup> for bulk quantities, assuming that wholesalers pay for any transportation involved before reselling in retail markets. 2008 estimated price of bedding provided by Wang *et al.* (2011). Manure production and resultant fiber recovery per cow extrapolated from Wang *et al.* (2011) value of 23.3 m<sup>3</sup> per day for an average herd of 1212 cows. Off-farm sales estimated at 50% and 25%. Blue Spruce Farm, which has 1,500 cows, sells roughly 50% of excess fibers elsewhere (Blue Spruce Farm). Wang *et al.* (2011) found an average of about 22% of solids sold elsewhere for four Vermont farms.

Percentage sold off-farm	End Use	Price	Number of Cows in Herd		
			500	1000	1500
50%	Bedding	\$13.00/m <sup>3</sup>	\$22,804.97	\$45,609.94	\$68,414.91
50%	Peat Moss	\$10.50/yd <sup>3</sup>	\$24,091.66	\$48,183.32	\$72,274.98
50%	Peat Moss	\$17.00/yd <sup>3</sup>	\$39,005.55	\$78,011.09	\$117,016.64
25%	Bedding	\$13.00/m <sup>3</sup>	\$11,402.49	\$22,804.97	\$34,207.46
25%	Peat Moss	\$10.50/yd <sup>3</sup>	\$12,045.83	\$24,091.66	\$36,137.49
25%	Peat Moss	\$17.00/yd <sup>3</sup>	\$19,502.77	\$39,005.55	\$58,508.32

### 2.3 Energy Policy Framework

Although the installation and maintenance of digesters are a huge expense to owners, Vermont has several policies in place that will help to make biomethane digesters more economically viable so that they can be adopted to help meet the state's energy goals.

The Sustainably Priced Energy for Economic Development (SPEED) Goal was established in 2005 with the goal of promoting the production of sustainable energy in Vermont as well as to encourage electric utility companies to purchase renewable energy. The SPEED program states that beginning in 2017, 20% of retail electric sales in Vermont must be met by renewable energy sources (State of Vermont Department of Public Service). According to the Vermont Public Service Board (2016), the state is on its way to meeting this goal.

The Vermont Energy Act of 2009 (Act 45) included modifications to the SPEED program. Its Total Renewable Energy Goal states that beginning in 2017, 55% of each retail electric utility's annual sales must be met by renewable sources, increasing by 4% every third year until 2032, at which point 75% of sales must be met by renewable energy sources. In 2015, Vermont backed this goal with its first Renewable Energy Standard law. The law reiterates the goal of 75% renewables by 2032 (State of Vermont Department of Public Service).

The Standard Offer Program was included as a 2009 amendment to the SPEED program and is one of the nation's first feed-in tariff programs. It offers a 20-year fixed price to renewable energy developers, thereby encouraging them to overcome economic instability and enter the market (Vermont Department of Public Service, 2016). Vermont's feed-in tariff program has supported anaerobic digesters as well as other renewable energy projects. Feed-in tariff programs are not particularly common in the U.S. Vermont is one of a small number of states that have

feed-in tariff programs mandated by law; the other states are Maine and Rhode Island in the east and California, Hawaii, Oregon, and Washington in the west (U.S. Energy Information Administration, 2013).

As recommended by the 2011 CEP, the Vermont Energy Act of 2012 (Act 170) expanded the Standard Offer Program and mandated the use of a market-based mechanism to determine pricing for Standard Offer Projects (State of Vermont Department of Public Service; VEPP Inc., 2016). More recently, Vermont passed legislation that included an updated Comprehensive Energy Plan, whose ultimate goal is for Vermont to obtain 90% of its energy from renewable sources by the year 2050. The Vermont Department of Public Service states, “Not only can Vermont be a leader in global climate change efforts, but we can do so while increasing our energy security, improving our economy, protecting ratepayers, and reducing our total energy costs.” With this in mind, the state passed its Comprehensive Energy Plan, with the following goals:

- Reduce total energy consumption per capita by 15% by 2025, and by more than one third by 2050.
- Meet 25% of the remaining energy need from renewable sources by 2025, 40% by 2035, and 90% by 2050.
- Three end-use sector goals for 2025: 10% renewable transportation, 30% renewable buildings, and 67% renewable electric power.

(Vermont Department of Public Service, 2016)

Vermont’s net metering program was established in 1999 and has undergone many changes since then. Through the net metering program, the owners of small electric generating systems can receive credit for the electricity that they produce beyond what they themselves use on their own property. Certain biomethane digester sites in Vermont, such as Monument Dairy, have taken advantage of net metering (Vermont Public Service Board, 2016).

Vermont continues to update these programs to encourage renewable energy development. In April 2015, the Standard Offer program established a new price of \$19.9 kWh for projects of 150 kW or less (as compared to the 14.5 cents kWh for those above the 150 kW mark), making it more possible for farms with 500 to 600 cows to install a digester. This made smaller scale digesters more financially appealing (Department of Public Service, 2016). However, as we have stated, the majority of Vermont’s dairy farms have fewer than 200 cows, so further policy modifications can be made to make digesters on even smaller scale farms more feasible.

Digester owners can also take advantage of carbon credit trading systems. This includes the Regional Greenhouse Gas Initiative (RGGI), which puts a total greenhouse gas emissions cap on its nine northeastern state members, including Vermont. These states can then trade carbon credits amongst each other. RGGI was the first mandatory market-based program in the U.S. to reduce greenhouse gas emissions. However, there are not many offset projects taking place via RGGI because more money is available through California’s cap and trade system. Vermont-based parties can take part in the California system; it is not limited to entities within the state of California. Green Mountain Power will be selling carbon credits within the California system through its planned St. Albans community biodigester project, which we will discuss further later in this report (D. Dunn, personal communication; P. Wood, personal communication; Regional Greenhouse Gas Initiative).

The federal Farm Bill, a new version of which is passed every five years, could provide another catalyst to the installation of biomethane digesters (or other projects on farms that will help to meet energy, water quality, and economic goals). Through the Farm Bill, NRCS works with farmers on conservation projects, so the promotion of and increased funding for biomethane digesters on agricultural land should be included in the bill and NRCS should provide financial assistance to farmers to implement the projects. Vermont Senator Patrick Leahy, who is known as the father of national organic standards and labeling, has done a lot of work in this arena. Senator Leahy was re-elected and will serve on the Agricultural Committee; he could potentially promote this (Addison County Agriculture Conservation Tour, September 26, 2016).

Given the combination of Vermont as a state with a large dairy industry and as a state with ambitious goals for renewable energy production, biomethane digesters could be a significant pathway to achieving these goals while also encouraging the economic vitality and ecological sustainability of the dairy industry. The policies that are currently in place will help to promote digesters and make them more economically feasible to farmers, but because the start-up costs are so high, these policies need to be complemented with funding for these upfront costs in the form of grants.

## 2.4 Grants and Funding

A number of Cow Power's farm partners have been recipients of grant money made available for renewable energy projects through the §1603 American Recovery and Reinvestment Tax Act (ARRTA) program. This federally-funded program reimbursed eligible applicants for part of the installation costs of energy-generating equipment. Typically, grants were awarded that cover one-third of the total eligible cost basis of the project. The overwhelming majority of the projects that receive funding through this program are residential solar projects, with 83,761 residential solar projects funded as of July 31, 2016 compared to only 168 biomass projects. The most funding was awarded to wind projects at \$12,995 million compared to \$1,053 million for biomass. The estimated generating capacity for biomass projects is 1,334 MW, with an estimated generation of 7.5 TWh (U.S. Department of the Treasury, 2016).

Congress established the U.S. Treasury §1603 program when the number of tax equity investors willing to invest in renewable energy projects drastically declined during the 2008-2009 financial crisis, resulting in a lack of new renewable energy development projects. The program relieved developers from having to rely on tax equity investors to monetize the tax credits and eliminated the middleman in the process. As opposed to the investment of production tax credit, the program provided cash grants (U.S. Department of the Treasury, 2016).

The §1603 program began to accept applications on July 31, 2009 and expired at the end of 2011, though projects whose construction began prior to the expiration are still eligible for funding. The program has poured \$6,295,186 dollars into 11 open-loop livestock biomass projects (which can refer to any waste nutrients, including manure and other waste such as bedding material, from bovine, swine, poultry, or sheep) in Vermont, with the first recipient in the state receiving funding in November of 2010 and the most recent in 2014. The majority of the farms receiving this funding are Cow Power farm partners (see Table 4). Monument Farms, for example, was able to take advantage of this grant money and install a digester. Bob James of Monument Farms emphasized the importance of this money and that without it, farmers have a hard time paying the startup costs. Since the expiration of the §1603 program, many farmers have found it to be impossible to obtain the necessary finances to purchase digesters for their

farms (B. James, personal communication, October 28, 2016; U.S. Department of the Treasury, 2016; Boyd, Wunder, and Grayson).

**Table 4.** Applicants and Rewards in Dollars for Funding from §1603 Program  
(Green Mountain Power, 2016; Cow Power Partners; U.S. Department of the Treasury, 2016)

<b>Applicant</b>	<b>Rewarded</b>
<b>Audet's Cow Power, LLC</b>	\$550,931.00
<b>Chaput Family Farms Partnership</b>	\$542,269.00
<b>Dubois Energy LLC</b>	\$783,543.00
<b>Four Hills Farm Partnership</b>	\$904,117.00
<b>Gervais Family Farm, Inc.</b>	\$592,728.00
<b>Green Mountain Dairy Farm, LLC</b>	\$130,081.00
<b>Kane's Cow Power, LLC</b>	\$643,930.00
<b>Michael Benjamin d/b/a Riverview Farm</b>	\$511,624.00
<b>Monument Farms Three Gen LLC</b>	\$725,842.00
<b>Sandra Gebbie dba Maplehurst Farms</b>	\$477,221.00
<b>Westminster Energy Group</b>	\$432,900.00
<b>Total Rewarded:</b>	\$6,295,186.00
<b>*Cow Power partners are listed in bold.</b>	

Luckily, the §1603 program is not the only source of funding available to those wishing to install biomethane digesters. The U.S. Department of Agriculture (USDA) Rural Development’s Rural Energy for America (REAP) program, authorized by the 2014 Farm Bill, provides grant money for digester projects. However, grants provided cover up to one-fourth of the costs of the project or up to \$500,000, as opposed to the one-third covered by the §1603 program. USDA Natural Resources Conservation Service (NRCS) also provides funding through the Environmental Quality Incentives Program (EQIP) of up to \$300,000 per project or \$450,000 in exceptional cases. These two programs formed a partnership to provide funding for digester projects. In one of their most successful collaborative projects, the two entities divided the costs such that NRCS provided a grant that covered the manure handling components which included the digester itself, manure pumps, separator, and other equipment, while Rural Development provided funds for the electrical generation equipment such as engines, generators, and electrical hook-up. REAP and EQIP split the costs of funding approximately 50-50% between themselves (Ducharme and Thompson).

Entities at the state level are also accepting applications for grant money. Currently, the Public Service Department and the Vermont Clean Energy Development Fund (CEDF) are

seeking proposals for a couple of types of projects to which they will supply funding. One of these is a grant of up to \$300,000 for one or more anaerobic digesters in Windham County, including digesters that would accept a high portion of food waste or be supplied entirely with food waste. The other is a grant of up to \$79,000 applicable statewide for a digester that would accept quantities of manure equivalent to that produced by 200 cows or fewer, or for a project involving recovering heat from composting. As we have stated, due to economies of scale, grants are especially needed in order for digesters on these smaller farms to be viable (Vermont Public Service Department, 2016).

There are also grants available that are not focused on biomethane digester projects specifically but provide funding for projects that improve environmental quality more generally. Newtrient is applying for a grant under Vermont Clean Water Initiative Grants Program for a digester project because the digester has the potential to improve water quality (Newtrient LLC, “Strategic,” 2016). We will discuss digesters’ impact on water quality in a later section.

However, despite these other sources of grant money, the §1603 program was a significant source of funding, and there has been a decline in new digester projects since the program expired. Furthermore, some of the major companies that manufacture biomethane digesters, such as DVO Wisconsin, do not build digesters that are cost effective to operate on a smaller scale (B. James, personal communication, October 28, 2016). If smaller farmers want to install digesters, they need to demonstrate to manufacturers that there is a demand for smaller digesters.

Mendelsohn and Harper (2012) found that the tax credits model, which the §1603 program had replaced but which was reinstated once the §1603 program funding expired, limits project development because only a select few investors have the necessary capital, especially their current and future tax liabilities, to be able to invest in new renewable energy projects. They found that the benefits to renewable energy development of the §1603 program when compared to those of the tax credit program included the following:

- Increased speed and flexibility
- Lower transaction and financial cost
- Stretched supply of traditional tax equity
- Support of smaller developers (including new entrants) and innovative technologies that were less capable to tap tax equity markets
- Improved economics of most renewable energy projects
- Allowed use of more debt, lowering developer or project cost of capital
- General support of an extensive build-out of renewable power generation projects

(Mendelsohn and Harper, 2012)

The authors believe that smaller or less well-established renewable power developers will find it more difficult to obtain the financial resources necessary to complete their projects. Investment in new projects may decrease because projects that rely on tax equity include transaction costs as well as, in some cases, higher return in order to appeal to investors (Mendelsohn and Harper, 2012).

Clearly, the §1603 program assisted many farms in purchasing anaerobic digesters, and its expiration has resulted in increased difficulty for farmers to secure the necessary funds to purchase digesters. Although grant money is currently available through USDA programs, financial support from the §1603 program is essential. If digesters are to be promoted, the §1603 program should be reinstated, as it is more efficient and less costly than the tax equity system.

### 3. Alternative Revenue Sources to Consider

While grant funding can help farmers cover the initial investment for digester technology, alternative revenue streams also need to be further developed in order to make the system sustainable in the long-run. Savings from digestate used for cow bedding and compost sales can increase the economic viability of digesters to some extent, yet other opportunities still exist to maximize the potential of the byproducts from anaerobic digestion. In this section we will look into the potential revenue streams from trading water quality credits, transporting manure more cheaply, selling new phosphorus products, and incorporating community food scraps to increase energy sales.

#### 3.1 Monetizing the Water Quality Benefits of Digesters

High levels of phosphorus have led to the growth of harmful blue-green algae in Lake Champlain, which affects the lake's ecological health as well as its role as a source of drinking water and a place for public recreation and tourism in Vermont. In response to this problem, in 2002 the state set limits for the amount of phosphorus that is allowed to enter the lake from various sources, otherwise known as the Total Maximum Daily Loads (TMDLs) (Dobbs, 2016). However, in light of a lawsuit from the Conservation Law Foundation that condemned the inadequacy of Vermont's 2002 phosphorus limits, the U.S. EPA mandated a new set of more stringent requirements in 2016 (Dobbs, 2016). Overall, nonpoint source phosphorus pollution from farm runoff makes up almost 40% of the current phosphorus base load in Vermont. Although certain areas of the lake will face tighter restrictions under the new TMDL, as a whole, farms will need to reduce phosphorus runoff by 53% in order to meet the new requirements (Hirschfeld, 2014). Vermont's new regulatory landscape will create added pressures on farmers. However, it could also provide an incentive for new and existing digesters to monetize the benefits of improving water quality as an additional revenue stream.

