Worcester Community Project Center

Assessing Dairy Farm Waste Technologies in New England

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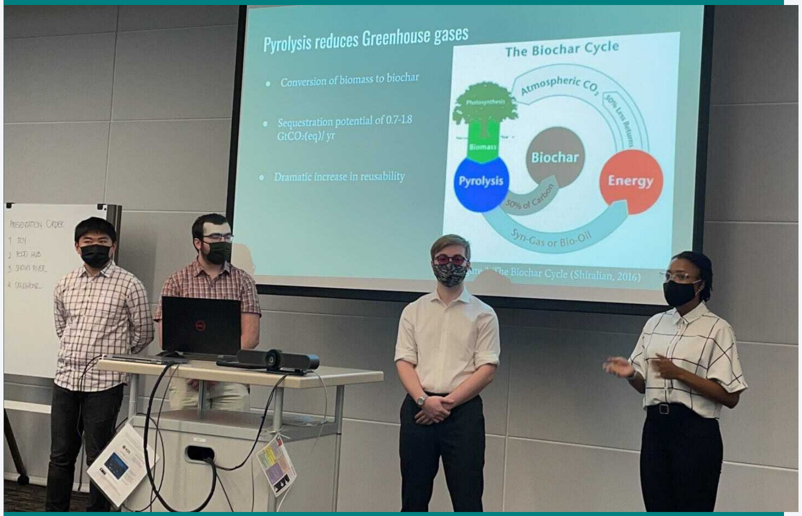
WPI | Worcester Community Project Center

Our Team



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Abstract

In this project, we sought to provide comprehensive and in-depth insight into the state of waste management innovations within the New England dairy industry, on behalf of Snowy River Innovations, a leader in sustainability technology adoption in Australia. More specifically, we explored adoption of anaerobic and aerobic digesters and pyrolysis technologies, and the drivers and challenges of small-scale operators adopting these technologies. Through a multi-method approach, including interviews, case study observation, and on-line research, we developed: 1) an overall mapping of key contextual factors and best practices and 2) more detailed insight into the lived experience of technology adoption, which can be shared with small-scale dairy farmers in Australia and beyond.

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Introduction: Understanding the Scope of Waste Management Innovations

Dairy Farm Emissions

The world is threatened by climate change. Greenhouse Gases (GHG) have invaded the atmosphere and have contributed to global warming and extreme weather events. Concentrations of carbon dioxide, nitrous oxide, and methane are increasing by “40%, 20%, and 150% of pre-industrial age levels” (Wang, Jin, et al., 2018). The emissions originate from multiple sources, including travel, agriculture, waste, energy, and factory usage. Ecological threats of climate change, including rising sea levels, rising temperatures, heightened forest fire activity, and endangered species have precipitated the need to find new technologies to mitigate the effects of greenhouse gases.

Figure 1: Ecological damage from a forest fire (Spence 2019)

In the United States, the agricultural and dairy industries emit GHGs and other pollutants into the atmosphere because cows generate methane from their digestion and waste. In 2018, the national dairy industry was responsible for 83.5 Megatons of carbon dioxide equivalent (CO2e), or 1.3% of the U.S. total emissions. Important forms of GHG emissions include methane and nitrous oxide, manure handling, and crop and pasture land (Rotz, 2018). For example, Figure 2 visualizes the production of methane and other GHGs from cattle as they eat and breathe. Manure storage and handling yield harmful effects in the environment, especially when manure is used as fertilizer, which increases toxic compounds in the soil. Cattle are one of the U.S.’s most common livestock and are used for different revenue streams. Dairy and beef farms exist in all 50 states. In terms of sheer numbers, the U.S. quarters “31.2 million beef cows” and “9.44 million milk cows” (National Cattlemen's Beef Association - Producers, 2021).

Cattle are one of the U.S.’s most common livestock and are used for different revenue streams. In 2021, there were 31,657 licensed dairy farms reported in the United States (USDA Report, 2021) and over 1,000 dairy farms in New England alone (Meet the Farm Families, n.d.). The large-scale dairy industry has roughly 40 million cows, which contribute to greenhouse gasses into the atmosphere, as well as creating “two billion tons of manure each year” (Hatchett, 2005).

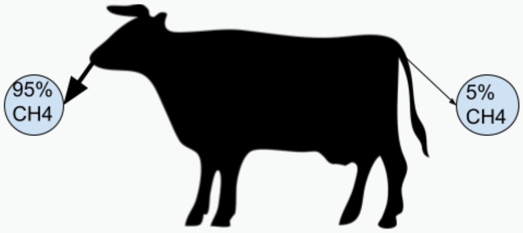

Figure 2: Breakdown of livestock base methane emissions (Information from Ruark 2018)

Uncertain Dairy Economy

The national dairy economy plays a large role in the daily life of farmers as well as major financial decisions including large developments added to the farm, modifications to the land, and implementation of technology. The economy is influenced by multiple variables, such as the current milk supply, quality of milk, and usage of the milk. Due to those variables, farmers do not receive an annual salary from an employer. In the early 2000s, there was a milk crash, where many dairy farms went out of business or transitioned into other types of farms. Dairy farmers struggled in recent times due to an oversupply of milk in the Midwest that impacts all dairy markets. As of 2018, farmers spent \$1.92 to produce a gallon of milk and made \$1.32 when they sold it to processors (McCausland, 2018). The price the processor pays is based on the regional base prices for milk set by the USDA. Manufacturers of dairy products provide the USDA with how much they made from those dairy products; then the USDA calculates the price the processors must pay the dairy farmers. However, the USDA’s prices are not based on an average farmer's expenses but market prices of milk products. To compensate for the low milk prices, local dairy farmers produce more milk to ensure the financial stability of the farm before the milk prices lower again, which causes an overproduction of dairy-related products (National Family Farm Coalition, n.d.). Facing challenging milk price dynamics, farms either increased their cow populations or filed for bankruptcy.

