Feasibility study of composting manure

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Three-paradigm approach to sustainability analysis of dairy manure composting in Pepin County, Wisconsin

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Abstract

Pepin County, Wisconsin is home to many dairy farms which commonly use animal manure as fertilizer for fields. High concentrations of the nutrients nitrogen, phosphorus, and potassium make the manure an effective fertilizer. However, this can result in runoff containing high levels of these nutrients which can lead to damage of ecosystems, health risks, and bad odor. Aerobically composting the manure is a possible solution and is considered in this report through the lens of environmental, economic and social impacts. The environmental impacts are analyzed by pairing a material flow analysis with a life cycle assessment to quantify the amount of nutrients that end up in runoff and emissions and how much are taken up by the crops. The economic impacts are measured by estimating the capital costs and maintenance costs which are used to calculate the payback period and the net present value. Social impacts are analyzed by looking at pathogen reduction in the soil, the amount of nutrients that leach into the ground from the fields, and the amount of greenhouse gases released which correlates to odor. This analysis found that there was a reduction of nutrients after the composting process which led to lower levels of these nutrients runoff and as emissions. There are financial costs to build the composting structure, but the maintenance costs are reduced with the composting process, which leads to a short payback period for a structure that will last decades. As well, the implementation of the composting process would decrease crop yield, potentially reducing revenue or usable crops for the farm. This analysis determines that the improvements of implementing an aerobic composting system on farms in Pepin County outweigh the associated negatives and that they should be put in place on farms throughout the county.
1. Introduction to Pepin County

Pepin County is located in the eastern central area of Wisconsin, bordering the Mississippi River opposite of Minnesota, as shown in Figure 1. With a population of around 7,500 people and land area of 232 square miles, Pepin County is the smallest county in Wisconsin by land area (“Pepin County, Wisconsin—Wikipedia,” 2019). Pepin County is most known for being the birthplace of Laura Ingells Wilder, author of Little House on the Prairie. It has more than 40,000 acres of public natural land which are enjoyed by hunters and fishermen (“Welcome to Pepin County—2017 Visitor’s Guide,” 2017).

2. Background on Dairy Industry and Manure Composting

2.1. Dairy Industry

Like much of rural Wisconsin, Pepin County is known for agriculture—specifically its dairy industry. This report will analyze both 500-animal unit farms and 1000-animal unit farms. A typical 500-animal unit farm consists of approximately 200 lactating cows, 20 dry cows, 170 heifers, and 45 calves (Pepin County, personal communication, 2019). These approximations are doubled for a typical 1000-animal unit farm.

In addition to dairy, many farms also produce crops which are either sold or used as feed for livestock. A typical 500-animal unit dairy farm manages around 1,000 acres of cropland: 200 acres of alfalfa, 50 acres of new alfalfa seeding, 250 acres of corn silage, and 500 acres of corn for grain (Pepin County, personal communication, 2019). Corn grain consists of hearty dried corn kernels, whereas corn silage consists of high-energy fermented pieces of the corn plant (“Silage Versus Grain—Glenn Seed Ltd.,” 2019; Wheaton, Martz, Meinershagen, & Sewell, 1993). Manure can be applied to land used for both corn silage and corn grain (approximately 750 acres). These acreage values are assumed to double for 1000-animal unit farms.

Manure comes from the cattle excretion, both solid and liquid. A typical 500-animal unit farm produces approximately 1,700 tons of solid manure and 3 million gallons of liquid manure each year and all is used as untreated manure (Pepin County, personal communication, 2019). The amount of manure produced in a 1000-animal unit farm is assumed to be double these values. This manure can be spread directly on the crop fields to fertilize the soil or be composted to create other products.

Manure and other fertilizers contain nutrients that can be applied to soil to help plants grow. The quantities of these nutrients in a given fertilizer can be summarized by its NPK value. An NPK value gives the percent of nitrogen, phosphorus, and potassium in the form of elemental nitrogen (N), phosphorus pentoxide (P₂O₅), and potassium oxide (K₂O). Solid and liquid manure have an NPK value of 3-3-6 and 8.6-4.6-20.7, respectively (Pepin County, personal communication, 2019). To achieve the yield goal for corn silage, the soil must have an NPK value of 140-50-115 (assumed to be ppm), and to achieve the goal for corn grain, the soil must have an NPK of 140-40-0 (ppm). The current soil nitrogen values are assumed to be slightly higher than zero because it is assumed that the farms rotate their crops. Legumes, such as alfalfa and soybeans, produce nitrogen (Flynn & Idowu, 2015). Each of the crops reduces the amount of phosphorus and potassium in the soil, which would make the P and K values realistically lower.

Most dairy farms in Pepin County apply their raw manure, both solid and liquid, to their crop fields to fertilize the soil without any treatment or composting. The solid is collected out of young stock housing and other barnyards and then applied to the surface of the ground via solid manure spreading trucks and not tilled into the soil, while the liquid is collected from the livestock housing “freestyle barns”, collected in a concrete storage structure. From there it is pumped by hoses to a tractor with tillage equipment and is released onto the field through the dragline.

One of the major concerns with crop fertilization and manure handling is the effects on ground and surface water. Under the Wisconsin Pollution Discharge Elimination System (WPDES), all manure and process wastewater must be collected and processed in some way to prevent contamination of water and to reduce the exposure of pathogens to humans (“Agribusiness, CAFOs and other farms—Wisconsin DNR,” 2019). When nutrients, specifically
phosphorus, enter surface water they can increase the amount of microbial growth through a process known as eutrophication. This process can reduce the amount of dissolved oxygen in surface waters, which can lead to fish kills and toxic algae blooms, and thus decrease the recreational use of the surface waters. Additionally this runoff can lead to nitrate accumulating in the ground and surface water, which is accessed through wells and used as drinking water by many residents of Pepin County. According to the South-West Wisconsin Groundwater and Geology study (SWIGG, 2019), 26% of tested groundwater wells in Pepin county showed positive results for *Coliform* bacteria (see Figure 2) whilst 22% of wells exceeded nitrate drinking water health standard (>10mg/L-N). The Concentrated Animal Feeding Operations section of WPDES requires that each operation has its own nutrient management plan to reduce nutrient loading into the environment (“Nutrient Management Planning—Wisconsin DNR,” 2019). In addition to pollution of ground and surface water, usage of synthetic fertilizers for tillage leads to the decrease of soil organic carbon (SOC) stocks, loss of biodiversity, erosion of soil and pollution of air (Viaene et al., 2015).

### 2.2. Manure treatment

One method to reduce the risk of pollution from manure and artificial fertilizers in agriculture is the conversion of manure to compost. Composting is a biological process during which microorganisms convert organics into stable and humus-enriched product under specific conditions of optimal moisture, temperature and oxygen (US EPA, 2019). It is reported that compost improves SOC content and thus fertility of the soil due to its high organic matter content (Vanden Nest et al. 2014). Moreover, compost prevents soil erosion because of available humidity and stability of aggregates (Diacano and Montemurro, 2010). The study by Powlson and colleagues (2012) compared organic carbon retention in soil after distributing equal amount
of manure and compost. They revealed that soil with applied compost contained twice higher organic content amount than manure applied soil, thereby validating its stability and resistance to decomposition. Another benefit of composting over manure is reduced volume and moisture content, which in turn decreases transportation and dispersion costs. In addition to compost contains large amounts of nutrients and hence can replace usage of artificial fertilizers thereby decreasing the cost and lower the ecological impact associated with it (Viaene et al., 2015). Other benefits of composting include improving sanitation in livestock housing, enhancing the soil carbon sequestering, and reducing the need for pesticides and water (Pergola et al., 2018).

Though there are many methods of composting manure, current research on manure composting has focused on two main types: aerobic and anaerobic digestion.

### 2.2.1. Aerobic digestion

Aerobic digestion uses microbial processes to treat dairy waste in an environment that contains oxygen. This often takes place under a simple covered concrete structure where maure is mixed with dry organic matter, usually plant waste and animal bedding. It is important to maintain a carbon to nitrogen ratio between 20-30, and oxygen supply between 5-20% of total manure volume (Pergola et al., 2018). Compost is piled in windrows (heaped into long lines) and overturned by machinery to incorporate oxygen, shown in Figure 3a and 3b.

![Concrete structure used for aerobic digestion](image1.png)

**Figure 3a. Concrete structure used for aerobic digestion.** Covered concrete provides protection from precipitation and reduces the amount of leachate released to groundwater. Image from (Pergola et al., 2018)

![Compost windrows](image2.png)

**Figure 3b. Compost windrows.** Example of how compost is piled into windrows during composting. Image from (“Aerated (Turned) Windrow Composting,” 2019)
2.2.2. Anaerobic digestion

Anaerobic digestion works similarly, but with microbial processes that do not use oxygen. Anaerobic digestion requires a specialized digester that keeps the compost oxygen-free and produces methane gas (CH₄) which can be used as an energy source. Figure 4 shows a farm-scale anaerobic digester. As it was stated before, the composting process significantly reduces the volume, mass, water content, and nutrient content. This makes the composted manure easier to handle and reduces the risk of nutrient loading in surface and groundwater (Larney & Hao, 2007). However, both composting processes release greenhouse gas emissions, which have negative impacts on climate change.

Figure 4. Farm-scale anaerobic digestion system. System includes anaerobic digester, biogas (methane) storage, as well as other features. Image from (“Farm Energy Anaerobic Digestion and Biogas – Farm Energy,” 2019)

Research has been done regarding the feasibility of on-farm manure composting. In an energy, economic, and environmental impact study on cattle manure composting solutions published in 2018, researchers found that composting manure with certain bulking agents was relatively cheap and had low impacts on the environment (Pergola et al., 2018). In a comparison of life cycle assessments—a common environmental sustainability analysis method—one study found that composting is less harmful to the environment than other waste disposal systems including landfills and incineration (Saer, Lansing, Davitt, & Graves, 2013).
2.3. Comparing current and proposed systems.

2.3.1. Current system

According to the information provided from Pepin County, the current manure management system consists of separate liquid and solid manure collection. Liquid manure is being pumped to a manure lagoon, an earthen structure lined with concrete with total volume of 7 million gallons. The collected liquid manure is agitated in spring and fall prior to being applied to cropland by either tracks or traktors. The solid manure is collected from cleaning out stock housing, piled and applied to the land also using spreading trucks or pull-type spreaders. The current manure management can be depicted in the figure below:

![Fig 5. Current manure management system at Pepin county.](image)

2.3.2. Proposed system

The proposed system being compared to the current system consists of a combination of solid manure, liquid manure, and dry bulking agent (straw, etc.). The manure will be statically aerated on a concrete slab covered by a roof to produce aerobically composted material. This material is then spread onto fields in the spring and fall, similar to the raw manure system. The proposed system can be depicted in the following figure:
3. Question

This project aims to consider various aspects of manure composting to determine the feasibility of an aerobic composting system at both a 500-animal unit scale and a 1,000-animal unit scale. Other dairy waste systems, such as anaerobic digestion and waste removal, were initially determined to be not as economically feasible for smaller-scale farms and thus would be less likely to be implemented. Though there are many alternatives to composting with aerobic digestion (Viaene et al. 2015), they are omitted from the analysis in order to limit the scope to the most feasible composting options.

The aerobic digestion composting system proposed is assumed to be a combined system of solid and liquid manure, with the addition of dry matter, such as plant waste or animal bedding, to solidify the compost mixture and increase the workability. Under this assumption both solid and liquid manure can be aerobically digested on a concrete surface. The compost system would include a simple tubing system on the bottom of the manure pile which allows for oxygenation of the compost. The compost produced in this proposed system could be spread on all 1000 acres of cropland (on a 500-animal unit farm).

This system will be compared to the current system, which is assumed to be collection and application of raw manure. Under this assumption, raw liquid and solid manure is spread onto 750 acres of cropland (only corn grain and silage) without pre-treatment.
The scope of this analysis will only include environmental, economic, and social impacts of aspects that differ between systems. The amount of manure produced, method of manure collection, general equipment maintenance and replacement, and nutrient content of manure will all be excluded from the analysis because they are assumed to remain constant between the current and proposed systems. As well, the impacts of dry matter in the composting process and the amount of water used in either system will be excluded for simplification of the nutrient analysis.

The scope will include impacts of the construction of composting facilities, the composting process, manure spreading, nutrient concentrations, and emissions into the air and water will all be taken into consideration in the analysis. The environmental impact analysis will compare eutrophication potential of runoff, greenhouse gas emissions, and nutrient leaching into groundwater for the current and proposed systems. The economic analysis will focus on the differences in cost between the current system and the compost system, namely capital cost for compost production facility, as well as differences in operational cost, transportation and spreading costs. It will also include the economic benefits of runoff reduction, and crop yield. Though more difficult to quantify, the analysis will also include the social benefits of reducing the amount of pathogens in the fertilizer and the reduction in odor.

4. Methods

The analysis will consider three paradigms of sustainability—environmental, economic, and social—to if aerobic digestion is the most feasible composting solution for both solid and liquid dairy manure. For the environmental impact assessment, the analysis will look at soil incorporation time as it applies to eutrophication potential.

One method of analysis will be by using the material flow analysis. This is a process in which the flows and stocks within a system are defined in space and time. The stocks are the materials measured in mass and flows are the mass per time moving through the system. This analysis will compare the levels of N-P-K throughout the processes in both systems, looking at
the fates of each of these nutrients at the end of the composting and fertilizing process. It will also take into account the energy required to go into the system and the GHGs that will result.

A life cycle assessment (LCA) will be used to analyze the environmental aspects of the proposed system through its life cycle. The life cycle assessment includes a goal and scope, defined in the above section above, an inventory analysis, which identifies the inputs and outputs of the process, an impact assessment of the various inputs and outputs requires, and an interpretation of the impacts to formulate a decision. The only impact assessment categories included will be global warming potential and eutrophication potential because those are the two main differences in emissions between the two systems and have the greatest effect on environmental and human health. The life of a material used as an input to a system includes the raw material acquisition, manufacturing, use and end of life. The analysis will employ the cradle to cradle LCA which includes the entire material cycle and recycling of the materials at the end.

Analysis of each of the outputs of the system will also allow for a comparison of social costs and benefits. This will include parameters such as water pollution, pathogen concentrations and human exposure, and impact on community attitude due to the smell of manure. Groundwater pollution will be determined in the environmental analysis, but, along with pathogen concentrations, will be measured based on differences in concentration and human exposure between the current and proposed systems. Smell will be measured more qualitatively using case studies as examples and greenhouse gas emissions as a proxy for malodorous gases.

The analysis will also include a breakdown of economic costs and benefits of the current system and the proposed system. This will include methods such as the payback period (Equation 1), the net present value (Equation 2), and the cost/benefit ratio (Equation 3). The net present value can be calculated multiple ways depending on the type of costs and benefits. This method will be used once the potential costs and benefits for each system are identified and quantified. Through these methods it will be possible to compare each of the systems to determine which is the more economically feasible for different scale farms.

\[
Payback \ Period = \frac{Initial \ Investment}{Cash \ inflows/savings} \quad [1]
\]
Net Present Value = \sum \text{Present Value}(\text{Net Cash Flows}) \quad [2]

\[ P = A \times \left( \frac{P/A}{i, n} \right) = A \times \frac{1-(1+i)^{-n}}{i} \quad [3], \]

where P - present value, A - annuity or annual cash flow, i - interest rate and n - number of years.

5. Assumptions

There are several assumptions that will be made in the comparison of dairy manure composting systems. One is that the total number of animals and the amount of manure they produce will remain the same in both composting systems throughout the study period. Another assumption is that all of the raw manure or compost will be used for agricultural field application. It is also assumed that the raw manure storage in the current system does not compost or produce any environmental consequences while sitting in the pit, but rather have an effect only after being applied to the field. The building manure composting system is assumed to not affect the cattle feeding. Furthermore, an assumption would be made that there is no space restriction for building the composting facility on the farm land, and that the manure collection and transportation cost is minimized. Moreover, zero cost for organic matter as well as manure would be assumed. During the lifetime of the project, neither major accidents nor animal/human health risks are expected. More assumptions would be added as the project would be advanced and depending on the information supplied from the farm owners.

6. Project Schedule

Table 1 shows the breakdown and timeline of work required to complete the project.
Table 1. Project Schedule. Table containing a record of completed tasks for final project, with assigned roles and due dates.

<table>
<thead>
<tr>
<th>Date</th>
<th>Task to complete</th>
<th>Person completing task</th>
</tr>
</thead>
<tbody>
<tr>
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<td>All</td>
</tr>
<tr>
<td>11/21/19</td>
<td>Project Proposal Edits</td>
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<td>Material Flow Analysis</td>
<td>Riley</td>
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<td>GHG Emissions</td>
<td>Riley</td>
</tr>
<tr>
<td>12/2/19</td>
<td>Odor and Pathogens</td>
<td>Riley</td>
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<td>12/5/19</td>
<td>Economical Analysis</td>
<td>Bexultan</td>
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<td>12/7/19</td>
<td>Discussion</td>
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<tr>
<td>12/8/19</td>
<td>Water Quality and Runoff</td>
<td>Avery</td>
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<td>Final Recommendation</td>
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7. Analysis

The sustainability analysis performed in this report contains four main parts: a material flow analysis of nutrients, a life cycle assessment of environmental impacts, an economic comparison of the current and proposed systems, and social effects of each system. Calculations for the environmental section of analysis can be found in Appendix A.

7.1. Material Flow Analysis

The material flow analysis was used to identify the nutrient stocks and flows of each of the systems and was used as a basis for the rest of the analysis sections. The goal was to analyze different nutrients, namely nitrogen (N), phosphorus (P), and potassium (K), to understand the
quantities and fates of each. The values determined in the material flow analysis could then be used in a life cycle assessment to determine environmental impacts. Figures 7a and 7b show the material flow analysis for both the current and proposed systems.