Processing raw manure through anaerobic digestion can help farmers manage the nutrients more efficiently. In contrast to most other manure management practices, anaerobic digestion does not lose any of the original nitrogen through volatilization (Topper, Graves, and Richard, 2016). Kirchmann and Witter (1992) found that ammonium concentrations are higher in digested manure compared to untreated manure, which makes the nitrogen more available for plants (Harrison *et al.*, 2013). Furthermore, because the fertilizer byproduct produced by anaerobic digestion is liquefied and more uniform than raw manure, it can be injected into the soil more easily, which helps the soil absorb the nutrients (Wisconsin Biogas Initiative, 2011). Better nutrient absorption can reduce runoff, especially during storm events.

Digesters do not inherently remove phosphorus from manure or change the amount of manure farmers apply to their fields. As Julie n, former environmental consultant turned Secretary of the Agency of Natural Resources, explained, anaerobic digestion changes the structure of the manure which, in turn, creates options for managing phosphorus, including the ability to recycle fibers from within the manure for bedding and also to sequester phosphorus from the manure through advanced treatment processes such as dissolved air floatation (DAF). Ultimately, the reuse of any components of the digested manure depends on the farm's soil needs and the nutrient management practices implemented on the farm (personal communication, November 3, 2016). Digesters can, however, be paired with certain separation technologies like decanter centrifuges, which can remove between 40 and 60% of the phosphorus (B. KillKelley,

personal communication, October 27, 2016). While the impact on water quality depends on what farmers ultimately do with the isolated phosphorus, if farmers succeed in diverting the separated phosphorus, they could reduce their phosphorus load by up to 60%. However, it is important to note that the technologies necessary to help digesters reduce phosphorus loading are more costly than other nutrient management technologies, such as cover-cropping and no-till. While revenue from a future water quality credit trading system could provide additional income for digesters, it should not be the only economic incentive for phosphorus removal.

### *3.1.1 Water Quality Credit Trading*

Assuming farmers with digesters take advantage of this ability to better manage phosphorus, they could potentially sell the water quality improvements achieved as tradeable credits. According to the EPA, as long as the TMDL requirements are met, the state of Vermont, specifically the Department of Environmental Conservation, has the authority to implement the law in whichever way it sees fit (U.S. EPA, 2016). Given the expenses involved in adopting Required Agricultural Practices, as well as volatile milk and feed prices that dairy farmers face, Vermont is considering supporting more market-based approaches, such as water quality credit trading.

Water quality credit trading provides greater flexibility for polluters and tends to work in situations in which some of the polluters are able to meet the requirements more easily than other polluters. For every unit of pollution removed beyond the baseline, that polluter generates a credit, which can be sold to a buyer (Blunk, Borisova, Abdalla, and Parker, 2009). The credit is sold for a price negotiated by the parties involved or by a third-party negotiator, and is almost always greater than or equal to the cost incurred to reduce the pollution but less than the cost that would have been necessary for the other polluter to comply with the baseline. Credit trading is governed by a trading ratio, which accounts for differences in the sections of the waterbody and other uncertainty factors. If the trading ratio is 2:1, for example, the buyer must buy two credits in order to reduce pollution by one unit (Blunk *et al.*, 2009; Conservation Technology Information Center, 2006).

### *3.1.2 Progress in Vermont*

Inspired by the success of the national sulfur dioxide cap and trade program in the 1990s, which used free market principles to dramatically reduce acid rain, former DEC commissioner David Mears expressed hope for a similar program to address water quality in Vermont. In 2014, the state offered \$100,000 in funding for research to determine the feasibility of such a program (Hirschfeld, 2014). The report, published in 2015 by Kieser & Associates and Tetra Tech, concluded that although a water quality credit trading program in Vermont has potential, more analysis of the policies and technological aspects involved is needed.

According to the 2015 report, most of the necessary conditions for a successful trading market have been met or partially met in Vermont. These include an adequate regulatory framework (partially met), willing regulators (met), sufficient demand for credits (partially met), and a large enough cost differential between different reduction strategies (partially met). The supply of water quality credits, however, is currently too low to support demand because not enough farms can meet their baseline requirements under the new TMDL law. Furthermore, in order to achieve an effective cost-differential, the costs for farmers must be low, and the costs for

stormwater and/or wastewater reductions must be high. The report estimated that a combination of practices—including riparian buffers, cover crops, conservation tillage, and grassed waterways—costs about \$126 per pound of phosphorus reduced per year. In contrast, costs for stormwater facility upgrades (in this case, wet detention basins) can range from \$742 to \$8764 per pound of phosphorus reduced per year. In addition, a large portion of stormwater reduction costs (at least 80%) must be assumed by public sources. Based on the analysis by Kieser & Associates and Tetra Tech, a bilateral water quality trading on a case-by-case basis would be most effective in Vermont. A bilateral scenario would include brokers and aggregators, which would help connect farmers with point source polluters and negotiate terms and prices (Kieser & Associates and Tetra Tech, 2015).

The feasibility scenarios produced by the 2015 analysis also suggest that several policy changes would improve the cost-effectiveness of water quality credit trading in Vermont. First, in order to increase the supply of credits from agricultural sources, a “phase-in” or interim trading model should be considered. This would allow farms to temporarily receive credits while working towards their baseline requirements, and afterwards only receive credits for reductions beyond the baseline. This policy could be combined with a “declining cap” model for credit buyers, in which stormwater facilities would be able to buy fewer phosphorus credits over the twenty-year implementation period of the law while working towards eventually meeting the TMDL requirements on their own. This would incentivize point sources to meet their own water quality requirements, even if the abatement costs are higher than the credits they could buy. Each of these policy changes would require additional legal analysis and approval by state regulators; however, if implemented, they could be essential in creating a viable system for water quality credit trading.

Future analyses should consider the participation of wastewater treatment facilities (WWTFs) because Kieser & Associates and Tetra Tech were originally directed not to include them in their 2015 report. However, WWTFs could significantly increase potential demand in a water quality credit trading market (Kieser & Associates and Tetra Tech, 2015). The total cost for upgrades for wastewater treatment facilities in Vermont can range from \$880,000 to \$20 million, which implies that there may be incentive for those sources of phosphorus to buy credits from farmers (Claudon, Ladue, and Pelosi, 2015). In addition, due to the stringent regulations for agricultural sources in Vermont, future analyses should consider the feasibility of a nonpoint to nonpoint trading system between farmers. Most water quality trading scenarios involve a nonpoint source like a dairy farm’s land and a point source, such as a wastewater treatment or stormwater facility, because nonpoint sources are generally less regulated and therefore more likely to meet baseline requirements. However, in Vermont nonpoint sources are strictly regulated, so it may be beneficial to allow farmers that can meet their baselines to sell credits to farmers who cannot.

### *3.1.3 Examples of Water Quality Credit Trading Programs*

In the past two decades, the number of water quality trading programs has grown significantly in the U.S. (Jones and Vossler, 2014). Despite its potential as a market-based solution to water quality problems, few of the programs have been successful in practice. In 2008, 80% of the trades occurring in the U.S. came from the Long Island Sound Trading Program, one of the success stories in water quality credit trading (Jones and Vossler, 2014).



Over the course of seven years, 15.5 million credits were traded as part of this Connecticut-based program (Greenhalgh and Selman, 2012).

However, this program uses an unconventional trading design. Unlike most programs, which use the traditional baseline-and-credit model, the Long Island Sound program is more similar to a Pigouvian tax/subsidy mechanism. Under this model, the trading is orchestrated by a third-party regulator “who automatically buys and sells credits at a pre-announced price” (Jones and Vossler, 2014). This approach lowers uncertainty about how much polluters can receive for selling credits and also ensures that the seller will receive a credit regardless of whether or not the demand exists at the moment the polluter decides to sell. This framework can also be categorized as a clearinghouse, in which a central entity “aggregates credits from different sources with different prices and converts them to a fixed-price commodity” (Greenhalgh and Selman, 2012). In addition to the clearinghouse, the Long Island program includes a declining cap for total nitrogen, which is supplemented by loans and grants from the Clean Water Fund to help facilities meet their baseline in the long-run by making the necessary upgrades (Rutgers Water Resources Program, 2008).

While the Long Island program expects to save \$200 million over the course of the program’s duration and the EPA considers it a model program, it cannot necessarily be applied to all contexts. Although the Long Island Sound watershed and the Lake Champlain basin are similar in square mileage, Connecticut’s land usage is much more urban and suburban, which means the demand from point sources like WWTFs and stormwater facilities may be higher than in rural Vermont. Furthermore, the Long Island program only includes trading between point sources, while Vermont’s program would have to involve nonpoint source dairy farms (Rutgers Water Resources Program, 2008). Still, Vermont should consider a program that incorporates the Pigouvian tax/subsidy model used in the Long Island program because a fixed price for water quality credits would offer farmers, typically a risk-averse group, more certainty to invest in better nutrient management strategies.

Another example of an alternative trading framework is PENNVEST (the Pennsylvania Infrastructure Investment Authority), which acts as a clearinghouse for credit buyers and sellers for both point and nonpoint sources in the Chesapeake Bay watershed in Pennsylvania. The clearinghouse helps lower trading costs as well as risks for buyers and sellers and offers several different contracts depending on the buyers’ and sellers’ specific needs. For example, the “forward” contract allows the credit seller to promise a certain number of credits at a certain date for a predetermined price, whereas the “spot” contract is used for one-time credit trading when the Best Management Practice (BMP) associated with the credit is implemented immediately. As Kieser & Associates (2015) noted, this flexible system could work well for Lake Champlain since supply and demand are not always equal (Kieser & Associates and Tetra Tech, 2015).

### *3.1.4 Challenges of Quantifying Water Quality Benefits*

The ability to obtain accurate and cost-effective water quality monitoring presents a challenge affecting whether or not farmers could directly receive monetary benefits from water quality improvements achieved through anaerobic digestion and careful nutrient management. Recently, the USDA’s Natural Resources Conservation Service has partnered with Vermont farms and Stone Environmental to test the effectiveness of certain conservation practices using edge-of-field monitoring stations (Overstreet). Although changes in precipitation during the study period made it difficult to measure and compare the success of these practices, the

technology demonstrated that there is a direct relationship between the amount of phosphorus in the soil and the concentration of phosphorus in runoff from the farm. So far, the edge-of-field monitoring stations have been installed to test the conservation effect of soil aeration, cover cropping, conservation tillage practices and grassed waterways (J. Moore, personal communication, November 3, 2016). However, expanding these monitoring stations has the potential to help farmers understand and prove the water quality benefits of anaerobic digestion in combination with other integrated nutrient management practices.

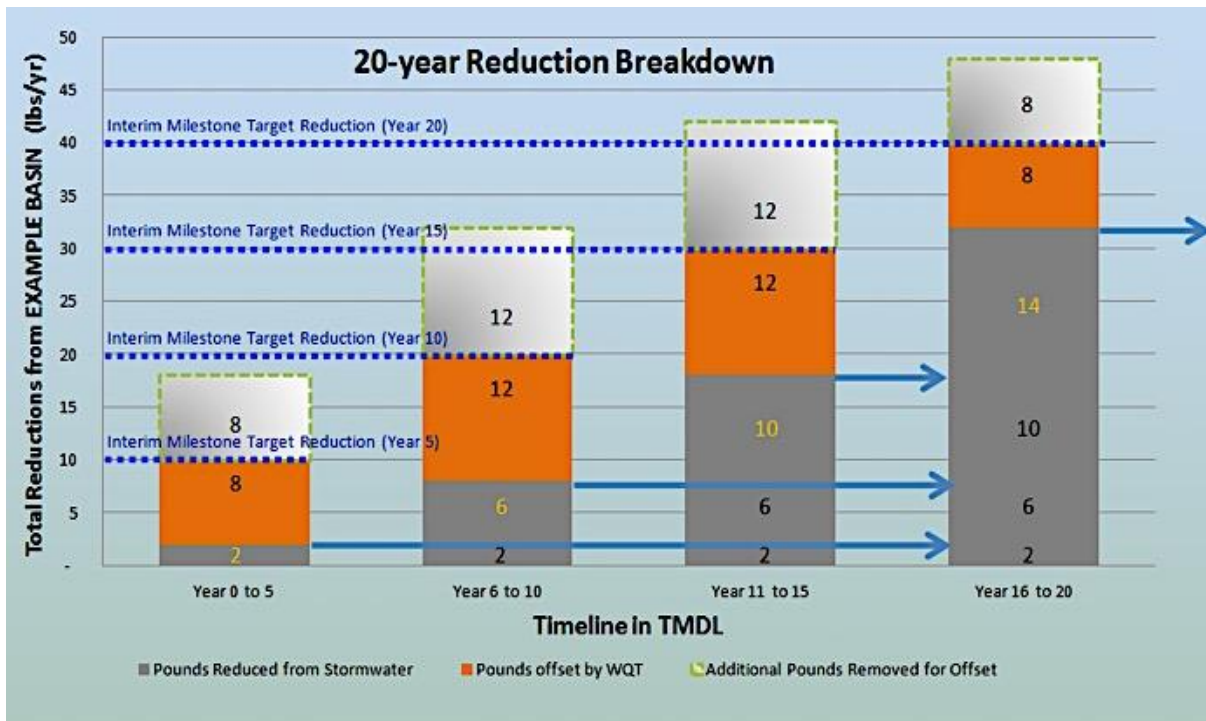
While edge-of-field monitors measure phosphorus levels directly on site, thus providing a more accurate estimate of phosphorus reductions, other simpler measures can be used as the technology is being further developed and installed on farms. For example, credit trading regulators can calculate nutrient concentrations using site-specific models that incorporate different land and soil variables to compute phosphorus reductions from different BMPs (Greenhalgh & Selman, 2012). This method is currently being used in a number of water quality credit trading programs and is more cost-effective than on-site direct monitoring.