The adversity facing dairy farmers was amplified by the political climate causing budget cuts. The farmers depended on organizations such as the United States Department of Agriculture (USDA) and Energy Efficiency and Renewable Energy (EERE). These two governmental branches provide farms access to loans and other monetary benefits. As the government transitioned from the Barack Obama administration to the Donald Trump administration, the USDA suffered major budget cuts, which then limited the amount of federal funding available for farmers. In 2020, the COVID-19 pandemic started to tear into the already unstable farmer economy, increasing supply while decreasing demand. To combat this, new 2020 Pandemic aid was distributed. This prevented small, local farms across the nation from going out of business; however, some farmers were embarrassed to rely on government payouts to sustain their livelihood, and others were not in favor of the pandemic aid program. Some believed that the money disproportionately went to the largest producers, which allowed those industrial farms to expand their land and operations while small farms declined (Charles, 2020). In addition to the 2020 pandemic aid payouts, the USDA continues to develop and improve programs to support dairy farms, such as the Pandemic Market-Volatility Assistance Program for reimbursing dairy farmers 80% of the revenue difference per month based on each farm's annual production of milk and sales (USDA Press, 2021).

For dairy farmers to reduce their reliance on federal funding and manufacturing prices, introducing a method of diversifying their income will aid in their fight to keep their farms alive. To do so, some dairy farmers researched sustainable methods of converting waste, specifically manure, into a reusable form of energy: biomass (Morrison, 2020).

Reclaiming Waste Through Biomass

Biomass is a renewable organic material that comes from plants and animals. The use of biomass fuels for transportation and electricity generation is increasing in many countries. In 2020, biomass provided nearly 5 quadrillion British thermal units (BTU), which is approximately equal to 1.465 quadrillion watts and about 5% of total primary energy use in the United States (U.S. Energy Information Administration, 2021). A British thermal unit is a measure of the heat content of fuels or energy sources. It is the quantity of heat required to raise the temperature of one pound of liquid water by 1 degree Fahrenheit at the temperature that water has its greatest density. Figure 3 displayed the various products used to create biomass. Biomass sources for energy include wood processing wastes, agricultural waste materials, biogenic materials in municipal solid waste, animal manure, and human sewage (U.S. Energy Information Administration, 2021).

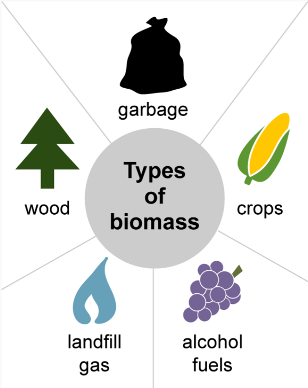

Figure 3: Types of Biomass
(U.S. Energy Information Administration, 2021)

According to a report by the United States Environmental Protection Agency, solid waste, including bio-waste which makes up almost half of the municipal solid waste (Hanc et al., 2011), is a large source of methane emissions and a large contributor to climate change (Environmental Protection Agency, 2016).

Bio-wastes are low-value materials, such as agricultural wastes, sludge, and municipal solid waste, that are composed of organic matter. If solid waste is incinerated, the water-based organic content in the waste contributes to CO_2 emissions. Bio-waste, including waste from slaughterhouses, households, the food and beverage industry, and restaurants, also carries the risk of spreading antibiotic-resistant microorganisms in the environment, then to animals and human beings (Kraemer et al., 2019).

If bio-waste can gain general acceptance as a fuel source or as fertilizer, fewer GHGs will be released into the atmosphere (Albihn, 2002). Using biomass and biowaste as resources can enable those products to be converted to high-value bio-based products such as biofuels, biochar, and biogas. Subsequently, the use of waste as bioenergy contributes to the reduction of environmental pollutants. n advantage of this method is the cascading effect of biomass, in which the biomass can be reused multiple times before the useful products are depleted. This enhances the appeal of reusable bioenergies over fossil fuels that are typically one-use and severely damage the environment (Ubando et al., 2020).

In the dairy industry, there are three sustainable technologies that transform biowaste into multi-use products: aerobic digestion, anaerobic digestion, and pyrolysis. Figure 4 provides a diagram of how these technologies can work together.

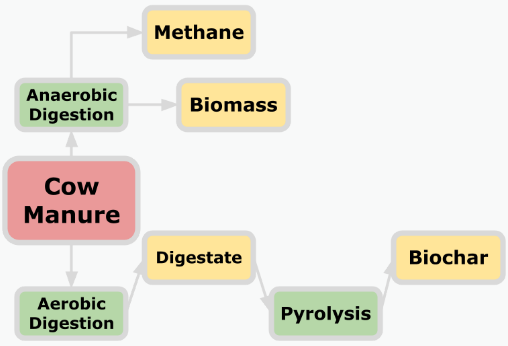

Figure 4: The Movement of Manure to High-Value Bio-based Products

Dairy Farm Innovations: Aerobic & Anaerobic Digestion

Aerobic digestion is the "biochemical oxidative stabilization of wastewater sludge in open or closed tanks that are separate from the liquid process system" (Shammas and Wang, 2007). Figure 5 shows the mechanics of the aerobic digestion process. In essence, the manure is combined with water into a mixing chamber, and oxygen is added throughout the process. This process occurs over 10 to 14 days to completely reduce the sludge down to usable biomass. Once the process is complete, the byproducts consist of carbon dioxide, water, ammonium, nitrogen dioxide, and nitrate (Shammas and Wang, 2007). While the process results in CO2 emissions, it emits less pollution compared to if the manure was not treated at all. After aerobic digestion has been completed, a sludge is left as stable biomass ready for other treatments/processes that can be used beneficially. The major drawback of aerobic digestion compared to anaerobic is the fact that aerobic digestion does not produce methane; as a result, it cannot be used to produce biogas.