**Figures 7a and 7b. Material flow analyses.** Material flow analysis of nutrients (nitrogen (N), phosphorus (P), and potassium (K)) in a) the current and b) the proposed systems.

The results of the material flow analysis show that there is significantly less nutrients not being taken up by crops in the proposed system compared to the current system. This means that there is more potential for nutrient leaching into ground and surface water as well as emissions into the atmosphere.

The NPK values included in the material flow analysis were calculated using assumptions and values from various research sources. The NPK values of wet and dry manure (assumed
percentage of manure by weight) were given by Pepin County (Pepin County, personal communication, 2019) and calculated into weights using density and concentration conversions (“Common Manure Test Results Conversions – Livestock and Poultry Environmental Learning Community,” 2019). It is also worth noting that the composting process reduces the total mass by approximately 66% due to water losses (Larney & Hao, 2007). From there, it was assumed that the manure would be spread directly on the field in the current system, whereas it undergoes aerobic digestion in the proposed system.

Nutrients are released into the air and leached through water in the digestion process, and the amount of emissions and leachate were calculated to be 13.1% and 0.38%, respectively (Yang et al., 2019). The manure or compost would then be spread on fields, which would then either be emitted into the atmosphere, leached into ground or surface water, taken up by plants, or left in the soil. It was found that the quantity of nitrogen emitted into the air is based on the total acreage, the amount of manure/compost being applied to the system, and the concentration of nutrients, around 200 lbs N/acre (“Impact of Manure Incorporation on Greenhouse Gas Emissions in Semi-Arid Regions – Livestock and Poultry Environmental Learning Community,” 2019). This rate was assumed to be the same for phosphorus and potassium.

The reduction of nutrients during the compost process also results in a decrease in the amount of nutrients that end up in the soil. With the current system there are approximately 25,800,000 lb/year of nutrients in the soil and with the proposed system there are 8,890,000 lb/year. The amount of nitrogen, phosphorus and potassium that are taken into the runoff water assumed to be 14mg/lb, 4mg/lb, and 7mg/lb nutrients in soil respectively (Panno & Kelly, 2019). From these rates, the amount of nutrients entering the water in each 500 unit farm each year are 4.96lb nitrogen, 0.86lb phosphorus and 5.45lb potassium for the current system. If the composting system is implemented these values would be reduced to 4.11lb nitrogen, 0.75lb phosphorus and 4.719lb potassium. Due to the linear relationship between the soil concentration and amount of nutrients in the runoff, the amount of nutrients in the runoff will continuously decrease with decreasing soil concentration. This 16% reduction in nutrients in soil results in a 16% reduction in the amount of nutrients that are seeping into the groundwater and running off into surface waters.
There is an annual rainfall in Pepin county of 34 in/year (“Pepin County, Wisconsin—Wikipedia,” 2019). This results in approximately 1 million gallons of water falling on each 500 unit farm not including any additional irrigation that will also contribute to runoff. It is possible to analyze the rate of leaching occurring by use of Darcy’s law, however in this situation there are too many variables involving volume so it is not applicable here. Due to the high permeability of the finchford loamy sand found in this area, there are few barriers preventing the nutrients in the soil from reaching the water table which lays only 40ft underground.

The amount of nutrient uptake from crops (corn silage, corn grain, alfalfa) was calculated using the desired NPK values for each crop type as nutrient demand. For example, alfalfa requires 30 ppm K and the proposed compost contains 42.5 ppm K, so the crop would use 30 of the available 42.5 ppm, leaving the rest to stay in the soil.

7.2. Environmental Analysis- Life Cycle Assessment

7.2.1. Inputs and Outputs

Based on the scope defined in this report, the material flow analysis was used to identify the inputs and outputs of both the current and proposed systems. The inputs of the system is the combination of liquid and solid manure (as well as dry matter which is not included in the analysis). The outputs include gas emissions, odor, leachate runoff, crops, and pathogens. As well, the materials used to construct the digestion system are considered inputs to the system, and their end of life deconstruction processes are considered outputs.

7.2.2. Environmental Impacts

The environmental impacts of gas emissions from both systems is quantified and compared using the global warming potential impact category. This compares all of the emissions from the current and proposed system by changing them all to amounts of carbon dioxide equivalent (CO2e). Phosphorus and potassium both do not contribute significantly to global warming potential, so they are omitted from the analysis of greenhouse gas emissions. The only gases included in the analysis are carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O). Each of these gases has different emission factors: 1g CO2 equates to 1g CO2e, 1g
CH4 equates to 34g CO2e, and N2O equates to 298g CO2e (Owen & Silver, 2015). Using these conversions and estimations provided by (“Impact of Manure Incorporation on Greenhouse Gas Emissions in Semi-Arid Regions – Livestock and Poultry Environmental Learning Community,” 2019) and (Biala, Lovrick, Rowlings, & Grace, 2016), the current system would produce 73 million pounds of CO2e per year, whereas the proposed system would only produce 3 million pounds of CO2e per year. The implementation of the aeration system would produce 25 times less CO2e, reducing the amount of global warming potential.

Converting the solid and liquid manure into compost has a large impact on the amount of nitrogen and phosphorus and potassium that travels from the surface. As the water content of the manure is reduced through the composting process, the mixture becomes more stable, meaning that they are less likely to enter runoff. Additionally, the percentage of water extractable nutrients in the composts decreased with increased composting. Nitrogen is reduced from 1.17% to 1.12% of dry weight, phosphorus is reduced from 0.7 to 0.49% and potassium is reduced from 0.55% to 0.28% (Das and Kirkland, 2008).

Nutrients in water, both ground and surface, can have environmental implications. Nutrients leached into groundwater can affect water quality, which is used by residents for drinking. Surface water with high nutrient contents, specifically phosphorus, can lead to increased eutrophication. Eutrophication is the process of nutrient loading in surface waters, creating conditions favorable for algae growth, which can often be toxic to humans and animals and result in fish kills.

For 1000-animal unit farms, the relative amount of manure spread onto fields for a 1000-animal unit farm would remain the same because it is assumed that the acreage of a 1000-animal unit farm would double as well. However, in the case that the number of animals doubles and the total acreage remains the same (1000 animal units and 1000 acres), the amount of nutrients in the soil would increase, causing increased leaching to groundwater and runoff into surface water.

Since the planned composting system takes place in a concrete structure under a roof, it is much less susceptible to nutrient runoff caused by rain compared with raw manure applied to the fields. Precipitation is a main cause of surface runoff that leads to nutrient build up in bodies of
water around agricultural areas (Lory, 2019). The planned composting structure will also have concrete barriers around any areas of incline to prevent any runoff water from mixing with the compost and transporting nutrients.

7.3. Economic Analysis

The economic analysis is comprised of capital cost estimation, operation and maintenance costs estimation, and cash flow analysis which would compute the net present value for proposed solution and would compare it to the existing solution.

7.3.1. Capital cost for proposed system - aeration unit construction

Prior to calculating the capital cost for the aeration unit construction, the dimensions of the concrete structure must be identified. According to the Northeast Recycling Council (2019), manure piles that are exceeding 8 ft in height are considered to be fire hazards. As a result, the maximum piling would be 7 ft, whilst the construction would be 10 ft, including a safety factor. It is reported that the pile width should be at least two times greater than the height of the pile (NRAES, 1992). Hence, in order to reduce capital cost, the maximum allowable pile width would be 14 ft, whilst the concrete pad with would be 16 ft including safety factor. The length of the manure pile is also assumed to be twice the height, with safety factor would similarly yield 14 ft.

![Aerated static pile dimensions](image)

Figure 8. Aerated static pile dimensions. From (NRAES, 1992).
For aeration, perforated drainage pipes with a 3 in. diameter and 10 ft length would be used, with the space 1 ft apart them. The pipe length is estimated to be 15 ft, since pipes should be longer than the length of the pile (14ft), in order to receive air. The composting pile length is 14ft, for identifying the number of 15ft pipes, following equation would be used:

\[0.25\text{ft} \times x + 1\text{ft}(x-1) = 14\text{ft} \quad [4],\]

where \(x\) is the number of pipes, \((x-1)\) is the number of spaces between pipes, 0.25 is the diameter of the pipe, 1 is the distance between pipes, 14 is total width of the composting pile. So:

\[x = 12\] pieces of 15 ft long pipes, or 180 ft total length

Appendix C gives the breakdown of costs associated with making the concrete pad as developed by United States Department of Agriculture (USDA, 2014) and for building supporting frame and roof. The total investment cost thus is equal to $59,545. This price for assembly and construction work of aeration unit is assumed only for good weather conditions as well as the fact that the price for services and material only is altered by inflation over the years. The farm owners from the Pepin county can apply for grants of the local Resource Conservation Districts which can cover the investment cost to a certain extent.

7.3.2. Maintenance and operational cost for current and proposed aeration unit

There are several literature reporting that operational cost for aerobic digestion is more expensive than anaerobic digestion due to pumps that consumes electricity (LPELC, n.d; Hochman et al., 2015). Nevertheless, in the proposed system which is free standing aerated static pile, there are no pumps needed for aerating and thus no electricity consumption.

The cost for mixing liquid and solid manure in proposed system is equal or less than the current separate spreading cost for liquid and solid manure. This is due to the fact that liquid manure is being transported to the crop field and being spread over an area of 1000 acres, which is greater than compost piling area. Accordingly, for the sake of simplicity, it is assumed that
manure mixing cost associated with transporting and spreading liquid manure over solid manure is equal to the current system of directly spreading the liquid manure over crop field.

It is reported that one of the benefits of composting occurs when the moisture level is 50% (MSU-Extension, 2017). With a good air supply, high C:N ratio (30) and moisture level (50%), the volume of the solid manure is reduced from 50 to 65% (NDSU, 2016). Reduction of solid volume will decrease the labour and fuel cost associated with solid manure transportation for solid manure by half. The labour cost for manure handling varies from $10 to $20/ton of feedstock, whilst $6/mile for manure transportation (Biocycle, 2010). For the current system, total solid manure it is 1,500 tonnes, whilst for the proposed system it would be 750 tonnes, assuming a 50% weight reduction. Moreover, in order to spread the solid manure over 1000 acres, approximately 1000 miles is being travelled each half-year for the current system, with the total 2000 miles a year. For the proposed system, this value would be 1000 miles a year.

In addition to compost obtained from the aerobic digestion unit is more nutrient rich, since it is more stable than nutrients in raw manure, which would decrease the addition of chemical additives to increase NPK value of soil. More chemicals fertilizers needed for the current system, as nutrient run-off from raw manure is expected to occur. One of the most widespread chemical fertilizers - granulated diammonium phosphate (DAP) with NPK value 18-46-0 has a price of $350/ton in 2019 (ERAMS, 2019). For 1000 acres approximately 25 tonnes of DAP each half-year or 50 tonnes a year are needed to maintain the fertility at high levels.

The maintenance cost for the proposed system, in addition to the maintenance cost for the current system, would have approximately 10% of installation cost of aeration unit, which is around $6,000. According to the information provided by the clients, the current solid and liquid manure are meeting WPEDS standards, thus the cost associated with the nutrient run-off would not be considered in the economic analysis.

Table 2 was constructed to compare maintenance and operating costs of the current and proposed systems:
Table 2. Maintenance and operating costs for current and proposed systems.

<table>
<thead>
<tr>
<th>Name</th>
<th>Cost/unit</th>
<th>Current system, yr⁻¹</th>
<th>Proposed system, yr⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor</td>
<td>$15/ton &lt;sup&gt;a&lt;/sup&gt;</td>
<td>$22,500</td>
<td>$12,250</td>
</tr>
<tr>
<td>Transportation</td>
<td>$6/mile &lt;sup&gt;a&lt;/sup&gt;</td>
<td>$12,000</td>
<td>$6,000</td>
</tr>
<tr>
<td>Maintenance</td>
<td>$6,000/unit</td>
<td>-</td>
<td>$6,000</td>
</tr>
<tr>
<td>DAP- fertilizer</td>
<td>$350/ton &lt;sup&gt;b&lt;/sup&gt;</td>
<td>$17,500</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total costs</strong></td>
<td></td>
<td><strong>$52,000</strong></td>
<td><strong>$24,250</strong></td>
</tr>
</tbody>
</table>

<sup>a</sup> (Biocycle, 2010)

<sup>b</sup> (ERAMS, 2019)

### 7.3.3 Net present value estimation

According to McMahon (2014), an average annual inflation rate of US dollar is 3.22% over the past 20 years. Figures 9 and 10 show the cash flow diagrams drawn for each of the systems for a five-year period:

![Figure 9. Cash flow diagram for current system.](image)

Figure 9. Cash flow diagram for current system.
Figure 10. Cash flow diagram for proposed system.

From this, the Net Present Value can be estimated using equations [2] and [3]:

\[
\text{NPV}_{\text{current}} = -$52,000 \times (P/A, 3.22\%, 5) = -$52,000 \times 4.55 = -$236,600
\]

\[
\text{NPV}_{\text{proposed}} = -$59,545 - $24,250 \times (P/A, 3.22\%, 5) = -$59,545 - $24,250 \times 4.55 = -$169,882.5
\]

The obtained NPV value for current system is greater than for the proposed system. It can be thus seen that in just a five year period, the investment for building aeration unit recovers itself.

7.3.4. Crop Yield

As shown in the material flow analysis, the amount of nitrogen, phosphorus, and potassium taken up by corn grain and silage crops is higher in general under the current system than the proposed system. This can be used as a proxy for crop growth. Under this assumption, the proposed system would reduce the amount of crop growth, and negatively affect either the amount of economic profit on crops or the amount of crops able to be fed to livestock. Though not quantified in this analysis, this reduction in profit should be taken into consideration when considering the implementation of the proposed compost system. In the case that the acreage remains the same and the animal head count doubles (1000-animal units and 1000 acres), the crop yield would increase due to more nutrients being added to the soil.
7.4. Social Analysis

The amount of greenhouse gas emissions produced can be used as a proxy for odor—one of the most prevalent social impacts of dairy manure fertilization. Strong odors emitted into the ambient air can cause discomfort for surrounding residents and businesses, and can cause adverse health effects at high concentrations (Han, Qi, Wang, Li, & Sun, 2019). Composting generally reduces the amount of gas emissions to the atmosphere. This holds true for the proposed composting system, as shown above. The severity of odor is determined by the types of gases emitted. The main odor contributing gases from aerobic composting is ammonia (Zhu et al., 2016), whereas the main contributing gas from anaerobic digestion is methane. Because of the aeration process, strong odorous gases like hydrogen sulfide and ammonia are converted to other compounds, therefore reducing the odor effects of the composting process. The reduction of odor emitted by aerobic compost digestion in comparison to the current system is demonstrated in the case of the Peterson farm in Appleton, WI. Though a significantly smaller farm, the implementation of an aerobic composting system reduced the odor from the farm to the point where a business 500 feet away could not detect any smell (“Dairy farm turns manure into compost side hustle,” 2019). The average Pepin County dairy farm is larger, but the population density of the county is low—only 13 houses/sq. mi. A reduction in odor from dairy farms would increase the quality of life for both people living in the vicinity of the farms and those who work on the farms.

The health of workers and surrounding residents can also be improved through the reduction of pathogens in the compost. Manure, both solid and liquid, contain pathogens that can be hazardous to human health. The current system includes spreading raw manure onto fields, where humans and animals can be exposed to pathogens through accidental ingestion, inhalation, and water contamination. The proposed aerobic composting method would significantly reduce the amount of pathogens in the material. In a review of cattle manure composting alternatives, researchers found that composting for 15 days at 55 °C inactivated Giardia cysts and Cryptosporidium oocysts to a level safe for exposure (Larney & Hao, 2007). The composting process naturally heats the compost to temperatures above 55 °C, which would provide ideal conditions for inactivating pathogens.
By reducing the amount of nutrient runoff in there will be a lower risk of contaminating surface waters which would result in a smaller risk to marine ecosystems habitats and eutrophication (Howarth, 2008). Eutrophic surface waters can be toxic to human health, and significantly decrease recreational use of lakes and rivers. Additionally, there are impacts on human health from groundwater, as high concentration of nitrates in the water lead to carcinogens in the body and certain cancers. In Pepin County, 55% of citizens use groundwater as their primary source of drinking water (“Nutrient Management Planning—Wisconsin DNR,” 2019), so it is very important to maintain a reliable source of water. Once a water source is contaminated it is costly and time consuming to fix, if possible at all. A reduction by 20% of the nutrients in soil would lower the concentration of nutrients in citizens wells, which would decrease the percentage of homes that are above the water limit of 10 mg/L and reduce consumer risk overall (“Nutrient Management Planning—Wisconsin DNR,” 2019).

8. Results

8.1. Environmental

The aerobic composting system resulted in a reduction of the three nutrients in the runoff. Nitrogen was reduced by 17% from 4.96 lb/year to 4.11lb/year. Phosphorus was reduced 12% from 0.86lb/year to 0.749 lb/year. Potassium was reduced 13% from 5.45lb/year to 4.71lb/year. These reductions resulted in an overall nutrient reduction of 16%. The emissions were reduced 65% for nitrogen 18,675 lb/year to 6,435 lb/year. 65% for Phosphorus 11,876lb/year to 4,095 lb/year, and 65% for potassium 42,755 lb/year to 14,742 lb/year. Due to these reduced overall values of nutrients in the soil, there are lower values of nutrient uptake by the crops. Additionally, an introduction of alfalfa crops reduces percentage of nutrients available for silage and grains. The nutrient uptake for silage is initially 50,944 lb/year N, 32,398 lb/year P, 75,811 lb/year K. For grains it is 103,431 lb/year N, 53,937 lb/year P, and 0 lb/year potassium. In the proposed system, these values are reduced to 33,370 lb/year N, 21,236 lb/year P, and 58100lb/year silage. 66,740 lb/year N, 39,923 lb/year P, and 0 lb/year K for grains. For alfalfa the nutrient uptake is 0 lb/year N, 15,077 lb/year P, and 49,691 lb/year K.
8.2. Economic

The capital costs for building the composting structure is $59,545, which accounts for the materials and construction. The maintenance costs for the proposed system are $12,250 for labor, $6,000 for transportation, and $6,000 for maintenance which results in a total of $24,250. This is less than half of the maintenance costs of current system which are $52,000. The net present value is calculated with the average inflation rate of 3.22% and results in NPV_{current} of -$236,600 and NPV_{proposed} of -$169,882. Due to the reduction of the maintenance costs the payback period is only five years. Due to the decreased nutrient uptake in the soil, there would be a decrease in the crop yields for these farms which would have a negative economic impact on the farmers and should be taken into consideration.