### *3.1.5 Recommendations*

#### *Flexible Credit Generation*

Overall, a water quality credit trading program could work in Vermont. However, the Department of Environmental Conservation will need to allow for more flexible credit generation by implementing a phase-in model for credit sellers. While this may result in slower reductions in phosphorus levels at first, it would help jump-start the process by offering farmers the incentive they need to invest in better practices and technologies. The Wisconsin Bureau of Water Quality provides a specific guide for water quality credit trading and how phase-in or interim trading can be implemented. Nonpoint sources (in Vermont's case, agricultural sources) could generate interim credits for five years, or for the length of time it takes that farmer to reduce phosphorus loads to meet the baseline requirement (Wisconsin Department of Natural Resources, 2013). This time frame is consistent with the Vermont twenty-year TMDL schedule, which requires the EPA to issue interim report cards evaluating the implementation of five-year Tactical Basin Plans for each sub-watershed (U.S. EPA, August 2016). The interim credits would be measured based on the nutrient level present before the implementation of the conservation practice intended to achieve the baseline. After five years (or fewer depending on the BMP), the source can only sell long-term credits, which represent additional reductions below the baseline (Wisconsin Water Quality Bureau, 2013).

The phase-in model described above will need to be combined with a declining cap model, because the number of credits available will decrease after the interim credits expire. Thus, point sources will eventually need to invest in on-site reductions to meet long-term load allocation goals. As Figure 3 shows, during the first five-year period, credits from nonpoint sources can account for 80% of the total reductions, but by the end of the twenty-year period, credits can only make up 20% (Kieser & Associates and Tetra Tech, 2015).



**Figure 3.** Potential Phosphorus reductions over a twenty year TMDL period with a declining cap model (Kieser & Associates and Tetra Tech, 2015).

### *Credit Price Certainty*

A predetermined price for water quality credits would also encourage credit trading and provide farmers with more certainty in their decisions to change practices. Similar to the Long Island Sound Program, this price could be set each year by the Vermont Department of Environmental Conservation to account for changes in the average cost of reducing phosphorus (Rutgers Water Resources Program, 2008). The 2015 report for Vermont suggests that a bilateral trading program would work best because a clearinghouse mechanism would require the highest stormwater BMP costs in order to be cost-effective. However, because the report did not consider nonpoint to nonpoint source trading or include wastewater treatment facilities, the trading framework chosen will need to be reconsidered as it is dependent on the cost differential between credit sellers and buyers. The state should initiate a second feasibility analysis that incorporates all potential market participants in order to determine if a clearinghouse would be more effective.

## 3.2 Access to “Cheap” Manure via Subsidized Manure Transportation

### *3.2.1 Market Based Approach for Manure Handling*

Other than benefiting from a market-based approach to reducing nutrient runoff from farms by selling water quality credits, digester owners may also benefit from receiving free manure from farms with excess phosphorus. Vermont could try to solve the problem of phosphorus loading by subsidizing the transportation of manure so as to get phosphorus out of the watersheds that are already high in phosphorus. After discounting transportation costs, Thompson *et al.* (2013) estimated the annual revenue potential of each ton of manure at

\$15.10—that is, when only the profits from energy generation are captured. Treating manure as a commodity rather than waste, such measures to reduce phosphorus runoff from the agricultural sector into streams and lakes in effect facilitate the transfer of valuable raw materials onto farms with a digester at a highly subsidized rate. The farmers can then sell the byproducts of their digesters and gradually relieve themselves of their financial burdens in this way. Farmers who are worried about the financial burdens that come along with compliance with the TMDL standards may increase their resilience by adopting a biomethane digester. Since approximately one-quarter of agricultural soils in Vermont are deficient in phosphorus, and another one-quarter have high or excessive levels of soil test phosphorus, there are clearly potential markets in the manure hauling to, and from, anaerobic digester businesses, potentially offsetting imports of mined rock phosphorus into Vermont (Lake Champlain Basin Program).

### *3.2.2 Maryland Subsidies on Manure Transportation*

One state that has attempted to capture the monetary values of manure-derived benefits through subsidizing manure transportation is Maryland. Since 1984, the Maryland Agricultural Quality Cost-Share Program (MACS) has begun to provide funding for farmers to install a wide range of thirty best management practices (BMPs) to conserve soil and water resources, as well as to protect and restore environmental quality (Maryland Department of Agriculture, “Annual Report,” 2016). The rationale behind subsidizing farmers to adopt new technologies revolves around the fact that the adoption of BMPs incurs public benefits, so implementation and maintenance costs should be shouldered by the state or other levels of governance rather than individual farmers (Maryland Department of Agriculture, “Maryland Water Quality,” 2013). The MACS administers the Maryland Manure Transport Program, which subsidizes poultry and livestock producers up to \$20 per ton to transfer their excess manure to other fields owned by the farm, to other farms, or to alternative-use facilities such as a mushroom grower that makes compost out of manure to grow mushrooms (Maryland Department of Agriculture, “Biosecurity,” 2015).

Since the Maryland Manure Transport Program’s start date in 1999, the annual total amount of manure transported has increased by nearly ninety fold, from the original 1,896 tons to 167,237 tons in 2015. Cumulatively, they have moved more than one million tons of manure around (Maryland Department of Agriculture, “Annual Report,” 2016). With this large quantity of manure being transferred each year, the concerns around biosecurity need to be addressed. They are being dealt with specifically in the state’s Required Biosecurity Measures. For example, manure transporters are required to cover all loads during transport on public roads, as well as to clean sweep, disinfect, and/or even wash the cargo area and all transport and handling equipment after unloading and before moving onto a new farm operation (Maryland Department of Agriculture, “Biosecurity,” 2015).

This approach to water quality management fills two needs with one deed: not only does it remove phosphorus from at-risk and heavily polluted sections of the watershed, but it also benefits owners of anaerobic digesters financially by handing them cheap raw material that they can then use to increase profits. This avenue is an important one to consider for Vermont, because it is one way that the 82% of Vermont dairy farms that have fewer than 200 cows can achieve economies of scale (Vermont Dairy Promotion Council, 2015). By subsidizing manure transportation, the state could turn every digester into a receptacle for excess phosphorus from

farms in the region and then facilitate the transportation of digester co-products to areas that need those nutrients.

The government of Maryland has regulations in place that require farmers to submit soil test data regularly to state regulators. This information is then put through the Phosphorus Management Tool (PMT), which calculates a Soil Phosphorus Fertility Index Value (FIV) for each county in Maryland (Maryland Department of Agriculture, “Agriculture Department,” 2016). In March 2016, the Maryland Department of Agriculture published, for the first time, a statewide set of soil data, which the regulators have used to conclude that 82% of farm fields will not be affected by new environmental regulations (because their FIV<150), 18% will be required to use the PMT to evaluate risks (because their FIV falls within the 150-499 range), and finally only 1% will be immediately banned from applying more phosphorus crop fertilizer (because their FIV>500) (Maryland Department of Agriculture, “Agriculture Department,” 2016).

Perhaps not coincidentally, Maryland saw a large increase in the volume of manure transported in the build-up to the full implementation of the PMT for the first time in 2016: total tonnage transferred went from 119,000 tons to 167,000 tons in the fiscal year of 2015, an over 40% increase (Maryland Department of Agriculture, “Annual Report,” 2016). The lesson for Vermont here is that a more comprehensive set of soil data will give the regulators a clearer and more accurate vision of where improvements are most needed. Given the right incentives, it is also likely to spur the redistribution of manure from areas of high phosphorus concentration to that of low phosphorus concentration, with some of the manure diverted to alternative-use facilities such as anaerobic digesters.

The Maryland Department of Agriculture also has a Manure Matching Service that helps farmers manage their resources and facilitates the redistribution of manure and the nutrients associated with it. By doing so, this service, which is available to all types of animal producers, including dairy, complements the Transport Program and moves the farms towards complying with the nutrient regulations within Maryland. Producers register with the Service by providing information regarding manure type available, nutrient value, condition, and price. Then, the Department of Agriculture presents this information to potential recipients based on location, nutrient, and timing needs. Whereas the nutrient management plans can help farmers determine how much manure to take and to give, a manure analysis can break down the nutrient content so that participants can negotiate a reasonable price (Maryland Department of Agriculture, “Matching,” 2013).

Overall, if Vermont could make the problem of phosphorus loading more visible, and create funding and matching mechanisms that will make transporting manure further afield more cost-effective, more farmers will do it. Most importantly for the purposes of this report, this suite of policies will reward technologies like anaerobic digesters that treat manure as a valuable resource.

### *3.2.3 Recommendations*

Vermont’s DEC should research the Maryland Manure Transport Program and the Manure Matching Service. Currently, the Department of Agriculture in Maryland subsidizes up to \$20 per ton of manure. Key considerations and recommendations include:

- The tonnage of manure moved by Maryland’s Manure Transport Program per year increased ninety fold from 1999 to 2015: with one-third of Vermont’s farms deficient in

phosphorus, and another third with excess phosphorus, the potential benefits of such a program can be immense.

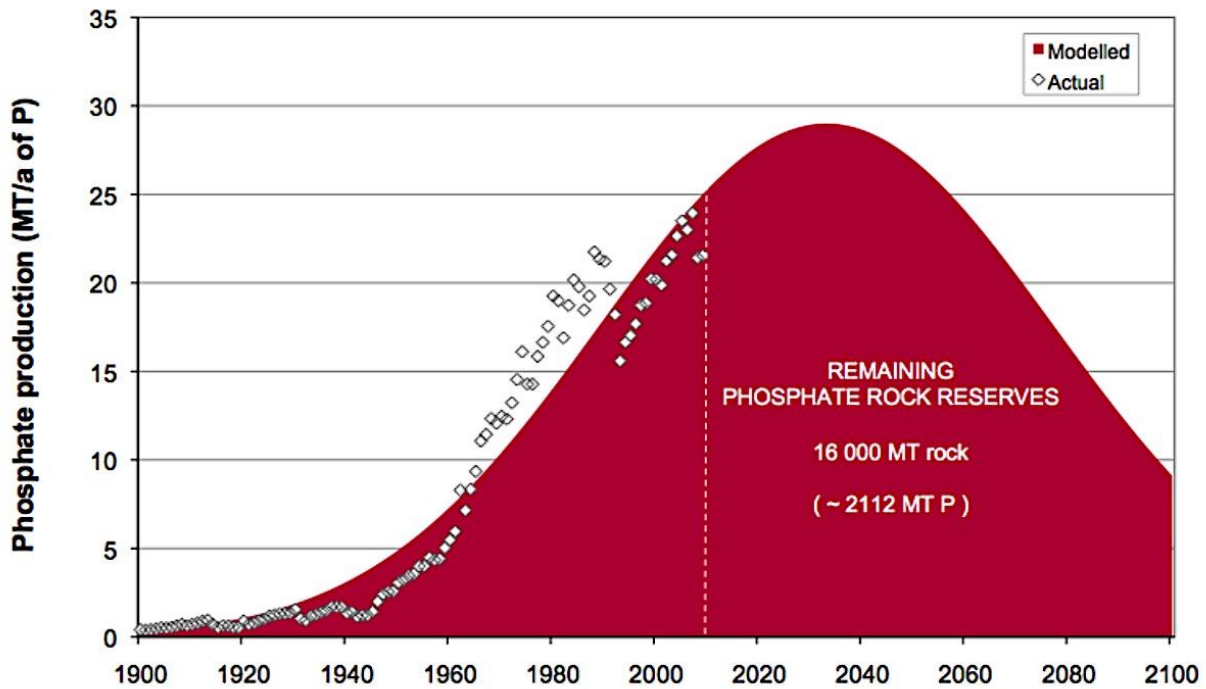
- Strengthen Vermont Agency of Agriculture and DEC's channels of communication with the Maryland Department of Agriculture on the theories and practice of capturing and expanding the water quality benefits of anaerobic digesters.
- Consider the current structure for reporting soil phosphorus: how may it be strengthened such that the Agency of Agriculture may acquire robust enough data to help farmers meet stricter standards of nutrient management?

### 3.3 Paradigm Shift from Extraction to Recovery: Potential Revenue from Excess Phosphorus

While still in the realm of nutrient control, but beyond water quality credit trading and manure transportation, marketing the extracted phosphorus has the potential to provide yet another revenue stream. Many phosphorus removal systems currently exist, ranging from fine removal centrifuge systems to more complex chemical polymer additives. In order to more fully capture the monetary benefits of manure using a biomethane digester, digester owners should consider investing in technological add-ons to aid in phosphorus recovery. The recovered nutrient could then be used to create a viable product to be sold in existing and future markets.

#### *3.3.1 Phosphorus Availability: A Global and Local Perspective*

In order to understand potential markets for Vermont phosphorus, it is important to consider the global phosphate rock market. de Ridder, de Jong, Polchar, and Lingemann (2012) outline the market dynamics for this nutrient. According to this study, China, the United States and Morocco dominated over two-thirds of global phosphate rock production in 2011. Given this limited concentration of export potential, this market is subject to destabilizing geopolitical events (de Ridder *et al.*, 2012). There are many different factors affecting extraction potential, and the notion of “peak phosphorus” (similar to the concept of “peak oil”) has been debated (de Ridder *et al.*, 2012). Figure 4 estimates global phosphorus reserves. According to de Ridder *et al.* (2012), extraction is influenced by constantly evolving geographic and economic feasibility. These parameters are in turn highly influenced by restrictive timeframes. Sudden shocks can cause dramatic price fluctuations, such as in 2008 when increasing agricultural production resulted in a heightened and thus unmet demand for phosphate rock. Although this was only temporary, it alludes to the price inelasticity of both supply and demand (de Ridder *et al.*, 2012). The overall uncertainty surrounding this market, as articulated in this study, highlights the importance of considering strategies that can reincorporate recycled phosphorus back into agricultural or other uses through closed loop systems.



**Figure 4.** Graphical representation of peak phosphorus (Cordell and White, 2011).

According to a Columbia University report, ninety percent of the world’s mined phosphate rock is used in agriculture and food production (Cho, 1 April 2013). In the United States, “phosphate rock ore is mined by five firms at ten mines in four states and processed into an estimated 27.6 million tons of marketable product valued at \$2.2. billion, f.o.b. mine” (USGS, 2016). Two states, Florida and North Carolina, accounted for around 80% of the United States’ total domestic output (USGS, 2016). A company called Mosaic owns the mines located in central Florida, where the phosphorus is extracted from matrices of phosphorus pebbles. The extracted phosphate is then processed and used by fertilizer manufacturers for agricultural applications (Mosaic). According to the Vermont Agency of Agriculture, Food & Markets, an estimated 10,000 tons of phosphorus fertilizer is imported into Vermont every year for agricultural use (J. Bingold, personal communication, November 29, 2016). The phosphorus balance in Vermont can only handle so much more loading as exemplified by the current fragile chemistry of Lake Champlain. It is therefore important to consider how we shift this paradigm to one that emphasizes recovery and recycling of these nutrients, as suggested by Mayer *et al.* (2016).

How can stakeholders work with the system to utilize a concentrated manure byproduct and efficiently recover phosphorus, while also generating a revenue stream? Anaerobic digestion is in many ways complementary to nutrient recovery. Anaerobic digesters provide necessary infrastructure sites, electrical inputs, and suitable outputs for nutrient recovery (Yorgey, Frear, Kruger, and Zimmerman, 2014). Digesters actually convert phosphorus from its organic form to its inorganic form, which may facilitate nutrient recovery (EPA and Partners, “Background”, 2015).