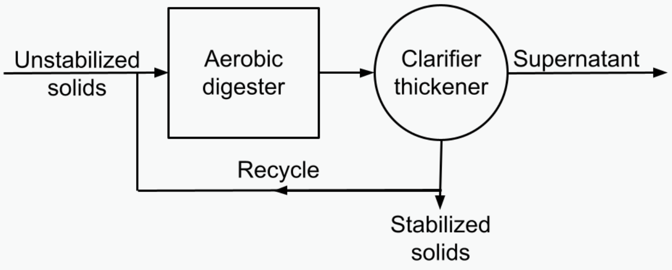

Figure 5: Diagram of the Aerobic Digestion Process (Shammas and Wang, 2007)

Anaerobic digestion is similar to aerobic digestion; the main difference between the processes is that anaerobic processes are done in the absence of oxygen and in a sealed container. The absence of oxygen allows for microorganisms to catalyze the reaction and break down the sludge. This process releases mostly carbon dioxide and methane, the methane can be collected and used to create biogas which is useful for creating energy or heat. The biggest drawbacks of anaerobic digestion are the strong smells that come from the machine. Additionally, anaerobic digestion does not break down the solution as completely as aerobic digestion. As a result, it is common for both of these processes to be used in conjunction with one another. Some farms or organizations first put the sludge through an anaerobic treatment to collect methane and afterward put the solution into an aerobic process to break it down more completely into biomass (Shammas and Wang, 2007).

Dairy Farm Innovations: Pyrolysis

In addition to aerobic and anaerobic digestion, pyrolysis is a process that thermodynamically converts biomass into biochar, syngas, and biofuel in an oxygen-deficient environment. The biomass used as an input in the process is digestate, a solid byproduct from anaerobic digestion. Pyrolysis occurs in two different forms: slow and fast. We explored the process and products of slow pyrolysis because the solid product biochar can be directly utilized in the agricultural and dairy industries as a fertilizer. The products of fast pyrolysis are typically used in chemical settings (Atienza-Martínez et al., 2020).

Before pyrolysis, livestock manure with high-water content is first subjected to anaerobic digestion. Liquid and solid parts of the waste are then heated at temperatures from 200℃ to 600℃. Throughout the process, it is essential that it occurs with little or no oxygen so that the biomass thermally decomposes into combustible products. If oxygen were present in the chamber, the biomass would be burned and would become useless; as a result, the burned product would contribute to the growing presence of atmospheric carbon. The solid biochar is generated after repeated heatings and drying (Atienza-Martínez et al., 2020).

Biochar presents a more environmentally-friendly fertilization option than manure due to manure's concentrations of toxic heavy metals and hazardous microorganisms. Over time, heavy metals accumulate in soils and migrate into water sources and food while contributing to greenhouse gasses (Atienza-Martínez et al., 2020). The application of biochar reduces the presence of pathogens and potentially toxic metals in the ecosystem. When the biochar is applied to soil, the sequestration of atmospheric carbon increases the pH of the soil. The sequestration potential of atmospheric carbon by biochar is 0.7-1.8 $GtCO_2$ (eq)/ yr, which equates to approximately 0.139 $GtCO_2$ in the reduction of the production of 9 $GtCO_2$ per year (US Department of Commerce, n.d.).

The intake of atmospheric carbon into soil stimulates soil fertility while reducing the number of metal toxins present. Subsequently, the crop yield and soil fertility can increase; therefore, food production for livestock and humans will increase. Figure 6 demonstrated the cyclic behavior of the interactions between anaerobic digestion and pyrolysis and the implementation of the products in agriculture sectors.

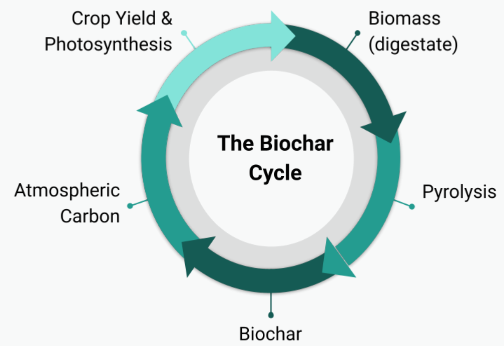

Figure 6: The Biochar Cycle

Summary

Table 1 summarizes the comparative technical benefits and drawbacks of the three dairy farm innovations that we examined in this project. The table presents data relating to each of the technologies and their respective benefits and challenges. From these, one planning to install a system could use these to make a selection or see if a specific system would be more beneficial to them.

*Table 1: Benefits and Drawbacks of Aerobic Digestion, Anaerobic Digestion, and Pyrolysis (From multiple sources)***

Technology/ Method	Benefits	Drawbacks
Aerobic Digestion	• Reduces waste size • Reduces odor • Used to make biochar	• Does not produce methane as byproduct • Can be costly
Anaerobic Digestion	• Produces methane to produce electricity • Produces liquid waste to be used as fertilizer	• Cannot be used to produce biochar • Produces very pungent odors
Pyrolysis	• Produces biochar for fertilizer/cow gut health • Sequesters atmospheric carbon through biochar	• Can produce air pollution • Can be costly • Produces toxic residues

*** The sources of Table 1 will be listed in the List of References*

Circular Bioeconomy

In order to have a system to support the sustainable aspects of biomass, a circular bioeconomy (CBE) could be implemented in the agricultural sector. CBE focuses on the sustainable, resource-efficient valorization of biomass while optimizing the value of biomass over time through cascading. Cascading is the sequential use of biomass from high-value to low-value applications (Stegmann et al., 2020). Figure 7 demonstrates the flow of biomass in a system. In the cycle, biomass is converted to different products to fit the needs of specific industries. For the dairy industry, the waste of livestock is converted to biomass through aerobic and anaerobic digestion. The products of those two processes are utilized for bioenergy and biofuels, or the product can further be converted to biochar through pyrolysis as another level of cascading. The cycle continues until essential molecules of the biomass are entirely extracted. This enhances the appeal of reusable bioenergies instead of carbon-based energies that are typically one-use and severely damage the environment.