8.3. Social

Odor was measured by analyzing the emitted gases. Through the composting process, the odorous gases hydrogen sulfide and ammonia are reduced which results in a net decrease in odor. Studies showed that the compost could not be smelled 500 ft away. The result of composting on the amount of pathogens in the soil is a large reduction to within the healthy level due to the temperature above 55°C that is reached in the composting structure for 15 days. Additional positive social impacts due to lower nutrient concentrations in the runoff include reduced surface water pollution that leads to eutrophication and lower levels of nutrients entering the groundwater, which is consumed by the citizens of pepin county.

9. Discussion

The analysis performed in this report considers the environmental, economic, and social implications of implementing an aerobic digestion composting system to dairy farms in Pepin County in comparison to the current system. While each of these three paradigms of sustainability are important and are taken into consideration for the final recommendation, each carries its own decision weight based on the factors considered and the relative importance in the context of a real-world farm. The clients from Pepin County expressed that special consideration
should be given to economic costs of implementing the proposed system and the impacts on groundwater.

Economically, the proposed system would cost less in the long run. After five years of operation, the proposed system would begin to cost less than the current system, which would save money for dairy farm businesses. However, the proposed system would decrease the amount of nutrients taken up by corn grain and silage crops, and thus the crop yield. The proposed system would also be better environmentally because the impact on air and water quality would decrease. Though the proposed system has a higher overall percentage of nutrients lost to air emissions, the total global warming potential is significantly lower, which is ultimately the most important factor when assessing atmospheric emissions. Surface and groundwater quality would also improve under the proposed system because the amounts of nutrients leached into groundwater or flushed into surface water decreases. The reduction in greenhouse gas emissions and nutrient in water have social benefits as well. The implementation of the proposed system will reduce odor and pathogens, creating safer and more pleasant conditions for farm workers and nearby residents. As well, water quality in Pepin County would improve because the water would contain less contaminants, specifically nitrates.

Though each of the three paradigms analyzes important factors, it is worth noting that the conclusions made in this report are not comprehensive or exact. As stated in the report, many assumptions were made to produce the values in the comparison of the two systems. It is important to keep a realistic perspective of the current situation in Pepin County. For instance, while water quality is proven to be an important issue, the reduction of nutrients to navigable surface waters does not matter much because the farms already comply with NPDES regulations.

**10. Final Recommendation**

Based upon the results from the analysis conducted in this report, the aerobic composting method should be implemented in Pepin County. The proposed composting system would reduce the amount of greenhouse gas emissions, groundwater pollutants, and odor while increasing human safety. The proposed system has a relatively high initial cost, but a short payback period in comparison to its lifetime. Under the proposed system the crop yield of corn grain and silage
would decrease, thus reducing profits or usable crops for the farm, though the extent of this effect is not quantified in this report. It is worth noting that this decision was made with many assumptions and weighted based on the interests expressed by the clients. A given farm may choose not to implement the proposed system based on different assumptions and goals. However, in general, the implementation of an aerobic composting system in Pepin County would be beneficial for businesses and the environment.

11. Conclusion

To sum up, in this report current manure management system as well as proposed aerobic compost digestion system at Pepin County, Wisconsin were analysed for three paradigms of sustainability.

Initially, background information for Pepin county was provided. This was followed by literature review for alternatives of manure handling: aerobic and anaerobic digestion. The aerobic digestion method was selected based on the size of the farm. Afterwards, material flow analysis for aerobic manure treatment and currently practiced manure management was performed. It was revealed that the current manure management system yields leaching of nutrients into the ground and surface water as well as emissions into the atmosphere as compared to the proposed system. Following this, LCA environmental analysis was done with identifying system inputs and outputs as well as environmental impacts. It was estimated that the implementation of the aeration system would result in 25 times less CO2e and thus in reduced global warming potential. Penultimately, the economic analysis was performed which compared maintenance and operation cost, as well as investment needed for constructing aeration unit. It was revealed that NPV value for current system in five-year period is outweighing the expenses associated with the proposed system, thereby making the proposed solution more financially attractive. Ultimately, the social analysis considered problems related to odour, human health and impact to the ecosystem. It was found that the proposed system reduces emissions of gases such as ammonia and hydrogen sulfite, and thus lower odor as well as that there is a lower eutrophication potential associated with it than the current system.
Overall, the proposed aerated compost digestion system was revealed to be more sustainable in all aspects than the current manure management system. Thus, for Pepin County farm representatives it was recommended to move from current to the proposed system.

12. Abbreviations:

*DAP* - Diammonium Phosphate  
*EPA* - Environmental Protection Agency  
*NPK* - Nitrogen (N), Phosphorus (P) and Potassium (K)  
*NRAES* - Northeast Agricultural Engineering Service  
*SOC* - Soil Organic Carbon  
*SWIGG* - South-West Wisconsin Groundwater and Geology study  
*USDA* - United States Department of Agriculture  
*WPDES* - Wisconsin Pollution Discharge Elimination System
13. Appendices


13.1.1. Manure

\[
\frac{3 \text{ million gallons liquid manure}}{1 \text{ year}} \times \frac{8.6\% \text{ N}}{100} \times \frac{5.5\% \text{ solids}}{100} \times \frac{8.5 \text{ lb liquid manure}}{1 \text{ gallon manure}} = 120,615 \text{ lb N/year}
\]

\[
\frac{3 \text{ million gallons liquid manure}}{1 \text{ year}} \times \frac{4.6\% \text{ P}}{100} \times \frac{5.5\% \text{ solids}}{100} \times \frac{8.5 \text{ lb liquid manure}}{1 \text{ gallon manure}} = 64,575 \text{ lb P/year}
\]

\[
\frac{3 \text{ million gallons liquid manure}}{1 \text{ year}} \times \frac{20.7\% \text{ K}}{100} \times \frac{5.5\% \text{ solids}}{100} \times \frac{8.5 \text{ lb liquid manure}}{1 \text{ gallon manure}} = 286,110 \text{ lb K/year}
\]

\[
\frac{1700 \text{ tons dry manure}}{1 \text{ year}} \times \frac{3\% \text{ N}}{100} \times \frac{33\% \text{ solids}}{100} \times \frac{2000 \text{ lb liquid manure}}{1 \text{ ton}} = 33,660 \text{ lb N/year}
\]

\[
\frac{1700 \text{ tons dry manure}}{1 \text{ year}} \times \frac{3\% \text{ P}}{100} \times \frac{33\% \text{ solids}}{100} \times \frac{2000 \text{ lb liquid manure}}{1 \text{ ton}} = 33,660 \text{ lb P/year}
\]

\[
\frac{1700 \text{ tons dry manure}}{1 \text{ year}} \times \frac{6\% \text{ N}}{100} \times \frac{33\% \text{ solids}}{100} \times \frac{2000 \text{ lb liquid manure}}{1 \text{ ton}} = 67,320 \text{ lb N/year}
\]

\[
\frac{25840000 \text{ lb manure/year}}{1000 \text{ acres}} = 0.593 \text{ lb manure/ft}^3 \cdot \text{ year}
\]

\[
\frac{133479 \text{ lb N}}{1000 \text{ acres}} = 133.5 \text{ lb N/acre} = 66.7 \text{ ppm}
\]

\[
\frac{84942 \text{ lb P}}{1000 \text{ acres}} = 84.9 \text{ lb P/acre} = 42.5 \text{ ppm}
\]

\[
\frac{305788 \text{ lb K}}{1000 \text{ acres}} = 305.8 \text{ lb K/acre} = 152.9 \text{ ppm}
\]

\[
\text{NPK of Compost} : 66.7 - 42.5 - 152.9
\]

- Set up of manure equations from (“Common Manure Test Results Conversions – Livestock and Poultry Environmental Learning Community,” 2019)
- Manure values from (Pepin County, personal communication, 2019)
- Ppm conversion factors from (Espinoza, Slaton, & Mozaffari, 2019)

13.1.2. Emissions

\[
154275 \text{ lb N/year} \times 13.1\% \text{ N emitted in composting process} = 20210 \text{ lb N/year emitted composting}
\]
98175 lb P/year * 13.1% P emitted in composting process (assumed) = 12860 lb P/year emitted composting
353430 lb K/year * 13.1% P emitted in composting process (assumed) = 46299 lb K/year emitted composting

- Percent N emissions and leachate from composting process (13.1% and 0.38%, respectively) from (Yang et al., 2019), assumed same value for P and K emissions
- Values for N2O emissions from soil application for raw manure and compost are 12.1% and 4.8%, respectively (Chadwick et al., 2011).

13.1.3. Runoff

Proposed system nutrient runoff:

\[
\begin{align*}
N: & \quad \frac{133479 lb}{year} \times \frac{14 mg}{lb} \times \frac{1 lb}{453592 mg} = 4.119 lb/year \\
P: & \quad \frac{84942 lb}{year} \times \frac{4 mg}{lb} \times \frac{1 lb}{453592 mg} = 0.749 lb/year \\
K: & \quad \frac{305788 lb}{year} \times \frac{7 mg}{lb} \times \frac{1 lb}{453592 mg} = 4.719 lb/year \\
\end{align*}
\]

Current system nutrient runoff:

\[
\begin{align*}
N: & \quad \frac{154375 lb}{year} \times \frac{14 mg}{lb} \times \frac{1 lb}{453592 mg} = 4.96 lb/year \\
P: & \quad \frac{98175 lb}{year} \times \frac{4 mg}{lb} \times \frac{1 lb}{453592 mg} = 0.8657 lb/year \\
K: & \quad \frac{353430 lb}{year} \times \frac{7 mg}{lb} \times \frac{1 lb}{453592 mg} = 5.454 lb/year \\
\end{align*}
\]

13.1.4. Crop Uptake

NPK of proposed compost: 63.5-40.4-145.5
NPK of current manure: 67.8-43.1-155.3

NPK uptake (current):
Grain:

\[
\begin{align*}
\frac{140\text{ppm required}}{67.5\text{ppm}} &= 100\% \times 67\% \text{ acreage} \times 135000 \text{ lbs N/year in soil} = 91000 \text{ lbs N/year uptake} \\
\frac{40\text{ppm required}}{43.1\text{ppm}} &= 92.8\% \times 67\% \text{ acreage} \times 86000 \text{ lbs P/year in soil} = 54000 \text{ lbs P/year uptake} \\
\frac{0\text{ppm required}}{155.5\text{ppm}} &= 0\% \times 67\% \text{ acreage} \times 310000 \text{ lbs K/year in soil} = 0 \text{ lbs K/year uptake}
\end{align*}
\]

Silage:

\[
\begin{align*}
\frac{140\text{ppm required}}{67.8\text{ppm}} &= 100\% \times 33\% \text{ acreage} \times 135000 \text{ lbs N/year in soil} = 45000 \text{ lbs/year uptake} \\
\frac{50\text{ppm required}}{43.1\text{ppm}} &= 100\% \times 33\% \text{ acreage} \times 86000 \text{ lbs P/year in soil} = 28000 \text{ lbs/year uptake} \\
\frac{115\text{ppm required}}{155.3\text{ppm}} &= 74.1\% \times 33\% \text{ acreage} \times 310000 \text{ lbs K/year in soil} = 78000 \text{ lbs/year uptake}
\end{align*}
\]

NPK uptake (proposed):

Grain:

\[
\begin{align*}
\frac{140\text{ppm required}}{63.5\text{ppm}} &= 100\% \times 50\% \text{ acreage} \times 127000 \text{ lbs N/year in soil} = 64000 \text{ lbs N/year uptake} \\
\frac{40\text{ppm required}}{40.4\text{ppm}} &= 99\% \times 50\% \text{ acreage} \times 81000 \text{ lbs P/year in soil} = 40000 \text{ lbs P/year uptake} \\
\frac{0\text{ppm required}}{145.5\text{ppm}} &= 0\% \times 50\% \text{ acreage} \times 291000 \text{ lbs K/year in soil} = 0 \text{ lbs K/year uptake}
\end{align*}
\]

Silage:

\[
\begin{align*}
\frac{140\text{ppm required}}{63.5\text{ppm}} &= 100\% \times 25\% \text{ acreage} \times 127000 \text{ lbs N/year in soil} = 32000 \text{ lbs/year uptake} \\
\frac{50\text{ppm required}}{40.4\text{ppm}} &= 100\% \times 25\% \text{ acreage} \times 81000 \text{ lbs P/year in soil} = 20000 \text{ lbs/year uptake} \\
\frac{115\text{ppm required}}{145.5\text{ppm}} &= 79\% \times 25\% \text{ acreage} \times 291000 \text{ lbs K/year in soil} = 57000 \text{ lbs/year uptake}
\end{align*}
\]

Alfalfa:

\[
\begin{align*}
\frac{0\text{ppm required}}{63.5\text{ppm}} &= 0\% \times 25\% \text{ acreage} \times 127000 \text{ lbs N/year in soil} = 0 \text{ lbs N/year uptake} \\
\frac{30\text{ppm required}}{40.4\text{ppm}} &= 74.3\% \times 25\% \text{ acreage} \times 81000 \text{ lbs P/year in soil} = 15000 \text{ lbs P/year uptake} \\
\frac{100\text{ppm required}}{145.5\text{ppm}} &= 68.7\% \times 25\% \text{ acreage} \times 291000 \text{ lbs K/year in soil} = 50000 \text{ lbs K/year uptake}
\end{align*}
\]

- Manure only applied to grain and silage under current system
- Compost applied to grain, silage, and alfalfa under proposed system
13.2. Appendix B: Environmental Analysis Calculations

13.2.1. Emissions and global warming potential

Current System:

\[
\frac{10000 \text{ lb CO}_2}{1 \text{ acre}} \times 750 \text{ acres} = 7,500,000 \text{ lbs CO}_2 \times \frac{1 \text{ lb CO}_2}{1 \text{ lb CO}_2} = 7,500,000 \text{ lb CO}_2e \\
\frac{1000 \text{ lb CH}_4}{1 \text{ acre}} \times 750 \text{ acres} = 750,000 \text{ lbs CH}_4 \times \frac{34 \text{ lb CO}_2}{1 \text{ lb CH}_4} = 25,500,000 \text{ lb CO}_2e \\
\frac{180 \text{ lb N}_2O}{1 \text{ acre}} \times 750 \text{ acres} = 135,000 \text{ lbs N}_2O \times \frac{298 \text{ lb CO}_2}{1 \text{ lb N}_2O} = 40,230,000 \text{ lb CO}_2e
\]

Total global warming potential from current system: \(-73,230,000 \text{ lb CO}_2e\)

Proposed System:

\[
\frac{97.9 \text{ g CO}_2}{1 \text{ tonne compost}} \times \frac{1 \text{ lb}}{453.6 \text{ g}} \times \frac{1 \text{ tonne}}{2205 \text{ lbs}} \times 2.58e7 \text{ lbs compost} = 2525 \text{ lbs CO}_2 \times \frac{1 \text{ lb CO}_2e}{1 \text{ lb CO}_2} = 2525 \text{ lbs CO}_2e \\
\frac{1138 \text{ g CH}_4}{1 \text{ tonne compost}} \times \frac{1 \text{ lb}}{453.6 \text{ g}} \times \frac{1 \text{ tonne}}{2205 \text{ lbs}} \times 2.58e7 \text{ lbs compost} = 29,355 \text{ lbs CH}_4 \times \frac{34 \text{ lb CO}_2}{1 \text{ lb CH}_4} = 998,066 \text{ lbs CO}_2e \\
\frac{265 \text{ g N}_2O}{1 \text{ tonne compost}} \times \frac{1 \text{ lb}}{453.6 \text{ g}} \times \frac{1 \text{ tonne}}{2205 \text{ lbs}} \times 2.58e7 \text{ lbs compost} = 6836 \text{ lbs N}_2O \times \frac{1 \text{ lb CO}_2e}{1 \text{ lb N}_2O} = 2,037,043 \text{ lbs CO}_2e
\]

Total global warming potential from proposed system: \(-3,038,000\)

- Current system calculation set up and values from (“Impact of Manure Incorporation on Greenhouse Gas Emissions in Semi-Arid Regions – Livestock and Poultry Environmental Learning Community,” 2019)- used NH3 as proxy for N2O
- Proposed system calculation set up and values from (Biala et al., 2016)
- Global warming potential measured by CO2, CH4, and N2O because of availability of research and prevalence of gases towards climate change
### 13.3. Appendix C. Capital cost estimation for building composting facility.