Newtrient LLC has been working to identify innovative phosphorus reduction strategies in Vermont. It submitted a recent grant to Vermont’s Clean Water Initiative Grants Program, focusing on cultivating economic opportunity through:

- 1) development of an interim NRCS practice standard to induce USDA funding for expensive P removal technology
- 2) identification of markets for physical products of P recovered by a variety of technologies at existing Vermont dairies in the St. Albans Bay area, and
- 3) identification and development of environmental asset markets or market-like structures for lowering overall cost of improved environmental protection outcomes.

(Newtrient LLC, “Strategic”, 2016)

Newtrient LLC has the hopes of procuring phosphorus materials from various technologies, some of which will be outlined in the next section, and developing new products for specific market niches.

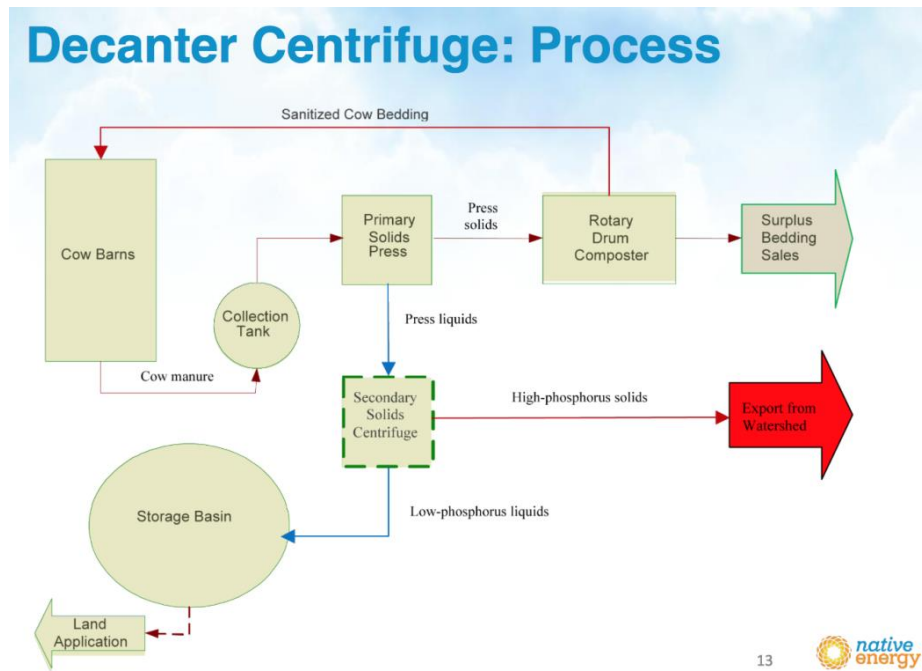
### *3.3.2 Phosphorus Extraction Methods: Trials and Opportunity*

One extraction method recently introduced to Vermont is a decanter centrifuge, which is used to spin manure byproducts. Unlike a screw press, which separates around 15-20% of the phosphorus because it tends to only separate the larger fibers, a centrifuge results in phosphorus-containing solids removal of anywhere from 40-60% because it is able to separate out the smaller fibers (B. KillKelley, personal communication, October 27, 2016). Combining the two results is a highly productive combination because the centrifuge can capture the smaller suspended solids that the screw press is unable to capture. Furthermore, adding a flocculent chemical into the mixture going into the centrifuge can result in phosphorus removal efficiency upwards of 70%. The flocculent would act as a coagulant to bind solids together and enhance the separation process (B. KillKelley, personal communication, October 27, 2016 and December 21, 2016). Using such phosphorus separator technology seems to be a crucial way to separate phosphorus and partake in a potential market. However, this technology presents similar obstacles as biomethane digesters: high start-up costs and lack of access to reliable capital.

Machia and Sons Dairy LLC, a farm with 725 milking cows, already has a screw press and just added a decanter centrifuge, which separates solids out from liquid slurry, through a partnership with Native Energy. The process is outlined in Figure 5. Together, the screw press and centrifuge investment, including a rotary drum composter and related building, reception pits, and ancillary equipment, cost approximately \$700,000. This cost was supported, in part, with a \$225,000 Green Mountain Power CEED grant and the purchase of the resultant lifetime carbon offsets through a NativeEnergy/Ben & Jerry’s partnership. Machia and Sons Dairy LLC uses the screw press solids for bedding and sells the solids generated from the centrifuge to regional compost operations, which blend it with other organics such as horse manure, straw and sawdust. The long-term objective is to either export this fertilizer out of the state or replace imported fertilizer for residential and agricultural purposes (B. KillKelley, personal communication, October 27, 2016 and December 19, 2016). Financial return estimates are outlined in Table 5, with total 10-year phosphorus exports estimated to be around 157,500 lbs. A case study at the Big Sky Dairy in Jerome, Idaho involving a decanter centrifuge resulted in total system phosphorus removal rate of 50-65%. This pilot study had an effluent flow rate two-thirds that of a 3,000 wet cow equivalent dairy. Operating costs were estimated at \$25-50 per cow per year, while capital costs of the combined screening and centrifuge system were around \$57-136 per cow per year. (Ma, Kennedy, Yorgey, and Freer, 2013). These wide ranges are arguably



telling of the gray area inherent to this technology. While potentially a promising technology for the Vermont dairy community, farmers will most likely remain wary of investing until more narrow cost estimates are available.



**Figure 5.** Digester operation with standard decanter centrifuge removing up to 50% of total phosphorus in the liquid outflow (Agricultural Working Group, 2014). Centrifuge creates a phosphorus cake. Image from Native Energy (2014, January).

**Table 5.** Financial estimates for 10-year return on digester operation with screw press and decanter centrifuge, for herd size of 500. Phosphorus cake sold as soil amendment. (Native Energy, 2014 January).

500-Cow Farm	10 Years	
Metric tons CO <sub>2</sub> e Reduced	25,000	Equivalent to taking 400 cars off the road for 10 years
Phosphorus Exported (lbs)	157,500	Equivalent to removing annual manure from 250 cows from LCW for 10 years
Farm Investment in foundations/structures	\$125,000	Design minimizes building requirements
Bedding Benefit Avoided Purchases + Sale of Excess + Sale of Centrifuge Cake	\$705,000	Composter produces excess sanitized bedding
Spreading/Hauling Savings	\$390,000	Reduced volume in lagoon to be spread
Operating Expenses	(\$488,000)	Power, repairs and maintenance
Net Benefit to Farm	\$607,000	

Beyond these mechanical separation models, several phosphorus separation technologies utilized on dairy farms involve chemical reactions through precipitation and crystallization for phosphate recovery. However, each technology recovers phosphorus in a unique form specific to different agricultural or industrial end-uses (Mayer *et al.*, 2016). According to Mayer *et al.* (2016), phosphorus is used in everything from pharmaceuticals to food and beverage production. This warrants technological design with specific end-products in mind (Mayer *et al.*, 2016). The forms in which phosphorus is available after the digestion process are priced out of the market by traditional cheaper forms of rock phosphate, necessitating special marketing and niche market use (Mayer *et al.*, 2016). Once suitable technologies become widely spread, Jerry Bingold, one of the founders of Newtrient LLC, suggested regional phosphorus recycling and reclamation centers could play a role in repurposing the phosphorus into a precursor for subsequent processing into fertilizer at manufacturing plants. This way, it can once again be repurposed to produce renewable fertilizer. However, farms currently do not have the capacity to recycle phosphate on a large enough scale. Enough product would have to be produced in order to viably ship it back and sell it to fertilizer manufacturers or the mines to use as a feedstock in their fertilizer production processes (J. Bingold, personal communication, November 29, 2016).

As noted, chemical additives can be used to complement mechanical phosphorus extraction (Ma *et al.*, 2013). Through the process of flocculation, chemical additives cause the phosphorus to become associated with particulate clumps called colloids. However, according to Ma *et al.* (2013), the price of some chemical coagulants and polymers tends to be very high and overtreatment using metals such as aluminum and iron salts can cause toxicity. A delicate balance must be reached in order to maintain the economic and environmental equilibrium of the system. Ma *et al.* (2013) outlines an anaerobic digestion system in Reynolds, Indiana which utilizes chemical treatments after the manure has been mechanically screened to remove fibrous product and additional fine suspended solids. The dissolved air flotation (DAF) system suspends particles in a large vat of water and separates out phosphorus with the addition of appropriate polymers. This results in total phosphorus recovery of 85-95% with operational costs around \$25-30 per cow per year, and \$130-150 per cow per year for capital expenditures for a co-digestion facility processing upwards of 6,000 wet cow effluent (Ma *et al.*, 2013). Costs per cow are likely to be much higher for smaller operations.

In a different process, crystallization aids in phosphorus recovery in the form of struvite, ( $\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O}$ ), which is a compound fertilizer (Huchzermeier and Tao, 2012). For an approximately 1,400 wet cow equivalent co-digester operation in Monroe, WA, crystallization has shown a phosphorus removal efficiency of over 75% for post-anaerobic digestion effluent, resulting in total system performance of 85-90% (Ma *et al.*, 2013). Total operating costs are \$80-100 per cow per year and \$75-125 operationally. A dry and pelletized product allowed for easy storage and transportation, and this system can use both digested and raw manures (Ma *et al.*, 2013). Comparative prices for the aforementioned technologies are shown in Table 6. The chemical processes seem to have much more financial burden. Given that not even the centrifuge systems are widespread in Vermont, it seems unlikely that many smaller farm operations will opt for the systems involving these more complex chemical processes.

**Table 6.** A comparison of costs surrounding various phosphorus extraction technologies to process digested effluent (Ma *et al.*, 2013).

<b>Key Technology Primarily P</b>	<b>Performance</b>	<b>Operating Cost /cow/year</b>	<b>Capital Cost /cow</b>	<b>Scale</b>
1' and 2' Mechanical Screens	TN 15-30%, TP 15-25%	\$5-6	\$32-36	Commercial
Sequential Screening + Advanced Non-Chemical	TN 24-30%, TP 50-65%	\$25-50	\$57-136	Commercial
Sequential Screening + Advanced Chemical	TN 45-55%, TP 75-90%	\$25-75	\$130-150	Commercial
Struvite Crystallization	TN 30%, TP 75%	\$90-110	\$100-150	Commercial
Enhanced Biological Phosphorus	TP 42-91%	\$150-170	\$275-300	Pilot

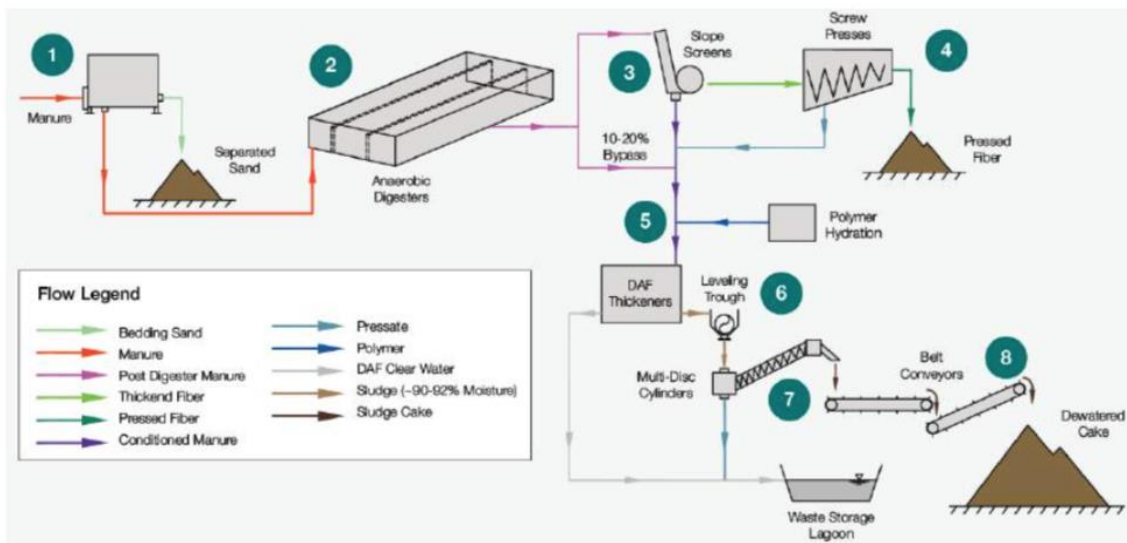
In order to motivate further research and development into phosphorus reclamation technologies, the EPA recently conducted a nutrient recycling challenge for technologies specific to livestock manure. The competition overview reads:

A major use of manure is as a renewable fertilizer, but it should be used properly to minimize water pollution and build healthy soils. In addition, there is a tremendous opportunity to generate environmental and economic benefits from manure by-products, but further innovation is needed to develop more effective and affordable technologies that can extract nutrients and create products that farmers can use, transport, or sell more easily to where nutrients are in demand. (EPA and Partners, “Competition”, 2015)

According to the EPA’s website, the competition involves three phases. Thirty-four of the seventy-five initial submissions for the phase one concept round were accepted. Phase II of the competition is now a non-competitive incubation period to cultivate technological design. Phase III will involve the development of actual prototypes, while phase IV will have finalists demonstrate pilots on farms (Nutrient Recycling Challenge). Given the lack of peer-reviewed analysis of commercially viable extraction systems, lenders have been cautious in their willingness to finance these operations (EPA and Partners, “Background”, 2015). However, such competitions have the potential to overcome technological barriers to entry. Trident Processes LLC and Soil Net LLC received an honorable mention in phase one for their plan to “recycle nutrients from livestock manure and create valuable products” (Nutrient Recycling Challenge). While Trident Processes LLC already has nutrient recycling systems in place on several dairy farms, they were joined by their partners in presenting new, more advanced concepts for this competition. One of their goals is to provide a “nutrient recovery solution that goes from raw dairy manure to granulized, certified organic, slow-release fertilizer bagged and ready to retail” (Trident Processes LLC, “Nutrient Recovery Goes”, 2016).