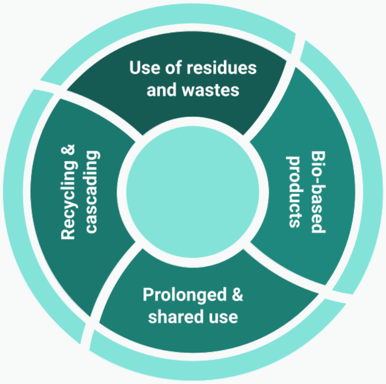

Figure 7: The Circular Bioeconomy

Snowy River Innovation

Snowy River Innovations (SRI), an Australian organization that sponsored this project, is focused on finding innovations to reduce greenhouse gas emissions and mitigate the impacts of climate change. More specifically, they have targeted the climate impacts of dairy farms, which constitute one of the larger industries in Australia and produce a large number of Greenhouse gasses. SRI seeks to understand whether and how technologies used to make dairy farms more sustainable in Australia have been in the Northeastern United States, and the reasons underlying adoption or lack of adoption within this dairy ecosystem.

Methodology: Mapping Innovations and Motivations Within the New England Dairy Farm Industry

In our effort to help SRI better understand the New England innovation landscape, we explored whether dairy farms in the northeastern US are knowledgeable and interested in three greenhouse gas emission reduction technologies: aerobic digestion, anaerobic digestion, and pyrolysis. Understanding the dairy industry became the focus of the project, including understanding the motivation for farmers to utilize these technologies. More specifically, our work was guided by five primary objectives: (1) Identifying farms and farmers' associations, (2) Exploring waste management techniques utilized in New England, (3) Developing case studies of innovation leaders in waste management, (4) Analyzing the data to find trends across the region, (5) Compiling findings and drawing conclusions from the data. Figure 8 showcases the flow of objectives for our methodology.

Objective 1: Identify farms and farmers' associations in New England to learn about waste management techniques

Utilizing search strings such as “dairy farms in Massachusetts” and “dairy farms in New England”, our team conducted an internet search to locate dairy farms in Massachusetts and New England. We then flagged farms that utilized at least one of the three biomass technologies. : aerobic digestion, anaerobic digestion, or pyrolysis. To do so, we performed a content analysis of farms’ websites to identify which technologies they utilize (if any). As part of this process, we also discovered organizations that farms have worked with to implement these technologies. As an example, the search strings relating to Jordan Dairy Farms provided information about Vanguard Renewables, the company that runs anaerobic digesters on multiple dairy farms in New England. We then conducted an internet search of “Vanguard Renewables", which enabled us to identify four other farms that partnered with Vanguard to install anaerobic digesters on their farms. Through this snowballing process, we developed a list of farms that utilize sustainable practices that we could then contact for interviews, tours, and observations.

We continued our snowball sampling as we progressed through the project. For example, after touring one farm, we gained a list of recommended farms to reach out to regarding their manure management techniques. Through our snowball sampling approach, we were able to develop a comprehensive data set of the Massachusetts dairy farm ecosystem from which to conduct our analysis. This comprehensive list also helped us diversify our sources of information to increase the validity of our findings.

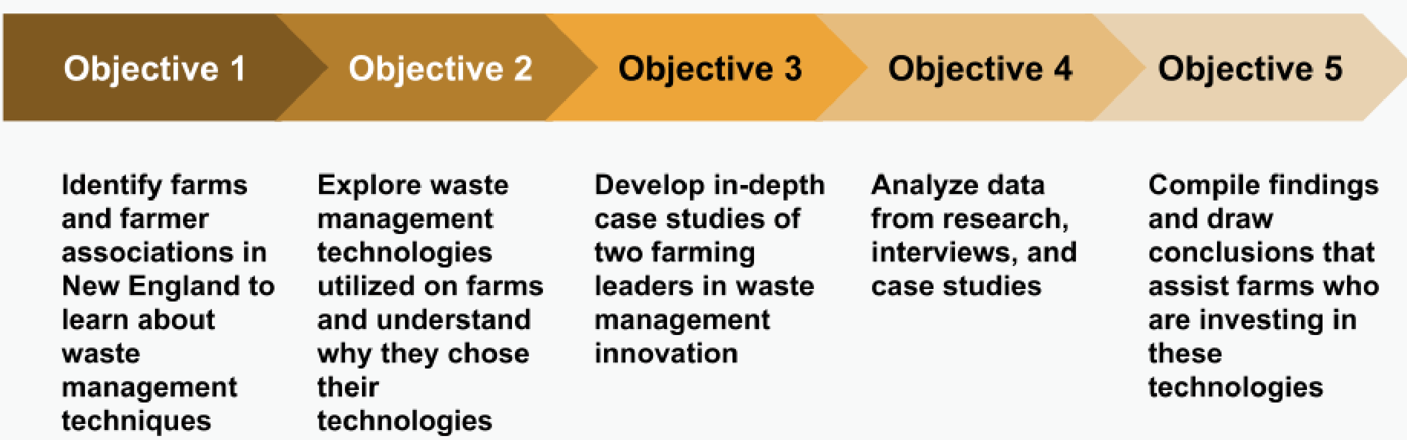

Figure 8: Overview of Objectives

Objective 2: Explore waste management technologies utilized on farms and understand why they chose their technologies

Using the list of farms we developed in Objective 1, we performed in-depth research into the farms that use sustainable practices. We found information via the farm's websites and through internet searches on each farm’s name to uncover relevant news articles, transcripts from other interviews, and any other related information. On the websites of farms and companies, the tabs such as “about us” or “our mission” contained details about their histories and their motivators for implementing or developing sustainable technologies. To ensure the credibility of the information, we avoided opinion-based blogs that may not have factual information or might be biased. To ensure the validity of the data, we cross-referenced information between sources. At the same time, we organized the contact information and the compiled details of the farms into a comparative matrix to track our interactions with them and to keep us organized.