<table>
<thead>
<tr>
<th>Name of equipment/installation</th>
<th>Description</th>
<th>Units</th>
<th>Price ($/unit)</th>
<th>Quantity (# units)</th>
<th>Cost in 2014 or 2015 ($)</th>
<th>Cost in 2019* ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excavation, side cast, common earth, small equipment</td>
<td>Bulk excavation and side casting of common earth with hydraulic excavator, (Includes equipment and labor)</td>
<td>yard³</td>
<td>2.14</td>
<td>630</td>
<td>1,348.20</td>
<td>1,465.60</td>
</tr>
<tr>
<td>Concrete, CIP, slab on grade, reinforced</td>
<td>Steel reinforced concrete formed and cast-in placed as a slab on grade by chute placement (Includes materials, labor and equipment to transport, place and finish).</td>
<td>yard³</td>
<td>132.13</td>
<td>260</td>
<td>34,353.80</td>
<td>37,346</td>
</tr>
<tr>
<td>Earthfill, Roller Compacted</td>
<td>Earthfill, roller or machine compacted, includes equipment and labor</td>
<td>yard³</td>
<td>3.98</td>
<td>315</td>
<td>1,253.70</td>
<td>1,362.9</td>
</tr>
<tr>
<td>Post Frame installation</td>
<td>Post frame with truss, post on frost foundation. Includes labor</td>
<td>ft²</td>
<td>15.2</td>
<td>420</td>
<td>6,384</td>
<td>6,958.6</td>
</tr>
<tr>
<td>Post frame roof installation</td>
<td>Roofing, includes labour</td>
<td>ft²</td>
<td>11.7</td>
<td>420</td>
<td>4,914</td>
<td>5,356.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name of material</th>
<th>Description</th>
<th>Unit</th>
<th>Price ($/unit)</th>
<th>Quantity (# units)</th>
<th>Cost in 2014 or 2015 ($)</th>
<th>Cost in 2019* ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate, Gravel, Graded</td>
<td>Gravel, includes materials, equipment and labor to transport and place. Includes washed and unwashed gravel</td>
<td>yard³</td>
<td>25.33</td>
<td>206</td>
<td>5,217.98</td>
<td>5,672.5</td>
</tr>
<tr>
<td>Piping</td>
<td>3in*10ft pipe, no installation cost assumed</td>
<td>ft</td>
<td>1.04</td>
<td>180</td>
<td>-</td>
<td>187.2</td>
</tr>
<tr>
<td>Roofing material</td>
<td>Material required for roofing</td>
<td>ft²</td>
<td>5.6</td>
<td>196</td>
<td>1,097.6</td>
<td>1,196.4</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>59,545.5</td>
</tr>
</tbody>
</table>

* US dollars in 2014 and 2015 was 8.71% and 9.00% greater than in 2019, respectively (Statistics & Indexes, 2019)

  - (USDA, 2014)
  - (UW-Extension, 2015)
  - Home Depot store price (homedepot.com)
14. References


Common Manure Test Results Conversions – Livestock and Poultry Environmental Learning Community. (2019, March 5). Retrieved December 1, 2019, from https://lpelc.org/common-manure-test-results-conversions/


Farm Manure Composting Facilities and Resulting Effects on Groundwater

(Windrow Composting, n.d.)

Client: Pepin County

Team Members: 

Course: CEE 421 Environmental Sustainability Engineering

Instructor: Dr. Andrea Hicks

Date: December 9, 2019
Introduction/Background

Pepin County, located in the western most edge of Wisconsin, is a rich agricultural center and has a total area of 249 square miles. The southwestern most section of Pepin County borders Pepin Lake which runs into the Mississippi River.

![Figure 1 Pepin County and the surrounding area through satellite images (Google Maps, 2019).](image)

Agriculture has conflicts in regard to the effects of both applied nutrients (including fertilizer spreads, specifically in regard to phosphorus and nitrogen), as well as runoff nutrients, such as those from manure. One of the biggest dangers of runoffs is nitrate ($\text{NO}_3$), which forms when nitrogen rich compounds – like those found in manure, as well as applied nutrients – combine with oxygen (Nitrate, 2019). In regard to health concerns about contact with nitrate in water, it is stated that: “[t]he health-based groundwater quality enforcement standard (ES) for nitrate-N in groundwater and the maximum contaminant level (MCL) for nitrate-N in public drinking water are both 10ppm”, where ppm stands for parts per million (Nitrate, 2019).

Being located in such an intensive agricultural area has its implications for the environment and local residents, especially in regard to water. In the state of Wisconsin, while there are municipal water systems (two of which are located in Pepin County,) to supply water to areas, much of the water consumption is sourced through wells. It is estimated that Wisconsin has a total of around 850,000 private wells, but when it comes to private wells, it is on the
owners to keep up with maintenance (Pepin County, 2007). In Wisconsin, Pepin County has one of the highest private well nitrate contamination rates, with an estimated 20% of private wells being above the national nitrate standard of less than or equal to 10ppm (Nitrate, 2019). Furthermore, besides for private wells, the overall nitrate levels in Pepin County above the Environmental Protection Agency (EPA) standard of 10 mg/L are 4.1% higher than across the rest of the state of Wisconsin (County Environmental Health Profile, 2019).

![Groundwater Contamination Susceptibility Analysis of Pepin County, WI](image)

**Figure 2** Groundwater Contamination Susceptibility Analysis of Pepin County, WI (Pepin County, 2007).

However, high levels of nitrates in groundwater are also perpetuated by the general livelihood found in Pepin County, and the resulting effects of manure runoff, if it is not composted correctly. In order to better moderate the application of fertilizers and manure as compost, Amendment No. 113 to Pepin County Ordinance 179 outlines manure storage tactics through qualifications in nutrient management plans to more adequately monitor which crops are having fertilizer applied, how much, and of what fertilizer, including manure substitutes. Additionally, the Amendment No. 113 outlines areas at risk for groundwater contamination, as seen in Figure 3.
I. An area within 250 feet of a private well
II. An area within 300 feet up-slope or 100 feet down-slope of direct conduit to groundwater, including but not limited to karst features
III. An area within 1,000 feet of a municipal well
IV. A channel that flows to a direct conduit to groundwater, including but not limited to karst features
V. An area where the soil depth to groundwater or bedrock is less than 2 feet.
VI. An area where the soil does not exhibit one of the following characteristics:
   A. At least a 2 foot layer with 40 percent fines or greater above groundwater and bedrock
   B. At least a 3 foot soil layer with 20 percent fines or greater above groundwater and bedrock
   C. At least a 5 foot soil layer with 10 percent fines or greater above groundwater and bedrock

**Figure 3** List detailing the qualifications of areas susceptible to groundwater contamination due to fertilizers, including manure (Amendment No. 113 to Pepin County Ordinance 179, 2017).

Manure composting can be effective in its application and soil nutrient benefit it provides to crops in agriculture. At the same time, potential issues and resulting consequences must be taken into account as effects of fertilizer and manure application, such as contamination groundwater from nitrates. This report describes how to mitigate groundwater contamination by nitrates through effective manure composting methods for different size farms (both 500 animal and 1,000 animal unit farms), as well as how the three paradigms of sustainability - environment, economic, and social - relate and support the composting methods detailed below.

**Project Scope and Specifications**

Implementing composting facilities in farms of varying scale in Pepin County will have several consequences both intended and unintended. It must be determined if the composting facilities are worth doing. This project aims to answer the questions, “Are large-scale composting facilities for farms beneficial economically for the farmers? Beneficial to the environment? Beneficial to society?” In the analysis of the design of composting facilities for Pepin County it will be determined how this project answers those questions and whether or not it can be deemed sustainable.
The proposed composting facilities are designed for a farm that has 500 animal units. The farm also contains a total of 1,000 acres of alfalfa and corn of which 750 currently have manure applied while compost could be applied to all 1,000 acres. This farm currently generates liquid manure at a rate of three million gallons per year. Liquid manure has a Nitrogen-Phosphorus-Potassium (NPK) of 8.6-4.6-20.7, the liquid manure also has a dry matter of 5.5% and is incorporated within 72 hours of its application. Solid manure is generated on the farm at a rate of 1,700 tons per year, the solid manure has an NPK of 3-3-6 as well as 33% dry matter. The soil on the farm is Finchford loamy sand; it has organic matter at 2.6%, a pH of 6.7, a P of 50 and K of 120. The levels for the liquid and solid manure are doubled if considering a farm with 1,000 animal units.

There are several goals for what this project is to accomplish on the farm. The yield goal for the silage on the farm is 25 tons per acre which can be achieved through the recommended NPK of 140-50-115. The recommended NPK to meet the yield goal of 190 bushels/acre for grain is 140-40-0. The farm also needs to meet Wisconsin Pollutant Discharge Elimination System (WPDES) permit standards by operating as a zero discharge facility. The mitigation of groundwater contamination by nitrates is the overall goal of this project that must be completed while also considering these other goals and specifications. Through the ability to meet these goals and the impacts on the three paradigms of sustainability, which are economics, environment and social, a decision can be made as to the method of composting is best for this project.

Assumptions

In this project there are a number of assumptions that are made in order to proceed with a reasonable scope to the project. One such assumption is that the specifications laid out above including the animal units, liquid and solid manure numbers and crop acres are not subject to change for the foreseeable future at any of the farms. If these numbers were subject to change the composting calculations would need to be adjusted. Another assumption made is that surface water and streams are nearby but over 1,000 feet away from the farm, allowing for runoff
through the soil and watershed but likely no direct contamination from the manure.
Economically, an assumption is made that the farms will have the capital available to fund any composting facilities chosen, however, Life Cycle Cost Analysis will still be performed for each method to determine which provides the most value to the farm.

Methods

Multiple composting methods were considered and compared for the most effective method for lowering nitrate levels, and thus, lowering groundwater contamination. These methods include Aerated (Turned) Windrow Composting, In-Vessel Composting (SV Composting System), and Rotating Drums. Summaries of each are presented in this section, and the methods are further explored in relation to their impacts on the three paradigms of sustainability - environmental, economic, and societal - in the following sections in regard to the 500 animal unit farm which can be scaled up to reflect values for the 1,000 animal unit farm.

Aerated (Turned) Windrow Composting

Aerated (Turned) Windrow Composting is designed for a larger volumes of waste and needs no construction of a facility or holding place. This method is conducted by forming manure into long piles (called windrows), with a recommended height of 6 feet and a width of 15 feet. The large pile is able to maintain its own heat, but not to the point where oxygen is unable to flow throughout the core of the windrows. The piles need to be aerated periodically to prevent the microorganisms from dying inside. The aeration can either be done manually or with machinery and will decrease in occurrence with age. Since the windrows will be relatively large to combat the winter season’s effects, turning will occur twice per day for the first week and will later only need to be turned three to five times per week. The active composting stage of the windrows method will last anywhere from three to nine weeks, with variations occurring from the composition of the manure and frequency of aeration. Since the windrows will be placed outside, it is necessary to collect the leachate off the piles to prevent it from entering the groundwater.
The Windrow method is the cheapest of the three and will only need machinery in order to turn the piles, such as the Aeromaster PT-130. It is more labor intensive, however, as the physical labor needed to aerate the piles is done quite frequently. Another issue is that the odor released from these piles would need to be contained, as it could travel to neighboring communities and citizens could find it unbearable. Environmentally, this method is a more natural method, but could end up contaminating the groundwater if not dealt with correctly.

In-Vessel Composting (SV Composting System)

The SV Composting system can be designed for a wide range of facilities, fitting somewhere in the middle for the desired amount of composting needed. There are many installations throughout the US, with one located in Hutchinson, Minnesota. It is able to operate in both warmer and colder climates without much variation in productivity. The facility is insulated with concrete and uses stainless steel on the interior of the doors. The SV Composting System is able to complete the aeration process on its own, needing little intervention. The period for obtaining ready-to-use compost is about two months, which is needed for the compost to balance the microbial activity and cool.

The SV Composting system is one of the more expensive methods discussed and some technical knowledge is needed to make sure it runs efficiently. There is little need for constant checkup on the system because it will be automatically monitored. Relatively no odor is produced and not as much physical labor is required to maintain a better quality of compost. The leachate produced from the process is collected and drained, making it environmentally friendly.

Rotating Drums

The rotating drums are used to mix the manure and allow oxygen to aerate throughout the system. The system is designed to be placed on large bearings and turned by the use of a bull gear. There are many different sizes available that range from residential use to large scale facilities. For Pepin county, a drum with a diameter of about 3.5 meters and length of 37 meters would be able to hold close to 50 tonnes. The residence time of the manure depends on how
quickly the drum is turned, so it is able to be controlled by the user to determine when and how much compost material is needed. A second stage of composting may be needed if the process is done too quickly. The drum is able to be divided into sections, which allows for different batches to be completed separately. Once the manure is ready to discharge it will go through a screening process. This process is used to remove any material that is too large to be used as compost, which is then returned to the drum process.

The rotating drum method is relatively inexpensive, although slightly more costly than the windrows method. It is not labor intensive, though there may be difficulty when considering how much manure is needed at varying times, therefore planning is required. The odor is minimal if completed using a closed drum and is only a potential issue when compost material is transferred between drums. Environmentally, this method does not allow leachate to run off into the groundwater and prevents any contamination if managed correctly; such that large particulates do not escape into the field when the compost is applied.

Environmental Impact and Life Cycle Assessment

This section outlines the concept of life cycle assessment (LCA) and its resulting application for the different system methods listed above: (Aerated) Turned Windrow Composting, In-Vessel Composting (SV Composting), and Rotating Drums. LCA portrays potential environmental consequences for a specific process, given the scope of that process, in order to make better informed environmental decisions. In general terms, an LCA has four main stages: goal and scope definition, inventory analysis, impact assessment, and interpretation.

LCA Goal and Scope

In regards to the manure composting project for Pepin County, the goal of the study is to help reduce nitrate levels being released into groundwater supplies due to runoff of excess fertilizer and manure practices. In doing so, the life cycle assessments of three different manure composting methods are outlined below to help quantify values of nitrate (seen as eutrophication potential) as well as GHG emissions. The scope of the study defines what inputs and outputs of a process the study will take into account while calculating the emissions and environmental
impact. The general scope of the study is shown below in Figure 4, but each method will reflect more specific boundaries for its precise inputs and outputs that will be taken into account, as the different methods require different inputs (such as energy) in different forms. The general scope reflects the four different stages of LCA as well, which include raw material acquisition (of both the composting input as well as the machinery inputs), manufacturing, use, and end of life. End of life in this system is only taken into regard with respect to the composted manure product, in which case the product is considered a cradle-to-cradle LCA model, because the manure product can be repurposed into fertilizer. The scope does not take into account excess composted manure produced, nor what would be done with any composted manure product; it is assumed that there will be none.

![Figure 4 General scope of the study.](image)

The functional unit for the scope of the 500 animal unit dairy farm is defined as 8,219 gallons of liquid manure per day, which can be scaled up to the farm with 1,000 animal units by doubling the results found for the functional unit in both processing through machinery as well as environmental effects. Likewise, functional unit for the 500 animal unit dairy farm solid manure production is defined as 4.66 tons per day. The provided NPK values for liquid manure show a ratio of 8.6-4.6-20.7, which means the produced nitrogen levels of the 500 animal unit farm is assumed to be 955.7 gallons of aqueous solution produced daily. The NPK of solid
manure reflects a ratio of 3-3-6, resulting in produced nitrogen levels for the 500 animal unit farm of 1.55 pounds per day. Additionally, the functional unit for farm acres for the 500 animal unit farm is defined as 1,000 acres, which can also be doubled to scale up to the 1,000 animal unit farm capacity. It is assumed the composted manure product will be applied to all 1,000 acres for the 500 animal unit farm.

In the study, it is assumed that the liquid manure is being applied directly to the land without treatment; therefore, no impact assessment for liquid manure treatment is being conducted, and composting methods will apply only to the solid manure production of the farm.

**Inventory Analysis**

An inventory analysis includes all inputs and outputs being taken into account while calculating the effects of a product or cycle in LCA analysis. For each of the three potential methods, an inventory analysis is detailed below.

The (Aerated) Turned Windrow Composting method is the most natural of the methods, forming windrows, or columns, of manure while aerating the windrows (manually or mechanically) a few times every week or month, depending on where the manure is in the composting cycle. The leachate produced from this method must be collected and treated in order to prevent it from running off into groundwater sources or nearby bodies of water. The method of leachate collection and its resulting impact will not be considered when conducting LCA impact.

Machinery to turn windrows, such as the Aeromaster PT-130 can turn 1,275 m³ of manure compost at 0.5 km/hr tractor speed; to operate, the tractor must be able to operate at 110 PTO HP (power takeoff horsepower) (Aeromaster Composting Equipment, 2016). Fuel put into the operation of the Aeromaster PT-130 will be assumed to use diesel fuel for the tractor operation. The system boundaries as well as inputs and outputs of the turned windrow composting method are shown in Figure 5.
Due to the natural nature of the Turned Windrow Composting method, few inputs and outputs are actually created and considered. Of those, the solid manure input is taken as the functional unit defined at 4.66 tons/day produced of manure. As a result of the hydration of manure during the composting process so it does not dry out, it is assumed that minimal mass is lost throughout the course of composting, so the output of composted manure is also assumed at 4.66 tons per the 4.66 tons of manure put into the system for compost. The diesel fuel is taken into consideration, as it helps to run the tractor that operates the Aeromaster PT-130. The inputs for construction of the tractor and the Aeromaster PT-130 are not taken into account into the table, because they are not directly connected to the composting process - only the produced machinery is. With the recommended height of the windrows at 6 feet and the width at 15 feet, a length of 25 feet, thirty windrows can be created that result in a total volume of 1,275m$^3$; if the tractor operating the Aeromaster PT-130 runs at the recommended 0.5km/hr speed, the total operation of aerating the windrows will be assumed to take about a half hour total. The inputs and outputs per day for the Turned Windrow Composting method are listed in Table 1.
Table 1 Inputs and Outputs for (Aeratated) Turned Windrow Composting method.

<table>
<thead>
<tr>
<th>Material</th>
<th>Amount</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid Manure</td>
<td>4.66 tons</td>
<td>Pepin County Project Detail Background</td>
</tr>
<tr>
<td>Diesel fuel</td>
<td>2.9 gallons</td>
<td>Dom, 2008</td>
</tr>
</tbody>
</table>

Some calculations were performed from the sources mentioned in the table above in order to compute the amount used or produced of each material.