In terms of what Trident Processes LLC has already developed preceding the competition, the Trident Nutrient Recovery System produces a cake that is higher in phosphorus than raw manure through a system outlined in Figure 6. Trident Processes LLC emphasizes its goal to generate both “cost savings and revenue potential all along each step” with a broken down process for simplicity (Trident Processes LLC, “Nutrient Recovery: Advanced”). In terms of the actual process, Fair Oaks Dairy in Indiana has a model system in place. The first step removes coarse solids from the digester effluent. The remaining liquid digestate is pumped into a concrete holding tank and then into two dissolved air flotation units. Next, polymers are added,

which cause the suspended solids to flocculate. Dissolved air then floats these solids to the surface, where they are scraped into a trough. This sludge is then dispersed and dewatered on disc rotating presses (Newtrient LLC, “Case Study”, 2016). In general, this final step produces a 20-25% solid, clay-like cake which can then be transported for further processing or used as a soil amendment (Bush, 2016). Fair Oaks Dairy, a 3,500 wet cow farm, noted the lower maintenance costs over dewatering systems such as centrifuges. For this farm’s operation, total DAF to digester effluent reduction in phosphorus was upwards of 81%, with DAF influent P concentration around 0.04% and DAF effluent only 0.01% P. The DAF cake average was 0.35%. While this system exhibited low power and maintenance costs, the ongoing cost of polymer for the DAF was noted as a clear downside. Trident estimates that this technology warrants a minimum of 500 cows in order to avoid underutilization, although the system is currently in place on six farms ranging in size from 300 to 15,000 (Newtrient LLC, “Case Study”, 2016; Trident Processes LLC, “Newtrient Recovery: Advanced”). Table 7 estimates the economics of this technology based on the smallest scale models (Newtrient LLC, “Case Study”, 2016). Given this likely 500 cow minimum for achievement of positive financial return, this system could feasibly work with many of the digesters outlined in Table 1; however, such a technology may be a better candidate for shared use among many smaller farms in a community-oriented digester model, as we will discuss later in this report.



**Figure 6.** Trident Separation Technology (Newtrient LLC, “Case Study”, 2016).

**Table 7.** Capital costs and expected revenues from Trident Separation Technology (Newtrient LLC, “Case Study”, 2016).

Estimated Capital Cost	“\$800,000 for smallest standardized system.”
Estimated Annual Operating Cost	“Approximately \$20,000 per year for fully utilized smallest standardized system.”
Estimated Gross Sales	“Approximately \$25,500 per year for fully utilized smallest standardized system at an average price of \$400/ton for N & P contained in the cake and effluent.”

### 3.3.3 European Guidance on Phosphorus Recovery Platforms and Markets

Having little to no internal access to phosphorus mines, Europe has been on the advent of phosphorus market research and is thus an excellent place to turn for insight. Use of mineral fertilizer has fallen to 1950s levels and overall application efficiency remains low (Buckwell and Nadeu, 2016). The Rural Investment Support for Europe put out a report called, “Nutrient Recovery and Reuse (NRR) in European agriculture: A review of the issues, opportunities, and actions.” This report questions consumer readiness to accept a product with questionable consistency and performance compared to traditional fertilizer sources: “Do the crops take the NRR product up and thrive? Is the product harder to handle, and store? Does it require special new investment for application? Is it less concentrated or slower release?” (Buckwell and Nadeu, 2016). The report suggests potential business models where nutrients recycled from manure could potentially be offered to other farmers for free. The farmer would ideally be compensated elsewhere in the process such as through fees associated with accepting other municipal or food chain waste. This could be applicable for digester operations accepting inputs from the Universal Recycling Law in Vermont, for example. This study concluded that further tests were needed to prove the effectiveness of recovered fertilizer products before they could be competitive in the market versus other more traditional mined sources (Buckwell and Nadeu, 2016).

Several European countries, including The Netherlands, Germany, and Belgium, have also developed their own nutrient recovery and reuse platforms as a means to cultivate awareness and action for this pressing problem. The Dutch Nutrient Platform, for example, has a cross-sectional focus on chemical, agri-food, water, and waste and energy industries (Nutrient Platform NL). It is comprised of 36 businesses, government entities and knowledge institutes. P-Rex is a major European demonstration project aimed at increasing the viability of phosphorus products. It is comprised of various phosphorus stakeholders and researchers including wastewater treatment (WWTP) facilities. P-Rex highlights three potential pillars for phosphorus market entry:

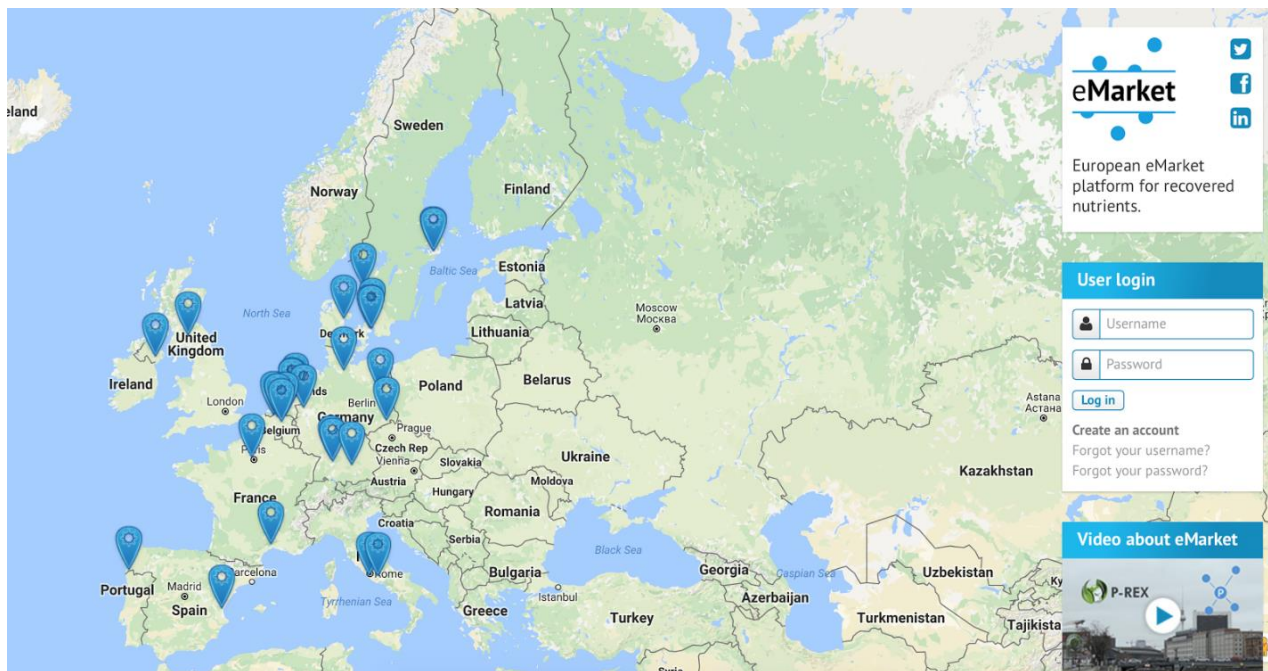
- A combined fertilizer and P-recovery-technology sales (dependent on each other, both require their own value propositions and customers),
- Addition of secondary P-sources to already existing P-product sales (adjustment of the existing production and sales-system), or
- Further processing of waste/byproducts (which are available more or less free of charge) and creation of a market-niche for novel byproducts.

(P-Rex, 2015 March)

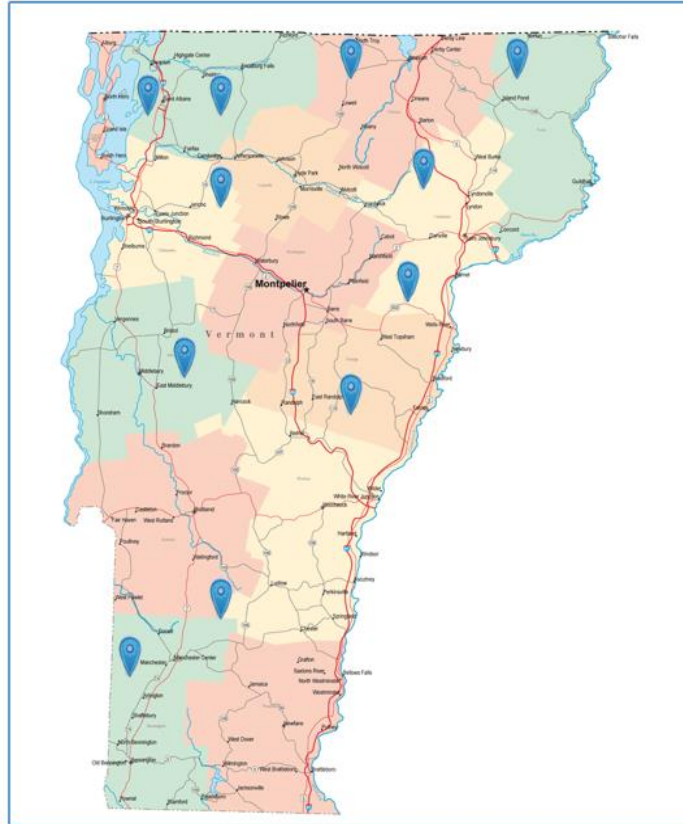
Such barriers must be addressed when considering local phosphorus market potential in Vermont. Studies must be conducted to couple the adoption of phosphorus recovery technologies with the value proposition that recycled phosphorous could be incorporated into markets on a large scale. Phosphorus could also be added to pre-existing production of valued products. This can be done through local partnerships with fertilizer producers; however, it was apparent throughout the course of our interviews that this process has yet to be streamlined. Novel byproducts with specific market niches are in line with the approach outlined by Mayer *et al.* (2016). Potential local Vermont phosphorus recovery centers, as suggested by Jerry Bingold, could play a role here in coordinating with local stakeholders in developing products and synergies.

As part of its mission, P-Rex has helped sponsor a phosphorous eMarket in cooperation with the European Sustainable Phosphorus Platform. This eMarket, shown in Figure 7, is

intended to match supply and demand for recovered phosphorus. Users simply create a user login identifying themselves as either coming from the supply or demand side. They then obtain access to a whole network of stakeholders representing an array of different industries. When they wish to interact in the market, they simply publish how much product they have to offer or demand. Such a network has potential on the smaller scale of Vermont or New England at large. Given the disparities in phosphorous availability across Vermont, this could be a perfect way to connect key farmer stakeholders within the state and prevent farmers from actually looking to outside resources and ultimately bringing additional phosphorus into the Lake Champlain watershed. It could be lucrative for farmers with excess phosphorus, who could either sell internally or to compost operations and other organics processing operations in other areas of the country. If farmers could coordinate in such a way, they could recalibrate phosphorus concentrations across Vermont, while also keeping funds from leaving the state and thus bolstering the local economy. Perhaps such a system could be viable where farmers could input the amount of concentrated phosphorus they had to sell and other farmers would pay for phosphorus at the current market price of imported fertilizer products from Florida, exclusive of a subsidized transportation cost. Figure 8 is an image of what a potential eMarket could look like in the Vermont landscape. Much like the European eMarket, this system would connect phosphorus supply and demand. Such an online platform rooted in a roadmap could also help determine the most efficient pathways of transportation. Transportation costs have the potential to be relatively low if farmers invest in technology that produces a very dry product, such as the Trident Recovery System.



**Figure 7.** Phosphorus supply and demand in Europe on the eMarket (Phosphorus E-Market). Points represent either demand or supply side stakeholders.



**Figure 8.** Hypothetical landscape of Vermont’s eMarket. (Locations are thrown randomly on map and not meant to represent any specific farms). VT Map image, without markers, taken from <http://www.vermont-map.org/road-map.htm>.

### *3.3.4 Phosphorus Extraction Without Digestion*

One promising alternative to the large investment required to purchase a phosphorus centrifuge to work in tandem with an expensive digester is a mobile manure solids separation unit. Native Energy recently received a \$1.2 million Conservation Innovation Grant from the USDA to develop a pilot mobile manure solids separation project (Vermont Project, 2016). According to Brian KillKelley, who is responsible for sourcing new carbon reduction projects for Native Energy, this mobile unit will provide access mostly to smaller farms that have been unable to utilize such technology. Given the poor milk market, small farms are not currently willing to personally invest in such technology. This is because the upfront costs are not attractive relative to the paybacks at this time (B. KillKelley, personal communication, October 27, 2016). Moving farm-to-farm, the mobile unit will be able to process a raw manure in just a couple of hours. It separates the solids and liquid, providing a solid product to local fertilizer and compost businesses. Specific financial arrangements are still being worked out; however, Mr. KillKelley imagines that it will involve an arrangement in which farmers pay for any newly processed bedding to stay on the farm, while the farmer would be paid for and/or benefit from any of the solid fibers taken off the farm. Farmers can benefit in a variety of ways from solids removal. In general, having less solid material to store lowers the risk of pond overflow in heavy rain seasons. There would also be less hauling required for field application. In addition, less solid material settling in the holding ponds would result in a reduced need to agitate the pond,

making pumping easier (B. KillKelley, personal communication, October 27, 2016). If these benefits are meaningful enough for the farmer and the costs of running the mobile unit are tight, the economics may work out in such a way where the farmer may not need any additional financial incentive to participate.

Another promising extraction model is PhosFarm, a German initiative seeking to develop a more efficient technology for phosphorus recovery from agricultural residues in the form of Phosphorus salts. Through an enzymatic process, phosphorus compounds would be mineralized into phosphates which are recovered through precipitation, resulting in a total recovery of more than 90% of the organic phosphorus. Much like the mobile phosphorus unit sponsored by Native Energy, this would be trailer-mounted and easily integrated into any raw manure or digester model. This is an exciting opportunity for efficient extraction of both organic and inorganic phosphorus (PhosFarm, “About PhosFarm”; PhosFarm, “Project Overview”).

Yet another method for reclaiming phosphorus from undigested, “raw” dairy manure slurries is hydrothermal carbonization (HTC), which forms solid “hydrochars” as inorganic phosphate salts. In the HTC process, manure slurries are heated up in water to temperatures ranging between 180 and 250°C. Heilmann *et al.* (2016) suggests that this HTC process can extract 89-100% of the phosphorus content in manure in the form of precipitated phosphate salts (usually around 0.71% P +/- SE of 0.04% for cattle manure). After the HTC thermal process, the phosphate is recovered through precipitation, which occurs after a sequential process involving acid treatment, filtration, and increasing the pH. The phosphorus is mainly associated as calcium phosphate and requires further treatment with yet another acid treatment to make an effective fertilizer (Heilmann *et al.*, 2016). This technology further speaks to the technology currently available for raw manure phosphorus reclamation.

### *3.3.5 Cultivating a Local Phosphorus Market: Recommendations for Vermont Agencies*

In order to cultivate a viable marketplace for this excess phosphorus byproduct, stakeholders will require initial financial support as it will be difficult for this system to develop solely through market forces. A great deal of research looking into how to best grow this market is currently under way. As part of its aforementioned grant proposal, Newtrient LLC is currently seeking funding to help the Vermont NRCS develop a practice standard for manure “handling, separation and processing” (Newtrient LLC, “Strategic”, 2016). Once in place, this standard would provide a more formal structure and grounds for federal funding to overcome the initial high cost of phosphorous removal technologies (Newtrient LLC, “Strategic”, 2016). Such a standard will also hopefully help overcome the current lack of consistency in recoverable forms of phosphorus. As recovery stands now, it is difficult to establish a market when extracted phosphorus can be incorporated into so many different compounds.