Two members of the team sent emails to the farms. We followed up with a phone call 1-2 business days after we sent the emails. We scheduled tours and interviews with two farms. We prepared for these interviews by reviewing the information we gathered from analyzing their websites and developed interview questions that would help us better understand the forces that influenced farmers’ investment in these technologies, as well as how they learned about them. For each tour and interview, two members went to the farm to collect data. One person was the interviewer and was responsible for asking questions and engaging with the interviewee; the other person was a scribe and was responsible for writing down the important information from the interview. To maintain a good rapport with the interviewee, we planned to be flexible to allow for follow-up questions when elaboration was needed. This included being prepared for different types of interviewees based on their talking styles (comfortable speaking at length and offered expansive answers vs. quieter, more reserved interviewees who offered short answers) and willingness to share personal information (Wilson, 2012). Our full interview protocol is provided in Appendix E, but Figure 9 provides an exerpt of interview questions.

- We were amazed to read about your history. Can you tell us more about your organization?
- Before using (technology), how were you managing the waste products of the animals?
- So we read about problems with this technology, were there any other factors that influenced you to invest in an aerobic digester?
- How did you come across this technology as a solution?
    - Did you look into any other technologies?
    - Why this system over the other solutions that you looked at?
    - Did someone recommend this? (Who)
- Through our research we found that you are beginning with a smaller scale system to work out the bugs, can you tell us about the struggles with installing it or any issues that you have run across?

Figure 9: Example Interview Questions

Objective 3: Develop case studies of innovation leaders in waste management

To further deepen our understanding of the experience of innovators within the New England dairy farm ecosystem, we conducted case studies of two farms that were leading innovators and with whom we had developed a good relationship. Case studies are invaluable as they allow us to better see things from different perspectives, examples being both the farmers and the perspective of a company like Vanguard Renewables, and elicit greater insight into dynamics that might not have been possible solely through single interviews or internet searches. Further, “case studies are the preferred strategy when ‘how’ or ‘why’ questions are being posed,” which is particularly relevant given our focus on why farmers choose a given technology (or not) and the driving forces behind those decisions (Yin, 2003, p.1).

Our case study research involved observations and more in-depth interviews with farmers and other workers on the farm. During our observations, we shadowed the farmers and asked questions as needed to understand what we were seeing at the moment during our observations. A concoction of different perspectives captured a deeper understanding of the lives of farmers. Team members conducted observations in pairs. We recorded anything interesting or useful that we found in our notebooks, for example, taking note of other sustainable practices on the farms that were not brought up in interviews. Taken together, these case studies helped us gain more insight into these farms and information that we missed in interviews and tours. While the dairy farm case studies provided deep insight into anaerobic technology, we needed to look outside the dairy industry to explore the drivers and experiences of those adopting aerobic and pyrolysis technologies. Towards this end, we also conducted a case study of Bob Wells, who was a leader of pyrolysis in New England, including a visit and multiple interviews. We also engaged in several interviews with the Cincinnati Zoo, which was one of the first zoos in the United States to implement an aerobic digester.

Figure 10: Haoyu Fu interviewing Denise Barstow Manz from Barstow's Longview Farm

Objective 4: Analyze data from research, interviews, and case studies

In parallel with our data collection, we engaged in data analysis. Data analysis involved 2 steps: 1) Comparative matrix analysis and 2) inductive coding of themes of our internet and interview data. As a first step, we organized the data from our internet searches, interviews, and farm tours into a comparative matrix to display the motivators of the farms, as well as other statistics including input, outputs, crops, number of cows, and farm area. In general, this information was what we hoped to get from every farm, motivators/drivers, as well as how they found the technologies were the biggest sections. From the comparative matrix, we created themes from the major sections, an example being money/survival of the farm as a motivator. This allowed us to organize our findings and to summarize the vast amount of information that we had gathered. The raw data was gathered throughout the rest of the project (objectives 1, 2, and 3). Without a good process for data refinement, it would have been much more difficult to draw out meaningful conclusions from this project. Figure 11 provides an excerpt of the comparative matrix. For more detail, refer to Appendix F.

			Vangua
	Jordan Dairy: Rutland, MA	Jordan Dairy: Spencer, MA	Barstow Longview: Hadley, MA
Technology	Anaerobic (puts cold organics into digester), 500,000-gallon capacity,	Anaerobic, 600,000-gallon capacity, 160,000-gallon hydrolyzer	Anaerobic (heats up food/organic waste before digester, two digesters)
Input	9,120 tons cow manure annually, 20,000 tons organics annually	4,400 tons cow manure annually, 38,300 tons organics annually	9,215 tons cow manure, 24,000 ton organics
Output	Powers 500 kW engine, more than 5,000 MWh of renewable energy/year, offsets 20,000 lbs of CO2 emission daily	8,410 MWh of renewable energy/year from 1 MW engine, displacement of 5,500 lbs of CO2 emissions daily	Liquid organic fertilizer, 7000 MWh of renewable energy, offsets nearly 20000 tons of CO2 annually
Farm Stats	950 acres of corn and hay	950 acres of corn and hay	450 acres

Figure 11: Excerpt of Comparative Matrix

Objective 5: Compile findings and drawing conclusions that assist farms that are investing in these technologies

The final step in our project was to take the analyses that we conducted towards objective 4 to help our sponsor get a better picture of the developments happening in New England with these technologies. For example, Peter Young, the project management director of Snowy River Innovations, was very interested in how anaerobic digestion became so popular in New England and the driving forces behind the farms' decisions. We wanted to highlight the reasoning behind these decisions along with how the farms originally heard about these technologies. Finally, we wanted our report to be useful to farms and other organizations in New England and beyond to help them get informed about these technologies and see if they were a good fit for their farm/organization.