In regard to the In-Vessel (SV) Composting Method, it is favorable, because the facility used to compost decreases the potential requirement for manual work to aerate the compost. SV composting reduces odor because it is contained in a facility, additionally, the facility helps to mediate and stabilize the core temperature of the manure while it is composting. The facility for this method would need to be built, and some can be customized to reflect the manure produced per farm. Energy would need to be put into the system to facilitate and automate the composting process. The leachate from this process is automatically collected and drained, making it easier to prevent and manage the possibility of groundwater contamination. The system boundaries are outlined for the inputs and outputs of the SV Composting Method in Figure 6.
When considering potential systems, there is the Earth Flow Site-Built Composting System, that at 10 feet wide and 32 feet in length, can process 1.5 tons of solid manure per day (Earth Flow Site-Built Composting System, 2018). Therefore, it is estimated to take at least 4 of these facilities in order to process the functional unit of daily solid manure production. The Earth-Flow Site-Built Composting System requires a motor with energy consumption of 30A 220V single, where A refers to amperes and V refers to volts (Earth Flow Site-Built Composting System, 2018). It is assumed the composting facility will be running continuously in order to compost the manure in the 10-14 day cycle estimation while hydrating and aerating the manure pile, resulting in a total energy consumption per day in kilowatt hours (kWh). The total consumption and production of materials in the SV Composting method that are taken into consideration are listed in Table 2.
Table 2 Input and Output assumptions for In-Vessel (SV) Composting method.

<table>
<thead>
<tr>
<th>Inputs (functional unit for dry manure at 4.66 tons/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Materials</strong></td>
</tr>
<tr>
<td>Solid Manure</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Energy</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

| Outputs                                                | **Amount** | **Source**                           |
| Composted Solid Manure                                 | 4.66 tons  | Pepin County Project Detail          |
|                                                        |            | Background                           |

Some calculations were conducted in order to attain the numerical data listed in the table above from the sources noted.

Finally, the Rotating Drum composting method allows for consistent and machine-driven aeration of composting the manure, thereby also reducing the manual work necessary. The user will need to decide how quickly the drum barrel will rotate, and thus, how fast the manure will complete the compost process; however, if rotated too quickly and therefore completing the compost process too quickly, the manure will need to finish composting after. Additionally, the amount of manure placed in the drums at a given time will affect the rotation speed and how quickly the manure will compost. Furthermore, the leachate of the rotating drum composting method is also collected automatically through the process, nullifying the need to manually collect and manage the leachate. The system boundaries considered and the inputs and outputs per day that lie within the boundaries are reflected in Figure 7.
Figure 7 System boundaries of Rotating Drum composting method, assuming drums of 3.5m diameter and 37m length, holding 50 tonnes of manure.

Rotating Drum composting systems come in varying sizes depending on the production of manure and the resulting need to compost it. For the purposes of quantifying the available space and energy required to run a similar system, information from the QuantorXL is used. The QuantorXL allows for a total of 10,000 m$^3$ of manure to be composted per year, resulting in the ability to compost around 12.0 tons of manure per day, assuming the density of cow manure to be around 400kg/m$^3$; however, these numbers may decrease slightly based on the composition of the manure and how long it needs to be processed (Density of Manure, 2019). It is assumed that the rotating drum system will be in constant use so as not to interrupt the composting process and to effectively regulate the hydration, temperature, and aeration of the manure. The resulting inputs and outputs per day included in the system boundary are denoted in Table 3.
Table 3 Input and Output assumptions for Rotating Drum composting method.

<table>
<thead>
<tr>
<th>Inputs (functional unit for dry manure at 4.66 tons/day)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials</td>
<td>Amount</td>
<td>Source</td>
</tr>
<tr>
<td>Solid Manure</td>
<td>4.66 tons</td>
<td>Pepin County Project Detail Background</td>
</tr>
<tr>
<td>Energy</td>
<td>54.8 kWh</td>
<td>QuantorXL, 2008</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Outputs</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Composted Solid Manure</td>
<td>4.66 tons</td>
<td>Pepin County Project Detail Background</td>
</tr>
</tbody>
</table>

Calculations were conducted in order to obtain numbers for the material amounts in the table above from the sources listed in the table.

Impact Assessment

Impact Assessment for each of the considered composting methods is calculated through the method Economic Input-Output Life Cycle Assessment (EIO-LCA). EIO-LCA is a method of environmental impact based on the materials being produced/used and the energy and resources required to produce those materials. It compares similar economic sectors and products and determines the environmental cost as a result of all of these factors. As a result, the equipment utilized in each of the three composting methods will be taken into consideration in the EIO-LCA assessment of environmental impact. The Carnegie Mellon EIO-LCA tool is used as the means to conduct this assessment. The parameters used to conduct the EIO-LCA are the US 2002 Producer model selected from the US National Producer Price Models. Additionally, the impact category chosen is the Tool for Reduction and Assessment of Chemical and other Environmental Impacts (TRACI) which is a general environmental impact assessment model provided by the EPA. The only categories that will be used in assessment from TRACI are the eutrophication impact and the climate change impact. The water eutrophication impact is chosen because of the background Pepin County has with nitrate issues and the resulting water quality.
The climate change impact is also chosen as another measure by which to compare the methods - this category has special interest in the release of greenhouse gases (GHGs).

In this study, manure is a bi-product of the normal farm operations; since the farm is not purchasing manure, a cost cannot be assessed for the manure being put into composting, and thus the environmental cost of manure cannot be assessed through the means of conducting an EIO-LCA analysis. However, estimated applied manure per acre as well as estimated average nitrogen released per acre is noted in Table 4. It is assumed that manure fertilizer is applied on all 1,000 acres of the farm, and it is assumed that half of the applied manure fertilizer will be liquid and half will be solid - in other terms, it is assumed that 500 acres will have liquid manure applied and 500 acres will have solid manure applied. Resulting calculations of estimated nitrogen impact from manure fertilizer application are also noted in the table, and will be taken into consideration in the overall impact assessment of each option. The quantification of manure application in Table 4 will be assumed to take place once a year in the Spring.

**Table 4** Fertilizer application and resulting nitrogen impact on soil for a 500 acre farm.

<table>
<thead>
<tr>
<th>Type of Fertilizer</th>
<th>Applied Fertilizer</th>
<th>Nitrogen Released</th>
<th>Total Nitrogen Released</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid Manure</td>
<td>7,500 gallons/acre (Using Manures, 2012)</td>
<td>75 pounds/acre (Using Manures, 2012)</td>
<td>17,009 kg</td>
</tr>
<tr>
<td>Solid Manure</td>
<td>25 tons/acre (Fred Madison)</td>
<td>75 pounds/acre (Using Manures, 2012)</td>
<td>17,009 kg</td>
</tr>
</tbody>
</table>

The estimation of nitrogen released in Table 4 can be scaled up for the 1,000 acre farm at 34,018 kg of nitrogen released once a year in Spring.

For the Turned Windrow Composting method, the tractor will be included in the EIO-LCA considerations, as well as the diesel put in to fuel the tractor while operating the Aeromaster PT-130. The lifetime of the average tractor is currently estimated at thirty years (Tractor By Net). The EIO-LCA results will not include the nitrogen impact from manure used as fertilizer; those impacts will be included in the interpretation of results. The environmental impact of the Turned Windrow Composting method is reflected in the data in Table 5.
Table 5 EIO-LCA results for the Turned Windrow Composting method (EIO-LCA, n.d.).

<table>
<thead>
<tr>
<th>Input</th>
<th>Water Eutrophication Potential/year</th>
<th>Climate Change Potential/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tractor</td>
<td>$9.33 \times 10^{-4}$ kg Ne</td>
<td>$1,870$ kg $\text{CO}_2\text{e}$</td>
</tr>
<tr>
<td>Diesel fuel</td>
<td>$2.31 \times 10^{-4}$ kg Ne</td>
<td>$369$ kg $\text{CO}_2\text{e}$</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$0.0012$ kg Ne per year</strong></td>
<td><strong>$2239$ kg $\text{CO}_2\text{e}$ per year</strong></td>
</tr>
</tbody>
</table>

**Abbreviations:** kg Ne is kilograms of nitrogen equivalent  
kg $\text{CO}_2\text{e}$ is kilograms of carbon dioxide equivalent

Calculations were made in order to estimate the average cost of a tractor as well as the expected average life-time of a tractor. Numbers were calculated so that the overall impact per year was estimated for a more holistic view. The trend in the Turned Windrow Composting method reflects higher numbers of climate change potential over water eutrophication potential, with the tractor having a greater contribution to both environmental impacts than the diesel fuel, as expected. The numbers can be scaled up for a 1,000 animal unit farm by doubling the results to yield a total water eutrophication potential per year of $0.0024$ kg Ne, and a climate change potential per year of $4,478$ kg $\text{CO}_2\text{e}$.

For the SV Composting method, the concrete used to create the facility is considered, as well as the steel for the doors. Additionally, the energy put into the system is considered in the environmental impact assessment. The life span of the facility built is estimated to be around 50 years (Gilliland, 2018). Table 6 presents the numerical data for the environmental impact of the SV Composting method.
Table 6 EIO-LCA results for the SV Composting method (EIO-LCA, n.d.).

<table>
<thead>
<tr>
<th>Input</th>
<th>Water Eutrophication Potential/year</th>
<th>Climate Change Potential/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel door</td>
<td>3.96x10^{-6} kg Ne</td>
<td>8.56 kg CO\textsubscript{2}e</td>
</tr>
<tr>
<td>Concrete bricks</td>
<td>5.56x10^{-7} kg Ne</td>
<td>1.97 kg CO\textsubscript{2}e</td>
</tr>
<tr>
<td>Energy</td>
<td>0.0052 kg Ne</td>
<td>8090 kg CO\textsubscript{2}e</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>0.0052 kg Ne per year</strong></td>
<td><strong>Total: 8101 kg CO\textsubscript{2}e per year</strong></td>
</tr>
</tbody>
</table>

**Abbreviations:** kg Ne is kilograms of nitrogen equivalent
kg CO\textsubscript{2}e is kilograms of carbon dioxide equivalent

Calculations were performed to estimate the cost of the inputs (steel door, concrete bricks), as well as energy. Due to the nature of the facility that is built having a lifetime that spans years, it lowers the overall environmental impact of building it. The input sector with the biggest input is the energy required to run the facility in order to maintain operation, which makes sense, because the energy has a finite lifetime and can only be used up before it needs to be replenished. Similar to the Turned Windrow Composting method, the SV Composting method also had higher levels of CO\textsubscript{2}e emissions than it did Ne emissions, resulting in a higher global warming potential than eutrophication potential. The results in Table 6 for the SV Composting method can be doubled to reflect the annual environmental impacts of a 1,000 animal unit farm: water eutrophication potential of 0.0104 kg Ne and a climate change potential of 16,202 kg CO\textsubscript{2}e.

For the Rotating Drum composting method, the inputs considered are the construction of the drum facility itself, as well as the energy input to run the composting method and maintain its processes to regulate temperature, hydration, and aeration of the manure. The lifetime of the drum is assumed to be 20 years on average, potentially longer. The environmental impacts of the Rotary Drum composting method are quantified in Table 7.
Table 7 EIO-LCA results for the Rotating Drum composting method (EIO-LCA, n.d.).

<table>
<thead>
<tr>
<th>Input</th>
<th>Water Eutrophication Potential/year</th>
<th>Climate Change Potential/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drum</td>
<td>0.0086 kg Ne</td>
<td>1605 kg CO$_2$e</td>
</tr>
<tr>
<td>Energy</td>
<td>0.0018 kg Ne</td>
<td>140 kg CO$_2$e</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td><strong>0.010 kg Ne</strong></td>
<td><strong>Total: 1745 kg CO$_2$e</strong></td>
</tr>
</tbody>
</table>

**Abbreviations:** kg Ne is kilograms of nitrogen equivalent  
kg CO$_2$e is kilograms of carbon dioxide equivalent

Calculations were performed in order to calculate numerical inputs to produce yearly environmental impact from the Rotating Drum composting method. Similar to the other results, the Rotating Drum composting method also had an overall higher trend for climate change potential; however, unlike the SV Composting method, the construction of the drum in this method had a much higher eutrophication and climate change potential than the environmental impacts of the energy put into the system. For the 1,000 animal unit farm, these results can be double to reflect a yearly water eutrophication potential of 0.020 kg Ne and a yearly climate change potential of 3,490 kg CO$_2$e.

**Interpretation**

The comparative environmental impacts (in regard to both water eutrophication potential as well as climate change potential) of each of the three composting methods are reflected in Figure 8. Included in each of the eutrophication potentials is the nitrogen released from application of composted manure once yearly at 17,009 kg of nitrogen. In the chart, TWC stands for Turned Windrow Composting method, SV stands for the In-Vessel (SV) Composting method, and RD stands for the Rotating Drum composting method.
Comparison of eutrophication potential and climate change impact from the three methods of composting proposed for the 500 animal unit farm.

All three methods have comparable eutrophication potential in regard to their environmental impact. This is because each method had a relatively small annual eutrophication potential due to the machinery and energy it would take to run the machinery; however, the eutrophication potential from the annual composted manure application as fertilizer for crops had the same value across all three methods, and was very large comparable to the eutrophication potential of the machinery involved in the methods. Of the methods, the Turned Windrow Composting method had similar results in carbon dioxide equivalent emissions, or climate change potential, to the Rotating Drum composting method. The SV Composting method had a much higher carbon dioxide equivalent emissions at 5,826 kg CO$_2$e more released annually than the Turned Windrow Composting method, and 6,356 kg CO$_2$e more released annually than the Rotating Drum composting method. Referencing CO$_2$e emissions and eutrophication potential, the Rotating Drum composting method has the smallest annual environmental impact within the system boundaries denoted previously of the three methods analyzed.
Economic Impact Assessment

In order to compare the economic impacts of the three chosen alternatives the Life Cycle Cost Analysis (LCCA) was used. This analysis method is used to evaluate the total lifetime costs of purchasing and operating the different systems that are used for manure composting by comparing their net present values (NPV). The NPV is used to put all of the future costs for a designated time period into present dollar worth, this is used to compare the alternatives on a level playing field. To compare the three alternatives with LCCA the initial cost of each system, the annual fuel/energy costs associated with each system, and the salvage value of the machinery in the system will be used. The LCCA will be performed for a lifetime of 20 years. According to a projection from the International Monetary Fund (IMF) the inflation rate in the United States is expected to be roughly 2.25% while the average inflation rate from 2009-2019 was 1.75% therefore an inflation rate of 2.0% will be used to evaluate the NPV for the three alternatives (Duffin, 2019). An assumption made in this analysis is that all the alternatives will be operational to the point where the yearly energy requirements are evenly scaled up from our daily energy requirements (e.g. yearly energy = 365.25 * daily energy). Another assumption is that all three alternatives will successfully compost all the manure required. Finally, it will be assumed for economic analysis that all equipment is being purchased new for the process evaluated.

The first alternative evaluated based on LCCA is the Aeromaster PT-130 for the Turned Windrow Composting method. The annual costs associated with the system are the gallons of diesel fuel that are used to operate the tractor used in this composting process. 2.9 gallons of diesel fuel are used daily as a part of this process which corresponds to 1,059 gallons of diesel fuel per year. Using the current price of diesel fuel per gallon of $3.05 according to the U.S. Energy Information Administration (2019), the total yearly cost due to fuel for this alternative is $3,250. The capital costs for the Aeromaster PT-130 and the tractor were found to be $50,000 and $70,000 respectively for a total cost of $120,000 (“Aeromaster PT-130”, n.d.). The salvage value at the end of 20 years was calculated from multiplying the estimated retail price of the Aeromaster PT-130 ($50,000) and the remaining salvage value percentage (20% at 20 years) for this machinery from the American Society of Agricultural and Biological Engineers (Edwards, 2015). The salvage value for the tractor was obtained using the same method with the retail price
at $70,000 with a remaining salvage value percentage of 23% (Edwards, 2015). This resulted in a total salvage value of $26,000. The LCCA for the Turned Windrow Composting method with the Aeromaster PT-130 is shown below as a cash-flow diagram in Figure 9.

![Cash-flow diagram finding the NPV for the Turned Windrow Composting Method with the Aeromaster PT-130.](image)

**Figure 9** Cash-flow diagram finding the NPV for the Turned Windrow Composting Method with the Aeromaster PT-130.

From the LCCA analysis and calculations provided in Figure 9 the total NPV for the Turned Windrow Composting Method was found to have a cost of $155,600. This value could come down significantly if the farm already possessed a tractor with sufficient power (110 horsepower) to operate the Aeromaster PT-130. For the 1,000 unit farm the NPV can be expected to be double the NPV found in Figure 9. The NPV would be a cost of $311,200 for the 1,000 unit farm.

For the LCCA analysis of the SV Composting with an Earth Flow Site-Built Composting System four of the Site-Built systems (1.5 ton/day capacity) are used to handle the load of solid manure at the farm. From “The Earth Flow Can Save You Money” (2015), an information guide offered by Green Mountain Technologies, the company that produces the Earth Flow Site-Built Composting System, it was determined that the capital costs to implement four of these systems
on the farm is $438,000 which includes construction, equipment, infrastructure, and installation costs. The daily energy requirements for this alternative is 158.4 kWh/day. At an average rate of $0.1428/kWh in Wisconsin from “Electricity Rates by State” (2019), the yearly cost for the SV Composting Alternative is $8,250. There is no salvage value associated with the equipment. The LCCA for the SV Composting alternative using the Earth Flow Site-Built Composting System is shown as a cash-flow diagram in Figure 10 below.