Once standardized processing technology is in place, all involved farmers will ideally be working toward producing recycled phosphorus in one specific form. This would most likely be P-cake, which is the product discussed in the Newtrient grant proposal. This P-cake would then henceforth be produced in larger quantities than it is today, but perhaps not to the extent where it could compete with traditionally sourced, mined phosphorus. Therefore, the Vermont Agency of Agriculture should develop policy geared toward subsidizing sales of this recycled phosphorus. A subsidy is preferable to a tax on imported phosphorus fertilizer because such a tax may result in an economic burden on farmers due to a heightened price of the product. If the



state can produce enough recycled phosphorus, hopefully the market would have the means to thrive on its own.

Furthermore, just as subsidies and grants have been used to support biomethane digesters, it would be advisable to provide similar funds to overcome initial barriers to acquiring solids separating technologies. While corporate partnerships can help to cover some of the upfront costs for such separation technologies, it is unrealistic to assume that private forces will widely assume this niche role. Government funds are therefore required either for investment in on-farm or mobile separation technologies. Mobile separation technologies arguably show great promise insofar as they have the potential to cultivate a cooperative model, defraying upfront capital costs for many of the smaller farms. While the unit developed by Native Energy focuses more on carbon abatement, further models could have design concepts revolving purely around phosphorus extraction.

As of now, smaller farmers are financially excluded from investing in phosphorus separation technologies because most of this mechanical and chemical separation equipment is developed for larger farms and, as previously stated, involves high startup costs. Therefore, beyond the aforementioned national EPA Challenge for nutrient recovery, it would be advisable for the Vermont Department of Environmental Conservation to conduct a similar competition seeking viable nutrient recovery strategies geared toward the Vermont landscape. This could very well include a mobile solids separator focused on maximizing not only solids separation, but phosphorus extraction. While many of these technologies would hopefully work in tandem with digesters and help generate positive financial returns, these phosphorus removal systems should also work with raw manure, in line with Native Energy's mobile unit. This aspect is key because it widens the supply of recovered phosphorus. If digested effluent is a necessary input, it will limit the overall market of recoverable product, even if systems running raw manure are less efficient. In line with the national EPA challenge, the initial concept development round would cast a wide net and offer smaller cash prizes, while each subsequent round would provide more incentives and technological assistance from appropriate government agencies.

The governmental backing and technological assistance offered by such a program would hopefully cultivate a lower cost and scalable phosphorus removal technology specifically catered to Vermont. This would ideally provide legitimacy to such technology and motivate more corporate partnerships, which would help shape market demand. The Vermont Department of Environmental Conservation could help pilot the new models, including educational programs for farmers from throughout the state. Logical next steps would be corporate synergies with specific end use products for the phosphorus in mind, or a more communal approach to phosphorus treatment as suggested by Jerry Bingold. These regional centers could help repurpose the phosphorus and have it sent out of Vermont's watersheds, thus lowering nutrient loading in Lake Champlain in line with broader nutrient control schemes.

There is also room for an eMarket, as modeled in Figure 8, which could play a role in repurposing phosphorus for local fertilizer application and providing real time supply and demand governed by the current cost of imported fertilizer. The recovered P-cake may not even require further processing and could potentially utilize the same transport mechanism as the mobile solids separator, thus cutting down on overall system cost. However, such a system would ultimately have to be in line with nutrient loading regulations put forth by the state. This could mean the phosphorus would have to be sent out of state. Either way, such a system could play a pivotal role in redistributing phosphorous loads.

## 3.4 Food Waste Incorporation

### 3.4.1 Food Waste Incorporation and the Universal Recycling Law

Beyond the potential revenue streams associated with removing phosphorus from water bodies or selling phosphorus products, the incorporation of food scraps and other organic waste matter presents a hopeful opportunity for increasing the efficiency and cost-effectiveness of biomethane digesters in Vermont. In fact, incorporating food waste introduces more nutrients into the system and could potentially generate more recoverable phosphorus, which could then be marketed (Mayer *et al.*, 2016). However, increased energy production is perhaps the most important component. Lisa Ransom of Grow Compost, a farm and composting operation that now hauls food waste to the Vermont Tech community digester, explained that because solid and liquid food waste has not been pre-digested like cow manure, it has a higher energy content, which means it can increase the energy produced by the digester (personal communication, November 4, 2016). For example, Monument Farms in Weybridge is currently using lees (leftover dead yeast) from Woodchuck Cider and rinse water from Cabot Creamery to increase the generating capacity of its digester by 15%, while saving the suppliers money they would have had to spend to transport and treat the liquid waste (B. James, personal communication, October 28, 2016). Vermont's Universal Recycling Law will also incentivize food scrap incorporation because food waste generators are now required to divert their waste from landfills and will need alternative receiving facilities (DEC, 2016).

Passed in 2012, the Universal Recycling Law (Act 148) states that all organic waste matter will be banned from landfills by 2020. Commercial sources of food waste, such as restaurants, grocery stores, schools, and breweries, which generate 18 or more tons of food scraps per year, are already required to comply with the law. Haulers will be required to collect food scraps from curbsides beginning in July of 2017, and the full ban will take effect in 2020. According to the new law, receiving facilities, like anaerobic digesters or community composters, can charge food scrap haulers for the waste they process (DEC, 2014). However, if solid food waste is processed at an off-farm treatment facility before digestion, it is likely that the treatment facility owner would receive a portion of this fee.

### 3.4.2 Benefits of Incorporating Food Waste

#### *Energy generation*

One of the primary advantages of adding food waste to digesters is the increase in the energy generated. Given that electricity sales account for over 50% of digester revenue, incorporating food waste could increase overall economic value substantially. While Monument Farms observed a 15% increase from adding a small amount of food processing waste, an expert from Agricultural Energy Consultants, Michael Raker, estimates that if liquefied food waste were to make up 10% of digester input, it could double the amount of energy generated (DSM Environmental Services, Tellus Institute, & Spencer, 2013). A study comparing the mono-digestion and co-digestion of food waste and cow manure found that co-digestion produced up to 3725 mL of total methane while mono-digestion of cow manure only produced between 14 and 16 mL (Zhang *et al.*, 2013). Methane production from co-digestion was highest when a 2:1 food waste to cow manure ratio was used (Zhang *et al.*, 2013). Lipids are also particularly beneficial for anaerobic digestion because of their high methane potential. Normal food waste usually

contains around 22.8% fat (Zhang *et al.*, 2013). However, adding “oily wastes” can increase digester productivity to an even greater extent. In fact, a study testing the optimal amount of fat that could be used in digestion found that continuous inputs and pulses of oil (total of 12gCODoil/reactor) were shown to improve methane production. However, after 18gCODoil/reactor, the extra oil and fat began to inhibit the process, which indicates that these energy-rich wastes should be added with caution (Neves, 2009).

### *Increasing Stability*

In addition to maximizing the energy generation of digesters, incorporating food waste can also make digester systems more stable, potentially reducing maintenance costs. The Gebbies family of Maplehurst Farm in Greensboro, Vermont noted in their application for a permit to receive food waste that their digester had “not been performing as anticipated ... exclusively using manure produced on the Farm, and the digester is at risk of stopping during the cold weather months without the addition of more potent substrate, such as food waste” (Goldstein, 2013). Co-digestion of food waste and cow manure actually helps balance pH level, which improves stability and allows it to take in organic matter at a higher rate. Specifically, co-digestion has been shown to produce a higher degradation of volatile fatty acids (VFAs), which is associated with increased buffer capacity. Furthermore, co-digestion produced lower levels of ammonia, whereas higher ammonia levels (700+) were observed in systems digesting solely cow manure. Ammonia has been shown to inhibit the process at concentrations higher than 700 mg/L. Combined, the ammonia from cow manure and VFAs from food waste neutralize each other, which helps stabilize the system (Zhang *et al.*, 2013).

### *Tipping Fees*

Although tipping fees, or the fee normally paid to landfills, could represent another source of revenue for digesters, it is currently ambiguous as to whether food waste suppliers will be required to pay the fee since digester owners will already benefit from the additional energy generation. The community digester owned by Vermont Technical College in Randolph, Vermont will be the first in the state to incorporate significant amounts of solid food waste. However, the facility is currently not requiring tipping fees in order to secure enough initial food waste. Additionally, the project team did not want to rely on tipping fees because Act 148 “has resulted in a very volatile market for organic wastes” (Sawyer, 2016). After its first year in operation, Vermont Tech plans to analyze the economics of not charging tipping fees, which may change its decision (Sawyer, 2016).

On the other hand, Thompson, Wang, and Li (2013) note that “it is an accepted practice for cheese producers in Vermont to pay a small fee” to digesters in return for getting rid of their whey, which would normally need to be treated at a wastewater treatment facility. Compost facilities such as Kimbell Compost and Green Mountain Compost also charge tipping fees, although these fees are usually much lower than those charged by landfills (Baird, 2014; Green Mountain Compost, 2016). A national economic study on the market value of anaerobic digester products found that “the majority of industry interviews indicate that digester owners receiving organic substrate should be able to receive the equivalent of landfill tipping fees in the states they are located in” (Informa Economics, 2013). For example, in Massachusetts, the waste hauling company Casella pays a tipping fee to a digester owned by Vanguard Renewables, which processes the waste that Casella would otherwise have to take to a landfill (M. Scallon, personal communication, November 15, 2016).

### 3.4.3 Obstacles to Incorporating Food Waste

#### *Contamination*

One of the largest concerns for digesters receiving food scraps is making sure the new feedstock does not contain any harmful materials that could affect soil quality or create health risks for the cows using the bedding byproduct. While oils, fats, and sugars are especially good for feedstock, as Bob James of Monument Farms noted, any trace of meat could contaminate the bedding with harmful bacteria (personal communication, October 28, 2016). According to Lisa Ransom, another problem is the microplastics that sometimes make it into food scrap piles because people forget to take off fruit stickers or accidentally throw in their forks or plastic wrappers. These plastics not only pose health risks for cows but can also cause mechanical problems for digesters and separation equipment, negatively affect soil quality, and be visually unappealing (L. Ransom, personal communication, November 4, 2016).

In order to ensure high quality, clean food waste, Grow Compost is constantly communicating with and training sources to make sure the waste is sorted and that no harmful materials are included. They also have representatives that work to educate the public, especially in elementary schools, on how to sort waste and what happens to their waste. Grow Compost also inspects each “tote” of food waste individually before it is processed into compost or incorporated into the digester. Abbie Webb, the sustainability director at Casella Organics, which collects waste on a larger scale, explained that they are relying on existing relationships with food waste producers to convey the importance of proper sorting and will work with municipal governments to relay their message to the residential sector (personal communication, November 10, 2016).

Although adding food waste to digesters can improve the quality of the fertilizer produced because of the additional nutrients being processed, it can also complicate farmers’ nutrient management plans (DSM Environmental Services, Inc. *et al.* 2013). As mentioned in the Monetizing the Benefits from Water Quality section, farmers are already pressured to reduce phosphorus loading from their land, so managing additional byproducts from digesters may make it harder for farmers to reach their TMDL baselines, especially for small farms without enough land space to apply the liquid digestate or without the phosphorus separation equipment discussed earlier in this report.

#### *Permitting*

In addition to keeping contaminants out of food waste, the permitting process represents another obstacle for incorporating food scraps into anaerobic digesters. Digester operators must receive a permit from the Department of Environmental Conservation’s Solid Waste Department, in addition to the approval process required by the Agency of Agriculture. While most farms are accustomed to dealing with the Agency of Agriculture, as Carey Hengstenberg of the Vermont Agency of Natural Resources (ANR) explains, “a lot of farms seem hesitant to have ANR involvement in their operations” (Goldstein, 2013). While Bob James uses liquid waste from Woodchuck and Cabot in his digester, when asked if he would consider adding solid food scraps, he explained that the application process is highly complex (personal communication, October 28, 2016.) In fact, the Vermont Tech digester is the only digester in Vermont with a permit for solid waste incorporation (Sawyer, 2016). At the onset of the Vermont Tech project, the permitting requirements for incorporating solid food waste were still very unclear. However, by

2015 Vermont Tech had clarified many of these questions by working with state regulators and hopes the process can be simplified even more in the future (Sawyer, 2016).

### *Transportation and Processing*

In order to successfully divert food and other organic waste matter to anaerobic digesters on farms, it needs to be transported efficiently and delivered in a form that can be easily incorporated with the on-farm feedstock. Although trash and recycling haulers will likely take on the additional role of picking up and distributing food waste as Act 148 is implemented, they cannot simply drop off food waste at farms. Because most food waste in Vermont is in solid form, and not the pumpable slurry form required by digesters, farms would have to process the food waste, the equipment for which could cost between \$50,000 and \$100,000 (DSM Environmental Services, Inc. *et al.*, 2013). Most digester owners would not be willing to invest and operate this type of processing facility on their farm, so centralized collection and processing facilities should be constructed across the state in order to provide farms with a slurry free of contaminants and ready to be put in the digester (DSM Environmental Services, Inc. *et al.* 2013).

Currently, both Casella and Grow Compost are working on a pilot program for treatment facilities that liquefy food waste into a slurry, which is collected and inspected beforehand (A. Webb, personal communication, November 10, 2016). The final slurry can then be delivered to neighboring farms that have permits to accept food waste. The Casella West Rutland facility and the Grow Compost facility are currently the only waste processing plants in Vermont that turn food waste into slurry for digestion, so more will need to be developed in order to make food waste a reliable source of feedstock for digesters (B. Gauthier, personal communication, November 17, 2016).

### *3.4.4 Recommendations*

#### *Waste Screening*

In addition to continued communication with food waste providers and close inspection of waste totes, new technologies could also be used to keep harmful contaminants out of digester feedstock. Agri-Cycle Energy, an organics collection company in Maine, recently developed a “depackaging machine,” which separates out expired or damaged solid food waste as well as plastic and other contaminants. It simultaneously grinds the waste into a liquid slurry, which is then stored at the facility before being sent to a digester (Agri-Cycle, 2016). Similar technologies could be developed in Vermont in order to depackage and liquefy waste more efficiently.

#### *Solid Waste Service Fee*

In order to provide on-farm digesters with slurried digester-ready food waste, more infrastructure is needed in Vermont. Although Casella and Grow Compost have pioneered in this area by piloting new Organics Reclamation Facilities supported by a grant from the Vermont Clean Energy Development Fund and Green Mountain Power, more are needed in order to minimize transportation costs and reach more digesters. Casella suggests that funding for more infrastructure projects could come from a solid waste service fee, which the state is considering as a way to successfully meet the goals of the Universal Recycling Law (Casella Resource Solutions, 2016). This fee would raise about \$5.5 million annually, compared to the current franchise fee, which raises \$3.3 million in revenue but does not cover the service cost of recyclables or organics (DSM Environmental Services, Inc., 2015). A portion of this revenue

could be used to help fund new organic collection and processing facilities as well as transportation to farm digesters.