Findings: Evaluating the State of Waste Management Innovations in New England

We begin our findings with a discussion of the unique features that dairy farms in New England face, including smaller farm acreage, climate variability, and an uncertain dairy economy.

Small Farm Acreage and Climate Variability

In contrast to large industrial farms in the western regions of the United States, New England dairy farms tend to operate on a couple of hundred acres with less than one thousand cattle. This forces farmers to be more dependent on government aid and makes surviving as a farm much more difficult. Farmers are at the mercy of the climate for operating their farms because the hot summers and the chilling winters impact the production of crops and dairy products. Furthermore, the soil in the New England area is rocky and acidic. Along the coast, the soil is sandy which can inhibit crop growth, which was the issue for the crops in Figure 12. The variation of soil types increases the difficulty of growing crops, which can be an issue for farms that grow feed for their livestock. Farms in New England face several financial and geographic challenges that can be aided with the adoption of new technologies.

Figure 12: Growing Turnips at New England Biochar in Eastham, Massachusetts

Many of the challenges dairy farmers have faced such as the geographical and financial issues, contribute to farms wanting to invest in these innovative waste management processes such as pyrolysis, aerobic and anaerobic digestion.

The financial benefits of these technologies can help reduce the economic stresses on these farms.

Additionally, many of the organizations that we talked with needed a method to deal with the enormous amounts of waste that they were producing. Both aerobic and anaerobic digestion help with this by reducing the volume of waste and by turning it into a useful resource. Another reason farms invest in these technologies is to use the products to improve their soil, so they are able to grow either more feed for their animals or grow more cash crops and earn more money. Next, we discuss the accumulated stories and experiences of people who implemented waste management technologies.

Anaerobic Digestion at Barstow's Longview Farm: Hadley, Massachusetts

Barstow's Longview Farm is a seventh-generation dairy farm that was established in 1806, which is shown in Figure 13. Barstow's mission is to support local business, to be environmentally conscious, to be a sustainable business, and to offer a space that continues important conversations around food, food systems, and agriculture in New England. Denise Barstow Manz, the Marketing and Education manager, and other members, provide farm tours by appointment for school field trips, large and small groups, as well as individuals and families.

Figure 13: Barstow's Longview Farm in Hadley, Massachusetts

They also host seasonal events where the public can take free farm tours. A farm tour in Barstow is a terrific way to visit a working, creative dairy farm. As they move into the barns and among the cows, the tour guide shares a history of the Barstow family farm as well as many other dairy farming points of interest. They offer several types of tours for the public to learn more about the farming community. These different methods allow the public to be connected with the farm and create a hub for information (Anaerobic Digester – Barstow's Dairy Store and Bakery, n.d.).

In our conversation with Denise Bastow Manz, we learned that her family implemented an anaerobic digester on the farm to diversify their income. Due to low milk prices and overproduction, the Barstow family recognized that milk-related products cannot be the only source of income (D. Barstow Manz, personal communication, November 4, 2021). Introducing methods of diversifying their income was critical for ensuring the livelihood of the family. By diversifying their income, the farm is no longer dependent on one product, specifically milk-related products, and increases their financial stability. Introducing an anaerobic digester was one method of diversifying Barstow's Longview Farm's income (D. Barstow Manz, personal communication, November 4, 2021).

While adding the anaerobic digesters was a positive change, many farms faced challenges in the implementation of these digesters. Installing these digesters is a big investment; for farms that are struggling financially, it may not be possible to add a digester to their farm.

Privately owned organizations, including Vanguard Renewables and Harp Renewables, can reduce the burden of implementing these technologies.

Vanguard Renewables primarily operates in the Northeastern United States. Vanguard helps farms by installing anaerobic digesters. As of 2021, Vanguard has partnered with five farms to install anaerobic digesters. Vanguard helps farms set up the digester, operate it, and maintain the machine (Vanguard Renewables, n.d.). This reduces the costs on the farmers and makes it easier to get these technologies onto farms. The Vanguard Renewables Farm Powered anaerobic digester partnership with Barstow's Longview Farm began in 2013. Barstow first learned of anaerobic digesters through Jordan Dairy Farm's partnership with Vanguard Renewables. With the expansion of the anaerobic digester project in 2016, Barstow has one of the largest and most modern anaerobic digestion systems in New England. Figure 14 displays their anaerobic digester alongside one of their transport vehicles. We learned that Barstow Longview Farm and the other partnered farms incorporate organic food waste alongside the manure as feedstock for the anaerobic digester because there are not enough cows to produce a large amount of manure for it to be the sole feedstock for the digester. Because of this, the farm receives nearly 24,000 tons of food waste annually from food and beverage processors, supermarkets, institutions, businesses, and the food service operations such as Cabot Creamery/Agri-Mark Cooperative, Geissler's Supermarkets, HP Hood, and Garelick. The food waste is combined with more than 9000 tons of manure a year from the farm in a 600,000-gallon digestion tank. Manure and food waste are mixed, and microorganisms convert sugars, fats, and other compounds into biogas, annually producing more than 5,100 MWh of renewable energy and 30,000 tons of low-carbon fertilizer. The farm offsets nearly 3,000 tons of CO_2 emissions annually. This is equivalent to taking 650 cars off the road for one year. Barstow's Longview Farm receives energy to power the farm and hot water to heat farm buildings and family homes. The farm also benefits by retaining the fertile, low-carbon digestate fertilizer remaining from the process, reducing the need for chemical fertilizers, and increasing crop yields (D. Barstow Manz, personal communication, November 4, 2021).

Figure 14: Anaerobic Digester and Transport Truck at Barstow's Longview Farm

Through the partnerships of Vanguard Renewables, the farms learn from each other's techniques.