![Figure 10](image)

Figure 10 Cash-flow diagram finding the NPV for the CV Composting Method with the Earth Flow Site-Built Composting System

The LCCA analysis for the SV Composting alternative shown in Figure 10 illustrates a NPV of a cost of $573,000. This is a significantly larger present value cost than the cost for the Turned Windrow Composting Method alternative. It makes sense that the SV composting would be more expensive because it involves the construction of additional structures on the farm. Because the 1,000 unit farm would likely require seven systems built as compared to four for the 500 unit farm the NPV can be multiplied by (7/4) to get a NPV cost of $1,002,750 for the larger farm.

For the LCCA analysis for the Rotating Drum alternative the Quantor XL rotating drum system was evaluated. From information that was offered by the Swedish Institute of Agricultural and Environmental Engineering in a knowledge report, the capital cost associated
with this rotating drum system is $354,000 (Sindhoj & Rodhe, 2013). Based on the energy demands of this system that were calculated to be 54.8 kWh per day and using the average Wisconsin energy cost of $0.1428/kWh from “Electricity Rates by State” (2019), the annual cost for this system was calculated to be $2,850. This system does not have a salvage value at the end of the 20 year analysis period. The LCCA for the Rotating Drum alternative using the Quantor XL system is shown below in Figure 11.

![Cash-flow diagram finding the NPV for the Rotating Drum Method with the Quantor XL System](image)

**Figure 11** Cash-flow diagram finding the NPV for the Rotating Drum Method with the Quantor XL System

The LCCA analysis for the Rotating Drum alternative shown in Figure 11 demonstrates a NPV cost of $400,600. This value is slightly less than the cost for the SV Composting alternative while being higher in cost than the Windrow alternative. The annual costs to operate this alternative are the lowest however the initial capital cost was significantly higher than for the Windrow alternative. The 1,000 unit farm would require one additional Quantor XL system to handle the manure load on the larger farm therefore the NPV cost can be doubled to obtain a cost of $801,200 for that farm.

The NPVs for all three alternatives were used to find a numerical value for the economic viability of each alternative to be utilized in the final decision matrix. Due to having by far the lowest NPV cost at $155,600, the Aerated Windrow system was given a 5/5. Both the SV
Composting and the Rotating Drum alternatives had NPV costs that were close but significantly more than the Aerated Windrow alternative; as a result, they were given a two and a three out of five respectively.

**Social Impact Assessment**

The social impacts caused by the three different alternatives have varying possibilities and must be narrowed down in order to display an effective comparison of the three. The analysis was based on standards set by the International Impact Assessment Association (IAIA) with an outline of the different steps shown in Figure 12. For simplicity reasons, each of the different methods for handling the municipal waste will be measured up to management strategies to avoid, mitigate, and enhance, as it will not be possible to monitor and report the situation at hand. In this analysis, the scope of the social impacts will be limited to the dairy farm itself, including the workers, and the surrounding community, including the residents and anyone else in the area.

![Figure 12](image)

**Figure 12** The phases of social impact assessment within a management process (Franks, 2006).

The impact to the dairy farm should be evaluated through labor intensity, health and safety, training, and aesthetic value. Labor intensity is evaluated based on changes from the
previous method, which will be viewed as having no relative work involved as there was no form of composting used, to the projected amount of involvement needed to perform the new method. Health and safety are evaluated based on the direct factors involved from adapting a newer method of handling the waste that impacts the workers directly. Training will involve the change form, which encompasses what is needed to be learned in order to perform the alternate method. The aesthetic values are evaluated based on how each new method will impact the farm’s physical appearance.

The labor intensity involved for the Aerated (turned) Windrow Composting would involve the highest amount of work compared to the other methods. The large piles of waste will need to be turned repeatedly throughout the day, either by hand or machinery. The beginning process will involve the most work, starting at rotating the waste two times per day, and will decrease to three to five times per week after the waste has matured enough. The rotating drums involve relatively low labor needed to achieve adequate results, but still requires transportation of the waste between drums. The in Vessel Composting (SV Composting System) would require the least amount of physical labor needed to produce the composted manure. The primary maintenance needed is to grease the fans inside the machinery.

The main focus for the health and safety of the farm itself focuses on how the labor or any direct catalysts for possible injury. For the Aerated (turned) Windrow Composting system, the biggest concern is the odor produced from the manure. Wisconsin standards have specific regulations where the odor must score less than 500, otherwise it will have to be approved by the government (WDATC, 2006). Because the composting process would occur outside, it would have the highest odor score and possible approval would be required by the government. Both the In Vessel Composting and the Rotating drums would score well below the Aerated Windrow method and neither would require government approval. All three methods would have relatively low likelihood for injury, with only the Aerated Windrows having possible labor induced injury.

Training needed to operate these three facilities is also relatively subjective, as it is difficult to know exactly what the farmers know. Instead, the three methods are ranked based off the difficulty of set up and technical maintenance of each. The most difficult to maintain is the In Vessel Composting, as the air quality must be monitored frequently and malfunctions would
need expertise to fix. The other two methods are relatively similar for the knowledge required and neither of them have a difficult system involved to maintain. All three methods have similar chemical processes for the physical waste. For the aesthetic of the farm, the only major alternative worth consideration would be Aerated (turned) Windrow method. The long piles of waste are not as appealing as placing the waste in a confined, closed off space. Any visitors who are not aware of the composting method could see it as unsanitary. The other two methods would be subjectively equally appealing, as both of them have a relatively similar look.

Taking into consideration all of the social impacts related to the dairy farm, the lowest performing method would be Aerated (turned) Windrow Composting. It has the most negative social impacts when compared to the others with the lowest outlook in three of the four categories. The one with the least negative effects is the Rotating Drums, although not far off from the In Vessel Composting.

The impacts to the community should be evaluated through health and safety, city aesthetic, and social acceptance. Health and safety are evaluated on how the alternate methods will impact the surrounding community, including the handling of the waste and any repercussions occurring. The aesthetic will be evaluated based on how community members will view the changing method and any possible findings related to appearance. Social acceptance will be investigated through how the community members view the different methods and if any are opposed to certain actions.

The factor of health and safety is similar to that of Aerated (turned) Windrow Composting that was previously discussed. The odor will reach directly surrounding communities, up to a mile around which has been estimated through the Wisconsin Department of Agriculture, Trade and Consumer Protection standards. The other two methods will have little to no odor that will impact the surrounding neighborhood. Another factor of safety for the community is the possibility of drinking water contamination, which would only be affected by the use of Aerated (turned) Windrow method if the leachate is not handled correctly. The other methods will be able to handle the waste and any possible runoff within the unit. The aesthetic value of each is relatively close, although the Aerated (turned) Windrow method may look unpleasant to passing citizens. The other two methods may give more of a pleasing view and
give off the impression of well organized farm with advanced technology. The social acceptance of composting varies little between each different method. In America, seventy-three percent of people do not compost, but of that percentage sixty-two percent of people would be willing to if it became more accessible to them. If the farm were to adapt to one of these alternative methods, more people in the community may be more willing to begin practicing their own form of composting.

Taking all of the social impact of the community into consideration, the results are similar to the findings for the social impacts of the farm. The aerated (turned) Windrow Composting system has the most drawbacks out of all three methods, with the other two being very similar. The impacts on the community are, however, very minimal and not as impactful as the impacts related to the farm directly. The overall results show that the Aerated (turned) Windrow Composting system has the most drawbacks when compared to the other two. Between the Rotating Drums and the In Vessel Composting, the drums has slightly less negative impacts, although not a significant amount.

**Conclusions**

Runoff from agricultural processes is a major factor for groundwater contamination. Located in an intensive agriculture area, Pepin county is highly susceptible to environmental risks from runoff. With much of the water consumption being sourced through wells, it poses a major risk to the community population’s health. Pepin County has one of the highest private well nitrate contamination rates. Furthermore, besides for private wells, the overall nitrate levels in Pepin County are above the EPA standard. The implementation of composting to the dairy farm of Pepin county will greatly reduce the nitrogen runoff caused from the manure produced.

The first alternate method for composting is Aerated (turned) Windrow system which uses long piles of waste, called windrows, that are turned periodically to be used as compost when the process is complete. The second method is the SV composting system which uses an insulated and stationary structure that regulates the needed environment to complete the process. The third and final method is the Rotating Drum system that allows oxygen to aerate through the
system by periodically tuming it. Each of the impacts for the alternate methods were looked at through environmental, economic, and social benefits and risks.

In terms of environmental impacts, a life cycle assessment was completed for the three different manure composting methods to help quantify values of nitrate (seen as eutrophication potential) as well as GHG emissions. For the economic impacts, a Life Cycle Cost Analysis was used. This analysis method was used to evaluate the total lifetime costs of purchasing and operating the different systems that are used for manure composting by comparing their net present values. The NPV is used to put all of the future costs for a designated time period into present dollar worth, this is used to compare the alternatives on a level playing field. The potential social impacts were completed by looking at the effects for both the farm directly and the community around it.

A weighted decision matrix was used to compare all three methods for handling the municipal waste using the three different paradigms of sustainability. The environmental, economic, and social impacts were rated in terms of importance to set by the needs of the farm. Each of the alternate methods were then compared and ranked on a 5 point scale, with five being the best option and one being the worst. Once all of the rankings were set, the weight of importance was multiplied by the respective method and summed up. The method with the highest score would be the most beneficial to the farm.

The environmental impacts were weighed at 0.40, because they are one of the most important impact categories to include; however, it was decided that economic impacts should rank slightly higher due to the economic feasibility of options for Pepin County to use. The Rotating Drums had the highest ranking of 5, because of the options, it had the lowest environmental impact, which is clearly seen in its ranking in GHG emissions. This composting method was very closely followed in ranking by the Aerated Windrow Composting, which is why this method received a ranking of 4; it had only a slightly higher environmental impact than the rotating drums. Compared to these two methods, the SV composting received a score of 2, because it had a much higher emission of GHGs compared to the other methods, but is still more controlled than if the manure were not composted or managed correctly.
The economic impacts were weighed at 0.45, this was determined to be the most important criteria in the decision matrix as economic feasibility is very important to Pepin County. The net present value of each alternative from the LCCA was used to determine the value for the economic impact of each option. Due to the lowest NPV cost, the Aerated Windrow Composting alternative was given a score of 5. The Rotating Drum and the SV Composting systems had significantly higher NPV costs with SV Composting being the most costly which earned it a score of 2 on the decision matrix with Rotating Drums earning a 3 on the decision matrix.

The social impacts were weighted at 0.15. This was determined to be the least impactful criteria when compared to the other two because many of the determinants were based off theoretical estimations and consumer ideas based on surveys. The impact for the Aerated (turned) Windrow composting system was rated a 2 because when compared to the other two methods it performed the lowest for both the farm and community aspect, with only one positive view in each. The In-Vessel composting (SV) System was ranked a 4 because although it was viewed highly in each, there were some negative outlooks. The Rotating drums method was ranked a 5 because there were little to no negative social impacts.

<table>
<thead>
<tr>
<th>Impact Assessment</th>
<th>Weighting Factor</th>
<th>Aerated (turned) Windrow Composting (1-5)</th>
<th>In-Vessel Composting (SV Composting) (1-5)</th>
<th>Rotating Drums (1-5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental</td>
<td>0.40</td>
<td>4</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Economic</td>
<td>0.45</td>
<td>5</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Social</td>
<td>0.15</td>
<td>2</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1.0</strong></td>
<td><strong>4.15</strong></td>
<td><strong>2.3</strong></td>
<td><strong>4.1</strong></td>
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</table>

Based on the results shown in Table 8, the final recommended option from this analysis the Aerated (turned) Windrow composting system, which received a score of 4.15. Although the
Rotating Drums method received an almost identical score of 4.10, the deciding factor was driven by the economic impact.

Future work could be completed by having a test run for the two methods that were ranked close in the final analysis, being the Aerated (turned) Windrow system and Rotating drums. This could be done by having a smaller scale of each being completed and compared at the site. Another method of testing could be to test one method at a time at the scale needed to fulfill the desired needs. Overall, this is a guide for the best method to reduce groundwater contamination for the farm.
## Project Contributions

**Table 9** Project inputs and contributions.

<table>
<thead>
<tr>
<th>Section</th>
<th>Work included</th>
<th>Contributor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction/Background</td>
<td>Research on information provided and issue considered</td>
<td></td>
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<tr>
<td>Project Scope and Specifications</td>
<td>Limits and needs from the farm explained</td>
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<tr>
<td>Assumptions</td>
<td>Items assumed as part of the project</td>
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<td>Methods</td>
<td>Three Alternate Methods</td>
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<td>Environmental Impact</td>
<td>System scope, inputs and outputs for all three methods</td>
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<td></td>
<td>Running EIO-LCA tests for all three methods</td>
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<td>Interpretation of results</td>
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<td>Economic Impact</td>
<td>LCCA Analyses</td>
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<tr>
<td>Social Impact</td>
<td>Scope of Farm and Community</td>
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<tr>
<td>Conclusion</td>
<td>Summary</td>
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<td>Environmental matrix ranking and explanation</td>
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References


How many hours is too many hours? (n.d.). Retrieved from Tractor By Net: https://www.tractorbynet.com/forums/owning-operating/181779-how-many-hours-too-many.html


Pepin County, WI. (2019). Retrieved from Google Maps: https://www.google.com/maps/place/Pepin+County,+WI/@44.5455055,-92.2633877,10z/data=!4m5!3m4!1s0x87f85ad18a20537d:0x78f189f610b6b0f5!8m2!3d44.6451183!4d-92.027319


Pepin County Dairy Manure Composting Project: Evaluation of the Environmental, Economic, and Social Impacts of Composting Alternatives

Final Term Paper

Client: Pepin County

Team Members: 

Course: Environmental Sustainability Engineering CEE 421

Instructor: Professor Andrea Hicks

Date: 10, December 2019
# TABLE OF CONTENTS

**Executive Summary** .................................................................................................................. 3

1. **Introduction** ............................................................................................................................ 5

2. **Background** ............................................................................................................................. 7

3. **Methods** ................................................................................................................................ 8
   3.1. **Scope of Project** ................................................................................................................. 8
   3.2. **Alternatives** ....................................................................................................................... 8
       3.2.1. **Existing Manure Pit** .................................................................................................. 8
       3.2.2. **In-Vessel Composting** .............................................................................................. 9
       3.2.3. **Aerated (Turned) Windrow Composting** ............................................................... 11
   3.3. **Life Cycle Assessment** ..................................................................................................... 13
       3.3.1. **Goal and Scope** ......................................................................................................... 13
       3.3.2. **Inventory Analysis** .................................................................................................. 14
       3.3.3. **Impact Assessment** .................................................................................................. 15
       3.3.4. **Interpretation** ........................................................................................................... 15
   3.4. **Sustainability Assessment** ............................................................................................... 15

4. **Results** .................................................................................................................................... 15
   4.1. **Environmental Assessment** .............................................................................................. 15
   4.2. **Economic Assessment** ..................................................................................................... 20
   4.3. **Social Assessment** .......................................................................................................... 22

5. **Discussion** ............................................................................................................................. 25

6. **Final Recommendation** ........................................................................................................... 26

7. **Conclusion** .............................................................................................................................. 26

**Project Team Structure** ............................................................................................................ 28

**References** ................................................................................................................................... 29
Executive Summary

Wisconsin is well known for dairy farms, in addition to dairy products, cows also produce manure waste. This manure can be applied to agricultural crops in order to increase growth and yield; however, storage, management, and application of raw manure can be difficult and likely leads to issues such as contaminate groundwater resources. Rural areas such as Pepin County are more likely to rely on private wells for their drinking water. Farmers in the small county of Pepin would like to know if implementing a composting process for small and large farms would be viable for business and the environment.

In order to access this, multiple alternatives were investigated to see if a more viable option than current manure pit use would be beneficial. Investigation of these alternatives included an assessment of the three paradigms of sustainability: environmental, economic, and social. Environmental assessment included calculations of greenhouse gas emissions, social cost of carbon, runoff amount, and manure soil infiltration. The economic assessment included a calculation of payback period, net present value, and benefit to cost ratio. And finally the social effects due to composting were analysed. From these three paradigms a decision matrix was created and therefore determined the final suggestion for 500 and 1,000 animal unit farms.

The alternatives investigated in this assessment included doing nothing and leaving the manure pit for future use, in-vessel unit composting technology, and aerated turned windrow composting. Manure pit was assumed to be lined and is used for storage of the manure until it is applied to the agriculture fields. In-vessel composting technology is typically a container such as a tank that controls the air flow and temperature in order to produce compost from manure. Aerated windrow composting is comprised of piling the manure into long rows of piles that are about fifteen feet wide and four feet high, the piles are turned approximately every two weeks.

The environmental assessment of the alternatives showed that the manure pit was the least viable option for GHG emissions, eutrophication potential, and soil stability. The in-vessel technology was an improvement, moreso in the eutrophication and soil assessment. And finally
the aerated windrow composting was the highest in GHG emissions and the same levels of eutrophication potential and soil stability as in-vessel.

The economic cost analysis indicated that the manure pit option wasn’t very expensive, as there is no cost to implement since the pit is already in use, and minimal operation and maintenance cost. In-vessel composting was quite expensive to invest into and actually resulted in a negative payback period, and therefore not very economically viable. The aerated windrow composting system was also a positive net present value, however less so than the manure pit. This is most likely because the capital and operation and maintenance cost was higher than the pre-established manure pit.

Finally the assessment for the social analysis proved that the manure pit option was the least viable since it is highly probable the manure pit leakage will eventually contaminate the groundwater. Therefore both composting methods were preferred, and for public health effects of in-vessel and aerated windrow were the same. However due to the structure of the in-vessel and aerated windrow process it is likely that the in-vessel technology will produce less of an unpleasant odor since the manure is contained in a container while it is made into compost.

The input of these effects for each alternative for each size farm was put into a decision matrix and since it was heavily weighted on the economic paradigm the final recommendation for both size farms was the aerated windrow composting technology.
1 - Introduction

Pepin County is a historic farming community located along the Mississippi River in the North West region of the state of Wisconsin, approximately 35 miles South West of the city of Eau Claire. The county is relatively small in shape and population, with about 250 square miles in size and a population of about 7,500 in total (Pepin, 2019). There are many dairy farms located here that produce an immense amount of dairy manure from the stock on the farm. A satellite image of the county from Google maps is shown in Figure 1 below.