### *Simplified Permitting Process*

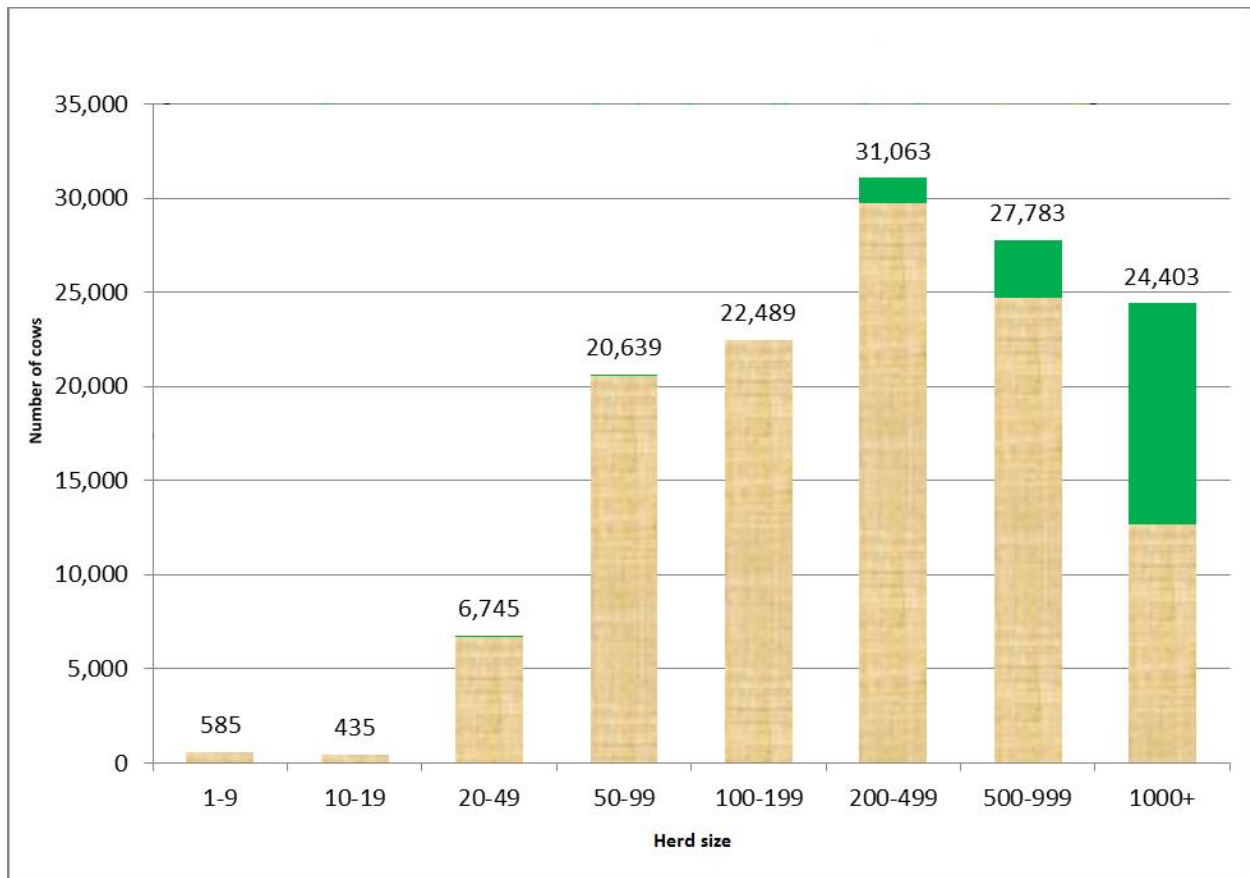
Clarifying the requirements in the current DEC Solid Waste permit would help farmers hoping to incorporate solid food waste. However, permits for digesters could also be combined under one general permit in order to save digester owners the hassle of going through multiple regulatory agencies. Massachusetts now has a general permit for digesters, which categorizes them as a “recycling activity” (Snellings, 2010). As William Jorgenson of AGreen and BGreen energy (a company that owns digesters in Massachusetts) and Vanguard Renewables notes, “There is significantly less expense and time involved in permitting a facility under this new rule” (Goldstein, 2014). While a similar permit could be designed for Vermont digesters, existing facilities may still need to apply for a solid waste permit, so the DEC should work with farms and food waste pioneers like Vermont Technical College to simplify the existing process.

## 4. Community Digesters: An Alternative Ownership Model to Consider

### 4.1 Digester Adoption by Herd Size

Although all of the additional revenue streams explained in the sections above could help small and medium-size farms to turn a profit on their investment eventually and sustain their operations in the long-run, they still do not remove the fact that without grants and low-interest loans, it is very difficult for any small- to medium-sized farms to access enough capital to pay for the sizable upfront costs of a digester in the first place. The community digester model, which by definition collects slurry from multiple farms, provides a solution to the substantial upfront costs problem by allowing farms to share the initial investment costs and to combine inputs in order to take advantage of economies of scale.

Treating manure as a resource instead of a waste product would entail that manure be utilized or processed on a relatively local scale, so that transportation costs may be minimized, as well as the associated carbon pollution. Quite shockingly, only 10% of dairy farm manure is currently processed by a digester system in Vermont, because most of it is generated on farms with fewer than 500 cows, and it has not been cost-effective for such farms to own a digester (Department of Public Service, 2016). As shown in Figure 9, to seriously scale up the capture of both the private and public benefits of manure as a valuable cash crop within Vermont, significant progress must be made on farms with fewer than 500 cows with regards to the adoption of anaerobic digestion technology.



**Figure 9.** Vermont Herd Size Distribution and the Proportions of Manure Digested (digested in green) (Vermont Agency of Agriculture, Food and Markets, 2014).

Historically in the U.S., digesters have mostly been built on large dairy farms. In fact, only four digesters can be found on farms with fewer than 200 cows (Lansing). Looking at overseas examples, however, proves that this is a culturally-specific phenomenon, as small-scale digesters do exist on farms in developing countries such as China—not to generate electricity, but to produce enough biogas to heat water or to cook. The capital-intensive, manure-to-energy digester model is not the only one out there, though it certainly has been made the dominant one in the U.S. by government agencies that heavily subsidize the research and construction of this type of digester (Welsh, Grimberg, Gillespie, and Swindal, 2010). Government programs and policy favor large-scale operations because food production is understood to be the most efficient that way. Conceivably, however, government efforts can just as well be spent on developing small-scale biomethane digesters for small and medium farms or centralized community digesters. The recent change to the SPEED program in 2015 that awards smaller digester projects with 19.9 cents per kWh instead of just 14.5 cents is a step in the right direction (Department of Public Service, 2016).

Due to limited research and development of small-scale anaerobic digesters, and the U.S. cultural and socio-political biases that promote the spread of large-scale digesters on big farms (Thompson *et al.*, 2013), many owners of small-scale farms have not even considered the prospects of installing an anaerobic digester on their farm. Small-scale farmers have internalized these biases; the survey conducted by the Castleton Polling Institute and commissioned by the Vermont Agency of Agriculture found that even amongst dairy farms with more than 200 cows,

over 58% of the 171 farms surveyed have not explored how to install a biomethane digester on their farm (Clark and Flood, 2014).

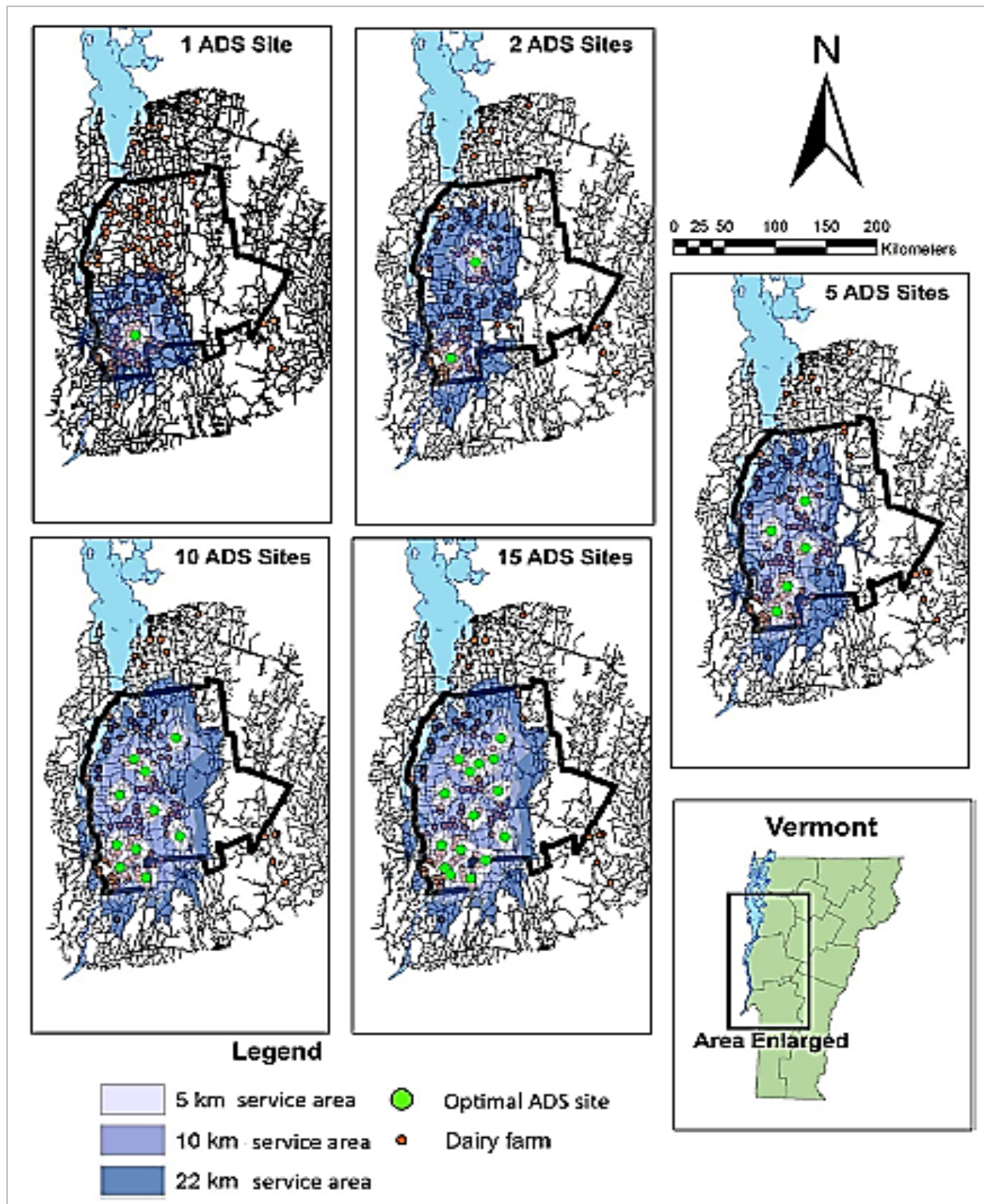
## 4.2 Communal Digester Model

In spite of these hurdles, GMP has been working on setting up a community digester in St. Albans that will be owned by the utility company itself. The project involves a total of three farms, with two of them being neighbors to one another, and the third one lying just within the reach of a pipeline. The permitting process is expected to be completed by early 2017, with construction taking place during the summer of 2017; the digester should be up and running by the fall. Once built, this community digester will be the first of its kind in Vermont to bring multiple farms together with the combined goals of renewable energy generation and air and water quality improvements. It will have a capacity of 800 kW, and it will be able to process manure produced by over 2,000 cows and digest 3,000 tons of food scraps and food processing wastes annually (D. Dunn, personal communications, December 6, 2016).

But while 2017 may be a milestone year for Vermont that marks the completion of the state's first community digester, it will be the 25th anniversary of a community digester in Denmark called Lemvig Biogas, built in 1992. That digester, touted as the reference biogas installation in the country, is one hundred percent privately owned by a cooperative of 69 farms and accepts slurry from as many as 75 farms. In the hopes of utilizing all of the nutrients available in the manure and in the other wastes deemed suitable for this co-digestion, Lemvig has set up a "digestate bank" to redistribute manure and nutrients in the agricultural area. Each slurry supplier will receive back only the amount of digestate that it is allowed to spread on its fields; the rest of the digestate is separated into fractions to be sold to crop farmers as alternatives to commercial fertilizers (International Energy Agency, 2013).

Geographic Information Systems (GIS) technology can be used to calculate the optimal number of regional anaerobic digesters and to locate the optimal sites for these digesters; furthermore, it can make visible all the pathways of synergies that could reduce transportation costs by preventing the trucks from having to make any trips with an empty load (Thompson *et al.*, 2013). Thompson *et al.* (2013) found that, in Addison County, six is the optimal number of community digesters to build; beyond this number, the marginal benefits of building an additional digester are smaller than the marginal costs (see Figure 10). The caveat here, however, is that GIS takes none of the local politics into account, so in the end, these "optimal" locations may not actually work on the ground. Even so, this mapping tool can make digesters more affordable by calculating the most cost-effective locations to place them and the optimal number of community digesters for a given region.





**Figure 10.** Optimal sites and service areas for 1, 2, 5, 10, and 15 anaerobic digesters in Addison County, Vermont (Thompson *et al.*, 2013).

Abbie Webb of Casella Organics and Lisa Ransom of Grow Compost and the VT Tech Community Digester project each insisted that, without transportation efficiencies such as backhauling, neither community digesters that make use of mostly manure nor those that make use of mostly food wastes will be cost-effective (A. Webb, personal communication, November 10, 2016; L. Ransom, personal communication, November 4, 2016). This does not, however, take away from the fact that manure and food wastes are valuable raw materials. Therefore the Vermont state legislature should consider subsidizing manure transportation so as to lessen the burden on farmers and haulers to figure out transportation efficiencies on their own (see Section 3.2: *Access to Cheap Manure via Subsidized Manure Transportation*).

In addition to using GIS to solve these issues, determining which trucks to buy and use is equally crucial. Ms. Ransom stated that Grow Compost's food waste collection operations are some of the most extensive in the region, and their experience with box trucks has been the most successful (personal communication, November 4, 2016). The state should consider providing incentives for purchasing high-efficiency trucks and/or set up communication platforms so that haulers can become more aware of this.