For example, Jordan Dairy Farm mentioned struggles with "keeping the digester happy" (L. Weis, personal communication, November 1, 2021). In other words, it is very important to maintain the chemical reactions inside the digester. If the chemical reactions or the input feedstock caused the digester to malfunction, then the digester could not be used for hours or days, depending on the type of maintenance needed. The input of cold organic waste, in the digester shown in Figure 15, triggered the digester to have issues (L. Weis, personal communication, November 1, 2021). The Barstow family learned of this specific problem from Jordan Dairy Farm and decided to heat the organic waste before inputting the waste into the anaerobic digester. While there are still challenges with these technologies, farms are working together to learn from each other to solve these issues. Despite the anaerobic digester maintenance issues, there are benefits to having an anaerobic digester on a farm. The benefits of anaerobic digestion at dairy farms are both financial and environmental.

Figure 15: Anaerobic Digester at Jordan Dairy Farm in Rutland, Massachusetts

There are numerous value-added products that result from anaerobic digestion and yield a financial benefit to farmers. Jordan Dairy farm uses the solids that came from the digester, a woodchip-like material, as bedding for their cows. Both Jordan Dairy Farm and Barstow's Longview Farm use the liquid waste product of the digester as a low pollution fertilizer to spread onto their fields (D. Barstow Manz, personal communication, November 4, 2021). While not currently in practice, Jordan and Barstow could sell the fertilizer product to community members for use in their gardens. Both farms collect the methane that is released and use it to fuel generators and produce electricity; in the case of Barstow's, 3% of the power produced by the generators was used on their farm (D. Barstow Manz, personal communication, November 4, 2021). The remaining power is added to the electrical grid to power 1,600 local homes. Goodrich Farm, another partnered farm with Vanguard Renewables, provides renewable natural energy (RNG) to Middlebury College to help the college reach its goal of using renewable energy as its primary energy source (Ray et al., 2021). See Table 2 for details of the benefits and challenges of anaerobic digesters.

Barstow's Longview Farm has always cared about being an ecological and sustainable farm. They have employed many tactics to reduce their "carbon hoofprint" and alleviate climate change one cow at a time. Barstow's sustainability efforts include no-tillage, riparian forest buffers, and food reuse (D. Barstow Manz, personal communication, November 4, 2021). No-tillage is a process in which the ground is not tilled to plant seeds, but instead, a small drill pokes through the soil and plants seeds. No-tillage does not release carbon from the soil into the air and promotes a healthier soil ecosystem. Riparian buffers are incredibly useful and can deliver many benefits including filtering nutrients, pesticides, and animal waste from agricultural land runoff; stabilizing eroding banks; filtering sediment from runoff; providing shade, shelter, and food for fish and other aquatic organisms; providing wildlife habitat and corridors for terrestrial organisms; protecting cropland and downstream communities from flood damage; producing income from farmland that is frequently flooded or has poor yields. By using no-tillage and riparian forest buffers with the liquid, organic fertilizer from the anaerobic digester, the fertility of the soil enables the farm to grow their food for the cows. Mixing the cow feedstock with cranberry pulp and leftover potatoes helps the reduction of food in landfills, which then reduces GHG emissions (Barstow, 2019).

Aerobic Digestion at the Cincinnati Zoo: Cincinnati, Ohio

While we found that aerobic digestion is not used by New England dairy farmers, we sought to understand how aerobic digestion might work on a small-scale dairy farm. To do so, we analyzed the efforts of the Cincinnati

Zoo. It is a sustainability-minded zoo that has worked on many green projects to reduce its impact on the environment, including a solar farm and stormwater recycling program. Similar to anaerobic digesters, aerobic digesters reduce the volume and mass of animal and plant waste and leave the valuable nutrients in the digestate that can be used as a fertilizer. The digester is shown in Figure 16. At the time of our study, the Zoo partnered and leased an aerobic digester from Harp Renewables, an Ireland-based company, to pilot the technology. Leasing is a lower risk option allowing the Zoo to try out the technology without committing to it for the long term. A drawback to the aerobic digester compared to anaerobic digestion is the lack of methane production from this process because the methane can be used as an energy source. This limits the benefits of the aerobic digester to the fertilizer that is produced.

Figure 16: Cincinnati Zoo Aerobic Digester (Richard, 2021)

The challenges that the Zoo faced relating to their aerobic digester mostly involved the feedstocks that went into the machine. Originally the feedstock was being put directly into the hopper that feeds the digester, but the Zoo found that some of the objects that were in the feedstock, such as pine cones, hay, mango pits, and orange peels, were damaging the machine or not fully being broken down by the machine. As a solution, they began to run the problematic feedstocks through a shredder prior to adding them to the aerobic digester. In general, they found that heavier, denser feedstocks worked better in the machine, but they have run into an issue of “bridging” in the hopper before it even goes into the digester. Bridging occurs when denser materials block the bottom of a hopper and prevent material from entering the digester (M. Geresy, personal communication, November 29, 2021). Aerobic digesters are the simplest of the technologies that we explored; they are a great starting point to begin getting involved in these sustainable technologies.

Pyrolysis at New England Biochar: Eastham, Massachusetts

The final technology that we investigated was pyrolysis. As there were no dairy farms that utilized pyrolysis currently in the New England area, we opted to learn from a leader in pyrolysis technology for New England. Many of the challenges and benefits that New England Biochar owner Bob Wells faced would apply to a dairy farm, so it is a valuable learning opportunity for farms that may consider investing in pyrolysis. The main benefits to this process are the variety of feedstocks that can be used. From wood to the digestate from the previous technologies, there are many options to keep the machines fueled. Pyrolysis produces biochar, a material mostly made of carbon that can be mixed with compost to create fertilizer. This resultant fertilizer could be used to increase the crop yields for farms, or it could be sold to the local community members to fertilize their gardens.