![Figure 1. Aerial map of Pepin county outlined by red borders, located on the border between Minnesota and Wisconsin (Google Maps, 2019).](image)

The dairy farmers in Pepin County would like to use this waste in order to make a profitable fertilizer product that can be used and sold. A design for composting facility for every farm is desired for the farms in the county that are typically 500 or 1,000 animal units large (Hicks, 2019). A benefit cost analysis will be conducted including return on investment in addition to an analysis on groundwater impacts. Farmers in Pepin County would like to ensure
that composting their dairy waste is good for both their business and the environment (Hicks, 2019).

On the smaller 500 animal farm, a total of 3 million gallons of liquid manure and 1,700 tons of solid manure are produced by livestock each year. Liquid manure is incorporated within 72 hours of application (Hicks, 2019). The waste contains dry matter of 5.5%, and the remaining 94.5% is water content. A nutrient analysis of the liquid manure indicates Nitrogen-Phosphorus-Potassium (NPK) of 8.6-4.6-20.7, each number indicates the percentage of the nutrient by weight (Hicks, 2019). Therefore the liquid manure contains 8.6% weight from Nitrogen, 4.6% from Phosphorus, and 20.7% from Potassium. The nutrient analysis for the solid manure shows an NPK of 3-3-6, and contains 33% dry matter (Hicks, 2019).

The larger 1,000 animal farms produce double the amount of liquid and solid manure, therefore producing 6 million gallons of liquid manure and 3,400 tons of solid manure annually. In order to prevent contamination of groundwater, the farms must be a zero-discharge facility, thus all manure and process wastewater must be collected to meet federal and state WPDES permit standards (Hicks, 2019). 1,000 animal unit farms will emphasize facility design and water quality impact.

An average 500 animal size farm has 200 milk-producing cows, 20 dry cows, 170 heifers, and 45 calves for approximately 500 animal units. In addition to the cow livestock, the farm produces 1,000 acres of crops including 500 acres of corn for grain, 250 acres of corn silage, 200 acres of alfalfa, and 50 acres of new alfalfa seeding (Hicks, 2019). Dairy manure is applied to the corn grain and silage for a total of 750 of the 1,000 crop acres. However, the farmers believe that a manufactured compost could be applied to all 1,000 acres of the farm (Hicks, 2019).

The soil in Pepin County is known to be Finchford loamy sand, this means that the soil contains about 70-85% sand, and 10-15% clay particles, additionally containing 2.6% organic matter. The pH of the soil as approximately an average of 6.7, slightly more acidic than exactly neutral at a pH of 7 (Hicks, 2019). The slope of the soil ranges from 2 to 6%. The depth of the water table in this region is 40 feet, this is an important parameter when considering impacts on
groundwater. A 500-animal farm silage goal is 25 tons/ acres, in order to achieve this yield a NPK nutrient balance of 140-50-115. And the yield goal for grain is 190 bushel/acre for a recommended NPK of 140-40-0 (Hicks, 2019).

The farmers of Pepin County would like to focus on utilizing the manure to make a usable fertilizer without contaminating the environment. Possible designs of in-vessel and aerated windrow composting can help achieve this goal. The three paradigms of sustainability must be considered to choose the best option.

2 - Background

Composting is a controlled breakdown of organic waste, creating a biologically stable mixture that is typically added to soils (Cooperband, 2002). The advantages of composting include efficient storage, absence of poor odor, and ease of handling (Cooperband, 2002). This method of organic-waste disposal continues to grow as landfills implement more restrictions on their acceptance of organic-waste altogether. Due to these restrictions, farmers widely adopt composting as a method to dispose of their animal manure and create a viable soil resource from it (Cooperband, 2002).

Composted manure can be used as peat, topsoil, mulches, and fertilizer replacements (Cooperband, 2002). The wide range of options for composted material can be resold into variable markets, and offer an economical solution for farmers to generate profit from their waste material. Moreover, the organic material from composting improves soil quality by stabilizing soil structure in clay-like soils, enhancing water-retention in sandy soils, and increasing fertility of soils– reducing the need for fertilizer by up to 50% (Cooperband, 2002).

However, adding large amounts of organic material to the environment may cause harm, too. Decomposition naturally creates Phenols and Biochemical Oxygen Demand, but large-scale composting can potentially generate problematic concentrations in nearby surface waters (Richard, 1994). Additionally, surface runoff and percolation may produce dangerous concentrations of ammonia, nitrate, and phosphorous levels in nearby surface waters if composting is not carefully managed (Richard, 1994). The State of Wisconsin regulates
commercial composting in order to reduce these environmental impacts, therefore the technology chosen for this project must comply with state guidelines while meeting the specific needs of Pepin County.

3 - Methods

3.1 - Scope of Project

The goal of the Pepin Dairy Manure project is to determine if composting is beneficial for both the environment and the business. Sustainability refers to the following three paradigms: environment, society, and economy. Each branch brings a separate entity to the project that must be considered to provide the optimal solution for everyone involved. This will be done by evaluating three alternatives using environmental life cycle assessment, economic impact assessment, and social assessment for dairy farm composting in Pepin County. Evaluating the design using these assessments allow for an overall analysis if composting is better for both the environment and the farmer.

3.2 - Alternatives

The existing setup at the Pepin County farm is using the manure from the feedlots as fertilizer for their crops. This project evaluates the use of In-Vessel and Aerated Windrow Composting technologies using the three paradigms of sustainability: environmental, economic, and social. A decision matrix will be used to determine if composting on dairy farms is better for both the environment and the economy.

3.2.1 - Existing Manure Pit

The current 500 and 1000-animal unit farm at Pepin County has a 3.5 and 7 million gallon manure pit respectively. Figure 2 shows that mass flow analysis diagram of the current layout at the farm that will be analyzed for this project. The functional unit is the amount of manure produced from the feedlots for each of the types of farms.
**Figure 2.** Mass Flow Analysis for Existing Manure Pits with a functional unit of 7550 tons of manure waste and 15100 tons of manure waste for the 500 and 1000-animal unit farms, respectively.

### 3.2.2 - In-Vessel Composting

The first alternative that will be evaluated is in-vessel composting. In-vessel composting comprises of drums, silos, or concrete-lined trenches, shown in Figure 3, that can handle large amounts of waste—allowing for more environmental control. Organic material is poured into the vessels where moisture, temperature, and airflow are well managed (EPA, 2016). This organic material can be composed of many different types of waste.
In order to guarantee that the material is properly aerated, the mixture is mechanically turned throughout the process (EPA, 2016). In-vessel composting creates viable compost in as little as 3 months, and up to 2 years (Cooperband, 2002). This alternative is viable for dairy manure composting because it can use animal waste and can operate under both warm and cold climates that are found in Wisconsin. (EPA, 2016).

The setup at the farm if this alternative is chosen is not much different from the current layout. Figure 4 shows that mass flow analysis diagram of the current layout at the farm that will be analyzed for this project. The functional unit is the amount of manure produced from the feedlots for each of the types of farms.
Figure 4. Mass Flow Analysis for In-Vessel Composting with a functional unit of 7550 tons of manure waste and 15100 tons of manure waste for the 500 and 1000-animal unit farms, respectively.

3.2.3 - Aerated (Turned) Windrow Composting

The second alternative that will be evaluated is aerated windrow composting. Windrows are piles of organic waste that are typically put into piles with a width of 14-16 feet and a height of 4-8 feet, shown in Figure 5. The height range allows for optimal heat generation while still allowing oxygen to reach the middle of the pile. (EPA, 2016).
Figure 5. Aerated windrow composting technique used at farms. Source: (Greenville County, 2019)

Either manual or mechanical turning must occur to maintain optimal oxygen conditions throughout the pile. It is also able to generate large amounts of waste into compost, which makes it suitable for large quantity composting. Waste can be gathered throughout the entire community and used within the composting system. This alternative is beneficial in Wisconsin’s climate due to its ability to work in both cold and warm temperatures. (EPA, 2016).

The setup at the farm if this alternative is chosen is not much different from the current layout. Figure 6 shows that mass flow analysis diagram of the current layout at the farm that will be analyzed for this project. The functional unit is the amount of manure produced from the feedlots for each of the types of farms.
Figure 6. Mass Flow Analysis for Aerated Windrow Composting with a functional unit of 7550 tons of manure waste and 15100 tons of manure waste for the 500 and 1000-animal unit farms, respectively.

3.3 - Life Cycle Assessment

The environmental and economic life cycle assessment is a tool commonly used to evaluate the impacts of a product throughout the stages of its life. A Life Cycle Assessment includes the four following stages:

- Goal and scope
- Inventory analysis
- Impact assessment
- Interpretation

The LCA method will be used for each of the three alternatives for dairy manure composting in Pepin County.

3.3.1 - Goal and Scope

In the first stage of the LCA, the goal of the assessment, along with the boundaries and functional unit of the system, are defined so that a comparison among the options can occur. The
question that will be answered is which of the alternatives, if any, have the least environmental cost associated with them compared to the current, no composting, status of the farms. The system boundary is set as the individual farm in Pepin county and the functional unit as the waste produced in tons by the farm.

3.3.2 - Inventory Analysis

The second stage of LCA includes the inputs and outputs of the dairy manure composting system for each alternative. The cradle-to-grave life cycle was analyzed for this project. The first phase included the raw material acquisition of the raw manure, the second phase is the processing and manufacturing of the fertilizer, the third phase is the transport of the fertilizer to the fields, and the last phase is the use phase where the fertilizer is applied to the fields. The boundary set for the Pepin Country Farm is shown in Figure 7.

Figure 7. An overview of the four phases in the life cycle assessment for the Pepin County Farm.
These four phases of the life cycle assessment will be evaluated based on sustainability criteria using the Economic Input-Output Life Cycle Assessment (EIO-LCA) tool when applicable.

3.3.3 - Impact Assessment

The third stage of the LCA will determine the actual environmental impact of composting in each relevant sector. The values of the waste produced will be determined so that the overall environmental cost can be calculated.

3.3.4 - Interpretation

The fourth and final stage of the LCA evaluate the impacts found in the previous stage to determine if composting is better for the environment and the farmer in any of the three alternatives that were evaluated compared to not composting.

3.4 - Sustainability Assessment

The three alternatives were evaluated based on the three branches of sustainability: environment, economic, and social. The project evaluated each alternative based on their greenhouse gas emission, groundwater infiltration, and runoff for environmental impacts. The payback period and net present value were determined for each. Social impacts using public health due to groundwater contamination were also considered.

4 - Results

4.1 Environmental Assessment

The environmental impact assessment for Pepin County’s Dairy Manure project included looking at the following variables related to manure production: amount of runoff due to rain and unstable soil into nearby waterways, depth of manure soil infiltration, and greenhouse gas emissions. Evaluating these variables according to each composting type (manure lagoon, in-vessel composting, and aerated windrow composting) deemed most fit for Pepin County’s scenario, they were applied to Pepin County’s 500 unit and 1000 unit farms. The values were
then translated to calculating the social cost of carbon. Based on the values calculated, the proper technology recommendation in regard to its least environmental impact for Pepin County was selected.

Runoff and sediment loss during crop season, before compost application, was compared to runoff and sediment loss during crop season, after compost application. These values were then used to determine the environmental impact that creating compost through in-vessel composting, aerated-windrow composting, or keeping Pepin County’s current manure pit for the 500 unit farm and 1000 unit farm would have on nearby waterways. In order to properly calculate these values, the compost application rate was also applied to these values. Technologies that generated higher values were deemed to have worse runoff impact on local waterways.

Calculating soil infiltration from manure during the production phase of each technology included varying soil permeability in accordance to the soil type on the farms in Pepin County, and changing permeability as the depth of soil increases. Using these variables, Darcy’s Law was applied to determine the seepage rates of manure through the soil from each technology over the area differences between the 500 unit and 1000 unit farm (Law 2019). Using the calculated seepage rates of manure from each technology, along with the amount of manure going into the system, groundwater infiltration rates from leftover/unfiltered manure from the soil could be calculated. The technology with the lowest soil infiltration was regarded to have the least environmental impact on groundwater.

Greenhouse gas emissions were calculated taking into account the following factors: total amount of CO2e impact produced by the cows each year, and energy inputs into each technology system. Inputs that were considered for each technology included collection, production, and implementation of the manure/compost. Each technology had individual processes that needed to be considered in order to collect, produce and implement into each farm. For the collection and implementation impacts, an EIO-LCA tool from Carnegie Mellon was used to calculate their impacts. By calculating the total CO2e emissions per year for each technology, the least GHG emissions produced from the three technologies was described as having the least environmental impact on the atmosphere.
The solid manure application rate was 30 lbs of solid manure per acre (Brown, 2007). The liquid manure application rate was 11,000 gallons of liquid manure per acre (Brown, 2007). Before compost application, runoff rates were estimated to be 3.2 acre-inches for both in-vessel and aerated-windrow technology, equating to 2400 inches of runoff each year (Koelsch, 2017). After compost application, runoff rates were calculated and estimated to be 1.2 acre inches per year, equating to about 900 inches of runoff each year for both in-vessel, and aerated windrow composting (Koelsch, 2017). Soil erosion before compost applications were estimated to be 600 lbs/acre, resulting in a total of 450,000 lbs soil loss each year (Koelsch, 2017). After compost application, soil loss was estimated to be 200 lbs/acre, resulting in a total loss of 150,000 lbs of soil each year (Koelsch, 2017).

In-vessel composting and aerated windrow composting had an infiltration rate of 0 yd^3. The manure pit, assuming it is lined, had an infiltration rate of 1.1 mm/day. (Ham, 2002). The size of the manure pit for the 500 and 1000 unit farm is 3.5 and 7 million gallons, respectively. This relates to a larger surface area for infiltration to occur due to the assumption that the depth of the pit remains at typical manure depth of 4 yards (Hilborn, 2010). The smaller farm has a total infiltration of the manure pit of 7.6 cubic yards annually while the larger farm was estimated to be at 20.4 cubic yards annually.

The Economic Input-Output Life Cycle Assessment tool from Carnegie Mellon University was used to estimate the greenhouse gas emissions from corn production. Knowing the cost to produce the desired yields, this price was converted to 2007 money value in order to account for inflation in order to use the US 2007 Producer price model. Then using the agriculture industry and fresh corn sector, the 2007 value of the corn production was input into the tool and total CO2eq in tons for all sectors was recorded. These values were then converted to Mg and can be found in the Manure/Compost Application Phase Below portion of Table 1. This value was then scaled for the In-Vessel and Windrow composting for the 10% increase in yield.

Using the EIOLCA tool, transport costs for collection and distribution of the manure were estimated to be 156.0 t CO2e, which was added to our final greenhouse gas calculations
(Mellon, 2002). Because the manure pit is uncovered, the amount of CO2e was calculated using the amount of manure that it could hold for the 500 unit farm and 1000 unit farm, assuming that each cow produces 7.4 Mg CO2eq per year through mature cow excrement (Subler, 2014). The assumption that of the 500 cows, there was an equivalent of 350 mature cows that released the 7.4 Mg CO2eq. Factors regarding the collection, production, and implementation of the manure for the in-vessel composting included: stockpile emissions (0 CO2e), methane emissions (121.7 CO2e/year for the 500 unit farm, and 243.4 CO2e/year for the 1000 unit farm), N2O emissions per ton of Nitrogen (1.51t/year for 500 unit farm, and 3.02 for 1000 unit farm), which were then converted to CO2e—assuming 1 ton of Carbon in methane for every 100 tons, and 0.02 ton of Nitrogen in N2O for every 100 tons, assuming maximum emissions would be 2.5% initial C and 1.5% initial N with piles containing 75% organic matter on a dry weight basis with C:N ratio of 1:30 (Subler, 2014). For aerated windrow composting, the same factors as in-vessel composting were used, but an additional 121.7 Mg CO2e for the 500 unit farm, and 243.4 Mg CO2e for the 100 unit farm was added to the calculation in order to account for diesel emissions required for turning of the compost every two weeks (EPA, 2001). The life cycle are shown in Table 1. These values were estimated using the methods described above to determine the inputs and outputs of each phase.

**Table 1.** General Overview of the Inputs and Outputs of the Life Cycle Assessment for the three alternatives.

<table>
<thead>
<tr>
<th></th>
<th>500-Unit Farm</th>
<th>1000-Unit Farm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Raw Material for Processing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acquisition</td>
<td>7,550</td>
<td>15,100</td>
</tr>
<tr>
<td><strong>Processing/Manufacturing of Fertilizer</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Output</td>
<td>90.6</td>
<td>181.2</td>
</tr>
<tr>
<td><strong>Transport/Distribution of Fertilizer</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Output</td>
<td>166</td>
<td>332</td>
</tr>
</tbody>
</table>

The social cost of carbon is a monetary value that shows the impact that each technology would have on its citizens. This value, accounting for the cost of CO2e emitted by each
technology, will determine the viability of each technology in regard to the environmental impact that creating the compost will have on the surrounding population. The social cost of carbon was calculated using a metric of $50/ton of CO2e emissions shown in Table 2. (EDF, 2019)

**Table 2.** The Social Cost of Carbon for greenhouse gas emissions for the three alternatives using a $50/ton of CO2eq emissions.

<table>
<thead>
<tr>
<th>Social Cost of Carbon</th>
<th>500-Unit Farm</th>
<th>1000-Unit Farm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manure</td>
<td>$142,000</td>
<td>$284,900</td>
</tr>
<tr>
<td>In-Vessel</td>
<td>$109,000</td>
<td>$218,000</td>
</tr>
<tr>
<td>Windrow</td>
<td>$115,000</td>
<td>$230,000</td>
</tr>
</tbody>
</table>

The breakdown of greenhouse gas emissions are shown in Figures 8-9. The majority of the emissions occur during the processing/manufacturing phase and application phase of the life cycle. This is due to the biological activity during manure decay in the first phase and the emissions due to the corn in the last phase at the end of fertilizer use. The manure pit contributes the most in the processing/manufacturing phase.