#### 4.3 Recommendations

Community digesters can be a very important piece of the puzzle for figuring out how Vermont is going to move beyond the current 10% mark of total manure captured by a digester system. The Agency of Agriculture should develop support and demand for alternative models of digesters from Vermont state agencies, digester design companies, and farmers. Farmers with fewer than 500 cows in particular have shown much ambivalence and hesitance towards even exploring the possibilities of installing a digester. The Agency can change this by conducting outreach programs that target small to medium dairy farms. At the state planning level, the Agency may also consider i) funding studies that will identify the most cost-effective locations of community digesters, and ii) promoting truck models that achieve highest fuel-efficiency standards through, for example, providing financial incentives.

### 5. Environmental Consequences of Digesters and Potential Solutions

Although biomethane digesters can be promoted as a green source of energy due to their benefits for greenhouse gas emissions reductions, this does not mean that they are without environmental impacts and safety concerns. In order to maximize net environmental benefits of digesters, the consequences should be carefully considered and minimized. It should not be assumed that the environmental benefits of digesters outweigh the costs; environmental consequences need to be analyzed and regulated.

#### 5.1 Air Quality Regulations

Digesters are a renewable source of energy that can mitigate the effects of climate change, but they do release toxic air pollutants from the engine generator. There are some regulations in place regarding these emissions, the implementation of which is overseen by the Vermont Agency of Natural Resources, Department of Environmental Conservation, Air Pollution Control Division.

The Air Pollution Control Division has determined that projects involving the use of biogas to produce energy are not required to obtain an Air Pollution Control Permit under the Vermont Air Pollution Control Regulations, provided that certain conditions are met. Engine emissions must follow, at a minimum, the federal emission standards for Tier 2 Non-road engines contained in Title 40 of the Code of Federal Regulations (CFR) Part 89. These standards are shown in the following table, which was provided to us by Jay Hollingsworth of the Air Pollution and Control Division.

**Table 8.** 40 CFR Part 89: Control of Emissions From New and In-Use Nonroad Engines (J. Hollingsworth, personal communication, November 21, 2016).

Pollutant	Emission Standard <sup>1</sup>
oxides of nitrogen plus hydrocarbons (NO <sub>x</sub> +HC)	4.8 g/bhp-hr
carbon monoxide (CO)	2.6 g/bhp-hr
particulate matter (PM)	0.15 g/bhp-hr

Newer spark ignition engines are subject to further regulations under recent legislation. These regulations are shown in Table 9:

**Table 9.** 40 CFR Part 60 Subpart JJJJ: Standards of Performance for Stationary Spark Ignition Internal Combustion Engines (J. Hollingsworth, personal communication, November 21, 2016).

Pollutant	Emission Standard*
oxides of nitrogen (NO <sub>x</sub> )	3.0 g/bhp-hr
carbon monoxide (CO)	5.0 g/bhp-hr
volatile organic compounds (VOC)	1.0 g/bhp-hr

\*g/bhp-hr means grams per brake horsepower hour.

For an engine that has a maximum power of 19 kW (25 HP) or less, is gasoline fueled, or is a rich burn engine fueled by liquid petroleum gas, and whose date of manufacture is on or after July 1, 2008, the manufacturer of the engine is responsible for certifying emissions compliance. Engine manufacturers are not required to certify other engines. If an engine is not manufacturer certified, the user must demonstrate that the engine complies with state regulations. An engine must undergo initial performance testing during its first year of operation, as well as some additional performance tests if it has a rating of over 500 brake horsepower (bhp). Some engine manufacturers are working with the federal Environmental Protection Agency (EPA) to certify their engines for biogas applications, so that individual users would not have to undergo on-site emissions tests. Because these regulations are federal regulations, not Vermont state regulations, owners of biomethane digesters must work with the engine manufacturer or supplier and the federal EPA to ensure that their engines meet the standards (J. Hollingsworth, personal communication, November 21, 2016).

The regulations on engine exhaust stack height are as follows: “The engine exhaust stack must be vertical and extend a minimum of four (4) feet above the nearest point of the roof. The stack shall not be equipped with any device that may obstruct the upward discharge of the exhaust gases such as a fixed raincap. Flapper valves are acceptable provided they open fully at

all loads.” Digesters must have a backup combustion device to prevent raw gas from being directly emitted into the air in case the main engine goes offline or if it cannot accommodate the quantity of biogas being generated at one time (J. Hollingsworth, personal communication, November 21, 2016).

Biomethane digester owners are required to submit documentation to the Vermont Agency of Natural Resources, Department of Environmental Conservation, Air Pollution Control Division, which will then send documentation stating whether or not an Air Pollution Control Permit is required and if any additional information is needed. If the operator makes any changes to the project, such as combusting a different fuel, altering the engine or flare, or changing the system capacity, he or she must notify the Agency of Natural Resources so that it can determine if the altered system requires a permit or not. The Agency of Natural Resources is currently in the process of having all digesters in Vermont under a permit, which will ease the registration process for the Agency (J. Hollingsworth, personal communication, November 21, 2016).

Additionally, as mentioned in the Economics section, digester owners must pay a registration fee for criteria pollutants and toxics. Bob James of Monument Dairy received his first registration fee two years ago, and the cost of the fee was a huge shock to him and other digester owners in the area. Monument Dairy was charged \$2,469 the first year and \$2,123 the second year; this cost was higher than Mr. James expected. According to him, the cost of certain pollutants changed during the time when he was preparing to install a digester and was first in contact with the Agency of Natural Resources and the time when he received his first registration fee. Despite Mr. James’ and other Vermont farmers’ surprise at the high cost of these fees, Vermont’s restrictions are more lenient compared to many other states, some of which require the use of catalytic converters and annual emissions tests. While admitting that Vermont’s regulations are not particularly strict, Mr. James told us that an emission test can cost \$6,600 and he does not “want to stir up anything that would make things more difficult or costly” (personal communication, October 28, 2016 and December 28, 2016). Currently, the economic burden of increasing regulations in Vermont could be too much for farmers and could further deter farmers from purchasing digesters. However, some farmers are already investing in technology to reduce their emissions. Blue Spruce Farm has invested in a gas scrubber to remove hydrogen sulfide, and they continue to refine their system (M. Audet, personal communication, January 3, 2017). The Agency of Natural Resources recently permitted a digester for GMP that proposed hydrogen sulfide controls and a catalyst for the engine. Depending on the performance of the digester and operation cost, the Agency may decide to require hydrogen sulfide controls and catalysts for farm digesters in the future (J. Hollingsworth, personal communication, November 21, 2016).

## 5.2 Leaks, Spills, and Explosions

Leaks and spills of both organic material entering the digester and the outputs of the digester are a concern and need to be taken into account when evaluating environmental risk associated with digesters. Biogas produced by the digester is composed of methane, hydrogen sulfide, and carbon dioxide. Methane gas is flammable or explosive in certain conditions, so fires and explosions are cause for concern (AgSTAR, 2011).

A biomethane digester in Dane County, Wisconsin, near Waunakee, provides an example of the real risk of spills associated with digesters. In just two years, the digester had three spills, an explosion and fire, and violations of state regulations, posing serious threats to the watershed. Following these events, Clear Horizons, the company operating the digester, installed a spill

containment system and other safety mechanisms. Eventually, Clear Horizons decided to sell the digester to Clean Fuel Partners, which it believed was better equipped to safely operate the digester (Glaze; Ivey). This event has become the classic example of a biomethane digester disaster and was mentioned by a few of our interviewees. These safety mechanisms are essential in order to minimize environmental and health risks associated with digesters.

### 5.3 Soil Health

George Foster of Foster Bros. Farm expressed concern about the use of biomethane digesters to produce fertilizer because the fertilizer it produces may pose a threat to earthworms, which are crucial for productive soil. Mr. Foster used to have a digester, but it caved in due to snow and he decided not to replace it. He now believes that practicing no-till agriculture is a better method of reducing phosphorus runoff into Lake Champlain and other bodies of water than is the use of biomethane digesters, especially due to his concerns regarding earthworms (G. Foster, personal communication, 20 October 2016; Penn State Extension, 2016).

Earthworms are essential for soil health. They enrich the soil by mixing the organic matter that they consume into it and by providing nutrients; their casts contain nitrogen, phosphorus, potassium, and calcium and their excrement contains zinc and boron. Earthworms can reduce water runoff by forming vertical burrows, excrete material that helps decompose organic matter, and regulate the pH of the soil by neutralizing the soil that passes through them. Agricultural practices that are beneficial to earthworms include no-till, crop rotations, manure, organic amendments, surface crop residue (for example, planting cover crops and leaving them on the field), fertilizer, and lime. Practices harmful to earthworm populations include tillage, acidification, removal of crop residue, and toxic products (Penn State Extension, 2016).

Clements (2013) found that when slurry or digestate manure was applied at a high enough amount, earthworms exhibited avoidance behavior. Further research should be conducted on the effects of digestate on earthworms, especially research specific to the soils and species of Vermont.

### 5.4 Recommendations

Vermont can minimize the negative consequences of digesters by requiring catalysts, other pollution abatement technology, and more emissions tests like other states, but it is important that these additional regulations do not place too heavy a burden on farmers. We suggest further research in the environmental consequences versus the benefits of biomethane digesters and how to further mitigate the consequences. Cost-benefit analyses must be conducted in order to truly decide if biomethane digesters have a net environmental benefit and, if not, what additional restrictions can be put on them to maximize their environmental benefits and minimize negative impacts. However, if the benefits of digesters substantially outweigh the costs even without stricter regulations in place, registration fees for air emissions should be eliminated or decreased in order to reduce the financial burden of owning a digester.

Disasters also pose a threat to human and environmental health; in order to reduce risk in the event of a disaster, workers should be trained on how to safely run digesters, and all sites with digesters should have an emergency action plan in place in case a leak, spill, explosion, or other safety hazard occurs (AgSTAR, 2011). We also suggest further research on the effects of digestate on the soil, in particular the soil in Vermont; studies in other regions of the country may

not be applicable to Vermont due to differences in soil type. This research should focus especially on earthworms, which are essential for soil health and crop production.

## Conclusion

Biomethane digesters are part of a complex system, and a wide range of policies taken together can make them more economically viable and take advantage of all of their potential benefits. A reliable source of funding is key to making biomethane digesters economically viable on Vermont dairy farms, since the high upfront cost, which is typically one to two million dollars, is the biggest barrier to purchasing a digester. Because the environmental benefits of digesters are public benefits, the financial burden of digesters should not be placed completely on farmers or other digester owners. The current policies that provide economic support for farmers, such as the feed-in tariff program, have provided more economic stability to biomethane digester owners. These policies are important and should stay in place. However, they are not enough to cover start-up costs, and that is why grant money is essential. The grants available from 2009 to 2011 through the §1603 program allowed a number of farmers to purchase digesters when they otherwise would not have been able to. According to Wang *et al.* (2011), 34.7% of the average total project investment of \$2 million dollars for a digester was funded by grants. A significant portion was funded by loans, but some farmers may not have sufficient credit to secure loans. Therefore, grant funding needs to be renewed in order for farmers to be able to purchase digesters.

In combination with initial grant funding, additional revenue sources will be necessary to make digesters self-sustaining in the long term. If farmers can monetize the benefits from water quality, digesters will be more economically feasible. While further research on the details of a water quality credit trading program is needed, Kieser & Associates and Tetra Tech (2015) found that most of the necessary conditions for a successful trading market have been met or partially met in Vermont. However, due to the stringent regulations in place for nonpoint agricultural sources, a phase-in model that temporarily allows farmers to sell credits in order to meet their baseline should be adopted in order to incentivize trading among farmers and between farmers and point sources. This could be combined with a “declining cap” model, in which entities would buy fewer and fewer credits each year until they can meet the TMDL goal on their own. According to Kieser & Associates and Tetra Tech (2015), a bilateral water quality trading on a case-by-case basis would be the best model in Vermont. However, a clearinghouse or Pigouvian tax/subsidy model could be effective frameworks as well, especially given that nonpoint to nonpoint source trading and demand from wastewater treatment facilities could change the cost differential. Establishing a system that encourages farmers to reduce their phosphorus runoff into Lake Champlain and other bodies of water is essential, because in total farms must reduce this runoff by 53% to reach the state’s TMDL goal (Hirschfeld, 2014).

The use of phosphorus separating technologies should be encouraged in order to maximize phosphorus recycling, diversion, or relocation. Within the state of Vermont and across the country, certain soils are deficient in phosphorus while others have excess phosphorus. Phosphorus is a valuable resource in the soil, so if phosphorus can be effectively separated, it could be bought and sold, thereby establishing a market for phosphorus. Just as digester projects are awarded grants to help Vermont reach its renewable energy development goals, phosphorus

separating technologies should be funded with grant money as well, thereby monetizing their water quality benefits as a public good.

Incorporating food waste can maximize the benefits of anaerobic digestion by increasing energy production and turning food waste into a resource. With a communal digester model, these digesters could accept waste from nearby dairy farmers and food waste facilities. With digesters on individual farms, dairy farmers and food providers can form partnerships like the one established by Monument Dairy and Woodchuck Cider. However, more infrastructure is needed in Vermont to clean and process food waste into a slurry that can be easily incorporated into digesters on dairy farms. A simplified permitting process would also assist farmers and other digester owners in beginning to incorporate food waste.

Despite their benefits for greenhouse gas reductions, digesters pose environmental consequences, which need to be further examined; stricter or looser regulations on air emissions may be called for. Currently, digester owners are required to pay fees for their air emissions, which may be counterproductive. Although these emissions are a concern, if it is determined that the benefits to air quality in the form of reduced greenhouse gas emissions outweigh the costs of other emissions, this fee should be eliminated or decreased. If digesters should be encouraged, owners should be given a tax incentive or rebates instead of a penalty. However, Vermont may be able to further mitigate the environmental consequences of digester operation without placing too heavy a financial burden on farmers. Most digesters in Vermont have no installed technology such as a catalyst to control air pollution. Depending on the performance and operation cost of the new GMP digester in St. Albans, which will feature hydrogen sulfide controls and a catalyst, these pollution abatement features may be required for digesters in the future (J. Hollingsworth, personal communication, November 21, 2016).

All of the alternative revenue sources discussed in this report would assist dairy farmers, especially small farmers, in successfully purchasing and operating biomethane digesters on their farms. However, because the majority of Vermont's dairy farms have fewer than 200 cows, in many cases it still may not be feasible for farms to own on-site digesters. Instead, a communal digester model may make more sense in Vermont. Communal digesters can be promoted by subsidizing the transportation costs so that these costs are not a burden to farmers who wish to haul their manure to a communal digester. Maryland has put this into practice, and Vermont can look to its model as an example. Maryland uses a Manure Matching Service that helps farmers find entities that are willing to give or accept manure. Vermont could establish similar programs to assist with the adoption of communal digesters. Farmers can save money if they have a digester available to them nearby instead of having to purchase their own digesters for use on their farms. We suggest further research on community digester models in Vermont, including how all of the alternative revenue sources that we have discussed, such as water quality credit trading, may be applied to communal digesters.

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