New England Biochar is an organization based on Cape Cod that not only produces biochar but also designs and builds systems for other organizations to utilize pyrolysis. The company began after the founder, Bob Wells, purchased land to start a farm on Cape Cod. He found the soil to be extremely sandy, and as a result, crops did not grow well (New England Biochar, n.d.). Mr. Wells took inspiration from people in South America, adding charcoal to the soil. Through researching this he discovered pyrolysis and began creating a new version of an Adam retort, a low-cost kiln system, to fit his needs on the farm to create biochar. There was so much interest in these pyrolysis machines that Wells sold his first machine before it was even built. Over time, he has built many of these machines and continues to improve the design, changing little details to make the entire system cleaner and more efficient.

The pyrolysis machine and process to make biochar are complicated, but it originates from a few basic processes. Figure 17 shows the modified retort system on the farm. To start, wood is loaded into the air-tight oven,and they begin heating it. The heat from the machine comes from a gasifier, it is started with propane, but once the wood inside begins to release the volatiles as smoke, they are the fuel that keeps the fire burning for a completely self-sustaining reaction that has very little smoke released into the air. When the smoke from the biochar stops the fire runs out of fuel and the biochar is ready to be processed. He uses a vacuum to remove the biochar from the oven; after he crushes the biochar, it is mixed with the compost, and it is ready to be used (B. Wells, personal communication, November 11, 2021).

Figure 17: New England Biochar Retort System

There has been a dramatic improvement in the quality of the soil on his farm since he started adding biochar to the soil as can be seen in Figure 18. Wells found that applying biochar directly to the soil was not beneficial because it would pull nutrients from the soil before the biochar added any back.

As a result, Wells learned that biochar works best when it is mixed with compost before it is added to the soil (B. Wells, personal communication, November 11, 2021).

Figure 18: Soil on the top is enriched with biochar-compost mixture and soil on the bottom is the coastal soil on the New England Biochar Farm

His one-acre farm is used as a laboratory to experiment and to try new add-ons to the New England Biochar pyrolysis machines or to test the effectiveness of the biochar. Wells explained that he planted a few maple saplings with his biochar compost mixture and one without the biochar compost mixture. Figure 19 showcased the extreme differences in growth among the trees in this experiment. (B. Wells, personal communication, November 11, 2021).

Figure 19: Tree on the left grown without biochar-compost mixture and tree on the right grown with biochar-compost mixture

The system that Mr. Wells developed numerous benefits beyond the obvious benefits to soil and crops. On his farm, Wells uses water storage tanks to pull heat from the pyrolysis reaction. This has two benefits. First, the water storage tanks cool the machine and prevent it from overheating. These systems get extremely hot and will melt apart if the temperatures aren't controlled properly. Second, he uses the warm water that is captured for heating his house and the greenhouse where he dries the wood before it is put into the machine. Mr. Wells also mentioned the possibility of making carbon credits and selling them for an additional profit stream that could be valuable for farms that may invest in pyrolysis (B. Wells, personal communication, November 11, 2021).

We asked Wells about the possibility of using pyrolysis to convert animal waste on a farm to understand the potential room for growth and application into different areas. He explained that it is possible but is unsure of whether or not it would be worth it. His concern is the amount of water found in animal waste. If cow manure were directly inputted into a pyrolysis system, the amount of energy needed to remove the water content and extract the carbon would be extremely high, and the end-product would have a low-carbon content. By processing the manure through an aerobic or anaerobic digester to treat the manure before transferring the digestate to a pyrolysis system, the amount of energy needed for the conversion is reduced, and the percentage of carbon content in the final product would be higher.

Biochar can provide other benefits to farms beyond improving the soil. Adding small amounts of biochar to the cow feed can positively affect their gut health, which not only helps the animal but reduces the amount of methane and other harmful GHGs that are released by the animals (B. Wells, personal communication, November 11, 2021).

Summary

As summarized in Table 2, each technology presents different pros and cons. It contains information from the farms in this report, but other farms across New England and other regions of the United States may have different procedures for managing their systems. All three of the technologies contribute to improving the soil to increase crop growth on farms; however, their challenges involve issues with maintaining the efficiency of the systems.

Table 2: Benefits and Challenges of Anaerobic & Aerobic Digestion and Pyrolysis

	Anaerobic Digestion	Aerobic Digestion	Pyrolysis
Benefits	• Produces biogas, liquid fertilizer, bedding for cows • Reducing Food Waste	• Produces fertilizer • Reduces waste	• Can be used with wood or digestate • Adding to animal feed can improve gut health • Biochar can be used as part of a fertilizer
Challenges	• Keeping the digester operating optimally	• Shredding feedstock • No methane production	• Keeping moisture content low • Keeping Temperatures in balance • Activating biochar with compost
Input	• Organic food waste • Manure	• Organic food waste • Manure	• Wood • Low-moisture digestate
Output	• Methane • Liquid, organic fertilizer • Solid digestate for livestock bedding	• Solid, organic fertilizer	• Biochar • Biofuel • Syngas

Conclusion

After spending considerable time speaking with farmers and people involved with the dairy industry we believe we have a strong understanding of why farmers are implementing these technologies onto their farms. We found a farm's financial situation to be a common driving factor in the farms studied in this project. Many early adopters of aerobic and anaerobic digesters and pyrolysis systems are sustainability-minded, like Barstow’s Longview Farm and the Cincinnati Zoo. We found that aerobic and anaerobic digestion was the simplest way that farms can get these technologies onto their farms. Organizations such as Vanguard Renewables or Harp Renewables help farms install waste management systems onto their farms with less risk. Pyrolysis is a much more involved process, but it may be a worthwhile investment for a farm interested in reducing its carbon footprint. It truly comes down to the situation on each farm, the number of cattle, the land available, and how willing they are to try new technology. New England farmers have encouraged each other to install the technologies. Farms are learning from the shortcomings of each other’s implementation of these systems is a crucial part of how these machines have developed.

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