**Figure 8.** Life Cycle Assessment of Greenhouse Gas Emissions for the three alternatives.
4.2 - Economic Assessment

An economic assessment will be conducted for each of the three alternatives to determine the economic feasibility of dairy manure composting in Pepin County. The payback period and net present value (NPV) were calculated based on the benefits and costs of running a farm with either manure or compost as fertilizer.

An economic analysis was determined for the second stage of the life cycle assessment, which is the Processing and Manufacturing phase of the fertilizer. The production of compost has both benefits and costs associated with it. Before the economic analysis could be done, the amount of compost produced and amount available to sell needed to be estimated. The following assumptions were made for these calculations:

- 5 tons of compost needed / acre for land application  
  ○ (Biernbaum, n.d.)
- Compost has weight of 1000 lbs / cu yd  
  ○ (Faucette, 2011)
- Composting reduces manure volume by 50%  
  ○ (Biernbaum, n.d.)
The land acreage and crop yields for the 500 and 1000 animal unit farms were assumed to be the same. It was estimated that the amount of compost applied to the field is 7500 cubic yards. Although the crop yield is the same, the amount of manure produced is doubled for the 1000 unit farm. The 500 animal unit farm produced 7500 cubic yards of compost, which was doubled for the 1000 units farm. Therefore, the smaller farm was estimated to have 60 cubic yards leftover to sell at a bulk price of $30 / cubic yard compared to the 7,620 cubic yards for the larger animal farm (Faucette, 2011).

The last area needed for evaluation was the Manure/Compost Application stage of the life cycle. During this phase, the production of the crops and compost or lack thereof were evaluated. The goal of the farm was to have a yield of 25 tons/acre and 190 bushels/acre (Hicks, 2019). The average cost of producing silage and grain were assumed to be $643.80/acre and $779.22/acre, respectively (Mitchell, 2015). The silage and grain can be sold at a product price of $36.75/ton and $5.25/bushel, respectively. (Macrotrends, 2019) The type of fertilizer used on the land affects the crop yield. Using the compost produced in both the in-vessel and windrow alternatives is expected to increase the yield by 10% compared to when manure is used as fertilizer (Blosser, 2019).

The two technologies that convert manure to compost are in-vessel composting and aerated windrow composting. The type of equipment used for fertilizer production and its size based on the functional unit has a determined capital cost and operational and maintenance (O&M) cost associated with it (Natalia, 2019).

The net present value (NPV) and payback period were determined for the 500-animal unit farm and the 1000-animal unit farm using the values estimated by the methods described above. The NPV was calculated using the following equation:

\[
NPV = -\text{Capital Cost} + \text{Annual Benefits} \times (P/A, 5\%, 5) - \text{Annual Costs} \times (P/A, 5\%, 5)
\]

\[(P/A, 5\%, 5) = 4.329\]
where Capital, Annual Benefits and Annual Costs are shown in Table 3, the assumed interest rate is 5% with a five-year lifespan. The economic analysis for the three alternatives are summarized in Table 3.

**Table 3.** Economic Analysis for the 500 and 1000 animal unit farms.

<table>
<thead>
<tr>
<th></th>
<th>500 animal unit farm</th>
<th>1000 animal unit farm</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Manure Pit</td>
<td>In-Vessel</td>
<td>Windrow</td>
</tr>
<tr>
<td>Capital Cost</td>
<td>$0</td>
<td>$1,000,000</td>
<td>$166,000</td>
</tr>
<tr>
<td>Annual Costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O&amp;M Costs</td>
<td>$5,650</td>
<td>$454,000</td>
<td>$181,000</td>
</tr>
<tr>
<td>Crop Costs</td>
<td>$517,000</td>
<td>$517,000</td>
<td>$517,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Benefits</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crops Sold</td>
<td>$590,000</td>
<td>$656,000</td>
<td>$656,000</td>
</tr>
<tr>
<td>Compost Sold</td>
<td>N/A</td>
<td>$1,800</td>
<td>$1,800</td>
</tr>
<tr>
<td>Net Present Value</td>
<td>$242,600</td>
<td>-$1,373,000</td>
<td>$51,316</td>
</tr>
<tr>
<td>PayBack Period</td>
<td>N/A</td>
<td>Never</td>
<td>3.3 yr</td>
</tr>
</tbody>
</table>

Based on the economic analysis of the three alternatives, the existing manure pit was the most economically beneficial for the 500-animal unit farm. This changed for the 1000-animal unit farm where the aerated windrow composting had the most benefit due to the larger amount of compost available to sell. The in-vessel composting was not economically viable for the farms.

**4.3 - Social Assessment**

A social analysis will occur to determine the impacts dairy manure composting has on the local community. Health and safety of the community is of utmost important when considering composting. Reducing the waste that is released into the rivers will benefit the community by protecting them from the hazardous material that may be contained within the discharge. Keeping the rivers and lakes clean encourage tourism for recreational activities within the area. Along with this, there may be a profit for the farmers with composting, which puts money into the local economy and promote economic growth. The local community, businesses, and employees will be affected by composting. Common complaints regarding farms is the odor from the manure and composting may help lower this for the community. Communication
between the community and the farmers is important for a composting project. Public meetings can be held to inform the public of any changes to the system and to gather input from the community members. Additionally, there are opportunities for schools to learn from the composting process and promote agriculture to students.

The presence of nitrates in private wells is a growing local concern in Wisconsin, a source of nitrates leaching into the groundwater is from animal waste, composting, and agriculture. Excessive exposure to this can lead to adverse health effects such as Blue Baby Syndrome. The EPA regulates this pollutant at 10 mg/L. The Figure 10 shows the average number of nitrate contaminated wells in Wisconsin. Nitrate can be removed using reverse osmosis or anion exchange.

Figure 10. Nitrate contaminated private wells (CEE 322 Environmental Engineering Processes Lecture Notes, 2019.)

Kewaunee County, located at the base of the Wisconsin peninsula, is a similar farming community to Pepin County. The people in the community have raised concerns about the water coming from their wells, afraid it contained human waste. However, tests were conducted on the water and soil from a nearby field; the results indicated that the soil and water contained the same fecal contaminants, and therefore the source was the application of manure not human
waste (Whites-Koditschek, 2019). In 2017, research found over 60% of wells indicated fecal contamination may result from animal waste and septic systems. Factors such as distance from well to agriculture field, well construction quality, and weather may affect contamination levels. The largest risk factor is well proximity to the animal waste storage (Whites-Koditschek, 2019). State regulations allow manure lagoons, such as the current manure pits used in Pepin County, to leak a maximum of 500 gallons per acre per day. Well contamination may result from pit leakage as well as run off from the manure applied to agriculture (Whites-Koditschek, 2019).

High nitrate levels in private wells indicate a need for a better management process for animal waste, therefore the alternatives indicated may be able to help the farmer’s financially, and reduce the impact on society. Other factors such as fractured bedrock which would allow for water to easily infiltrate the groundwater may be the reason for contamination (Whites-Koditschek, 2019). Governor Tony Evers has taken drinking water contamination from manure as a key political issue. The struggling Wisconsin dairy industry has decreased in small farm size in order to consolidate and increase production. Cows from these farms eat more and therefore produce more manure; and since they are in concentrated areas it leads to issues for the community (Whites-Koditschek, 2019). The resulting manure has the ability to become a public health hazard for 100,000 families and more. Nitrate in drinking water is concern for babies and pregnant women and can increase the risk of colon, stomach, and kidney cancers (Whites-Koditschek, 2019). Manure pits are a very traditional way to manage animal waste; however, the high levels of leakage and damage to water quality require change.

Research by US Department of Agriculture microbiologist Mark Borchardt found that septic systems were not linked to nitrate contamination and therefore the source of the contaminants is from agriculture. Also, contamination is linked to how close a well is to a manure pit or agriculture field and the depth to bedrock (Whites-Koditschek, 2019).

The effect of eutrophication is explained in the Environmental Assessment portion of this paper, however effects from this process could harm the recreational activities of the community.
Additionally this would harm tourism opportunities for the area which would cause the local economy to suffer.

The process of composting causes manure to undergo aerobic biological decomposition resulting into a stable, usable product. Composting processes identify the most suitable temperature and moisture levels in addition to carbon to nitrogen ratio, when these properties are controlled in aerobic conditions the unpleasant odors of manure are reduced (Gould, 2012). Composting could be a solution to reducing complaints of unpleasant smells from the farms.

Additionally, the composting done by the farmers in the community could be used to start a compost program at local schools. These opportunities could grow interest in students to further study agriculture in high school and beyond. Composting education programs can help kids understand the process, and bringing in composting bins for food waste, or using the processed compost in gardens can help children grow appreciation for the community and environment.

5 - Discussion

Pepin County farms have three alternatives to evaluate for their method of fertilizer. They can continue with the current practice of storing manure directly into the manure pit until it is applied to the fields as fertilizer. The other two alternatives converts the manure into compost before adding it as fertilizer to the fields. A decision matrix shown in Table 4 was created to evaluate the three alternatives using the three paradigms of sustainability: economic, environmental, and social. Each of the three sustainability criteria was given a total amount of points available to be given, with environmental having a total of 60 points, environmental with 25 points, and social with 15 points. These three were broken down further with categories that were previously analyzed with a weight that equaled the total available points for the criteria. The three alternatives were rated on a scale of 1-3 with 3 being the highest and 1 the lowest. The total amount of points available was 300 points. The total points of each alternative was calculated by multiplying the 1, 2, or 3 ranking with the available points for the category.
Table 4. Decision matrix created for the three different alternatives for the 500 unit animal farm and the 1000 unit animal farm.

<table>
<thead>
<tr>
<th></th>
<th>Points</th>
<th>Alternative 1: Existing Manure Pit</th>
<th>Alternative 2: In-Vessel Composting</th>
<th>Alternative 3: Aerated Windrow Composting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic</td>
<td>60</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>500 Animal Unit</td>
<td>1000 Animal Unit</td>
<td>500 Animal Unit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>2</td>
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</table>

6 - Final Recommendation

Using the decision matrix above, the final recommendation for Pepin County was determined to be the Aerated Windrow Composting alternative due to its economic, environmental, and social benefits.

7 - Conclusion

The reason that the environmental impact values for in-vessel and aerated windrow composting are the same is because the same compost content would be generated and applied from each technology, resulting in the same net effect. The only difference between the technologies is how the compost is generated. Therefore, both in-vessel and aerated windrow composting have the same environmental impact related to surface runoff, and are both a better option than keeping the manure pit.

Because the scope of the systems were based on their impact during their production phase, there were no soil infiltration rates from in-vessel and aerated-windrow composting, as the manure is isolated from the environment. The manure pit, which is lined, was still susceptible to groundwater infiltration. This means that the environmental impact during the production
phase of each technology was the same for the in-vessel and aerated windrow, and the worst environmental impact emanated from the manure pit.

In-vessel composting had the least greenhouse gas emissions compared to aerated windrow composting and Pepin County’s manure pit. This means that in-vessel composting would have the least environmental impact on the atmosphere, followed by aerated windrow, and the manure pit. The main difference between aerated in-vessel composting and windrow composting is that aerated windrow composting requires diesel combustion every two weeks in order to flip the pile. Although in-vessel composting has a lower impact on greenhouse gas emissions than aerated windrow composting, they both produce far less greenhouse gas emissions than the manure pit—making them both viable alternatives.

Taking into account the social carbon cost of each technology, the manure pit had the least social carbon cost, followed by aerated-windrow composting—leaving in-vessel composting technology with the least social carbon cost. This means that in-vessel composting, according to monetary impacts on the public, will be the best option for environmental sustainability. However, in-vessel and aerated windrow composting both have nearly 50% less social carbon costs than the manure pit, making them both great alternatives to mitigating the environmental cost on the public.

Overall, the impacts on society are improved when implementing a formal composting process. Composting reduces health risks associated with manure leaking, helps the local economy, reduces odor, and provides a learning opportunity for schools.

Recommendations for the future include:

- Evaluating the NPK value in-depth to determine if additional inputs are needed for composting
- Calculating percentage of NPK in runoff to determine more accurate eutrophication potential
- Evaluating material of technology for life cycle assessment
Project Team Structure

The Pepin County dairy farm composting project contains a wide range of aspects for evaluation. Each section was broken down and assigned to different team members shown in Table 5. The methodology included assigning roles according to where members believed they can contribute the most.

<table>
<thead>
<tr>
<th>General Sections</th>
<th>Task Description</th>
<th>Contributors</th>
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<tbody>
<tr>
<td>Introduction</td>
<td>Provide project information</td>
<td></td>
</tr>
<tr>
<td>Background / Literature Review</td>
<td>Explain background of composting using previously published literature</td>
<td></td>
</tr>
<tr>
<td>Scope of Project</td>
<td>Explain methods for analysis</td>
<td></td>
</tr>
<tr>
<td>Explanation of Pepin County</td>
<td>Provide information on alternatives</td>
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<td>Composting Alternatives</td>
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<td>NPV and payback period</td>
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<td>Environmental Analysis</td>
<td>GHG emissions, groundwater infiltration</td>
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<tr>
<td>Social Analysis</td>
<td>Public health, public awareness programs</td>
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</tr>
<tr>
<td>Conclusion</td>
<td>Final section</td>
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References


Google (n.d.). [Google Maps Pepin County]. Retrieved December 10, 2019 from https://www.google.com/maps/place/Pepin+County,+WI/@44.5455055,-92.2633877,10z/data=!3m1!4b1!4m5!3m4!1s0x87f85ad18a20537d:0x78f189f610b6b0f5!8m2!3d44.6451183!4d-92.027319


https://open.library.ubc.ca/cIRcle/collections/undergraduateresearch/52966/items/1.0103540.


Pepin County Dairy Manure Composting Solutions: Evaluation of Economic, Environment, and Social impacts of Manure Composting Alternatives
Executive Summary

1.0 Introduction
  1.1 Question to be Addressed

2.0 Background
  2.1 The Effect of Nitrate on Groundwater Quality
  2.2 Groundwater Quality in Pepin County, Wisconsin
  2.3 Existing Manure Management
  2.4 Proposed Manure Management Rotary Compostor

3.0 Methods
  3.1 Environmental Evaluation
  3.2 Economic Evaluation
  3.3 Social Impact Evaluation

4.0 Results
  4.1 Environmental Evaluation
  4.2 Economic Evaluation
  4.3 Social Evaluation

5.0 Conclusion

Works Cited
Abbreviations
GRP- Gross Regional Product
EPA- Environmental Protection Agency
RPA- Resource Protection Area
WQIA- Water Resource Impact Assessment
PV- Present Value
FV- Future Value
i- Interest Rate
n- Time scale of economic analysis
A- Annual Value
N- Nitrogen
P- Phosphorus
K- Potassium
Executive Summary

Pepin County is a rural county in western Wisconsin. Due to the large agricultural presence in the region, groundwater is showing signs of nitrate contamination. Pepin County would like to improve groundwater quality and increase economic growth in local farms by implementing composting as a way to manage manure.

Composting is an aerobic process of accelerating the breakdown of organic materials. Composting requires certain conditions such as oxygen, a sufficient carbon nitrogen ratio, and temperature. Composting can be done in a variety of ways, including an in vessel approach. This approach contains the waste while promoting optimal conditions for composting. The existing procedure of dairy farms in the area includes storing manure in a concrete lined pit until it is agitated and applied to fields by farming equipment. The proposed composting solution is introducing a rotary drum composting system called the Bedding Master. This composting drum will produce a compost products that can be used as fertilizer for crop fields or as cow bedding. The focus of the analysis is on the environmental and economic savings of this compost process and its products.

The environmental evaluation shows that the compost products will help to reduce environmental damages. The use of the compost product as bedding will reduce lumber product consumption of dairy farms, decreasing greenhouse gas emissions. Using the compost as fertilizer, which has a lower nitrogen concentration may help to decrease the pollution of groundwater and surface water eutrophication. The fertilizer will provide many benefits to the soil.

In regards to economic sustainability, the costs associated with purchasing and running the equipment, as well as the savings due to using the product as animal bedding were considered. For the 500 animal farm, savings due to generating bedding were estimated to be $50,000, resulting in a payback period of 5 years. Crop yield changes were not considered as part of this analysis.

From a social perspective, a composting system will provide many benefits for the community. Operations trainings will benefit farm labor, and lower odor will impact any members of the community that are often in proximity to a dairy farm. The composting system will increase community education and collaboration.

Overall, the Bedding Master composting solution will improve sustainability in regards to Pepin County’s environment, economy, and society. Particularly, the evaluation shows a significant economic advantage for dairy farmers. It is recommended that Pepin county implement this composting solution.
1.0 Introduction

Pepin County is located in western Wisconsin along the Mississippi river. It has a population of around 7,500 people across 250 square miles. The largest city and county seat is Durand, with a population of 2,000. Culturally, Pepin County is a rural area known as the birthplace of Laura Ingalls Wilder (Laura Ingalls Wilder Museum, n.d.). The soil of the region is Finchford loamy sand.

Agriculture is a key part of Pepin County’s economy. Pepin County has a concentration of agriculture more than 6 times larger than the national average, as shown by the location quotient. Agriculture accounts for the largest part of their gross regional product (GRP) at $25 million, as seen in Figure 1 (Pepin County, WI Economic Overview, 2018).

![Figure 1: The 2017 Gross Regional Product of Pepin County showing the top profiting industry as agriculture (Pepin County, WI Economic Overview, 2018).](image)

A standard 500 animal dairy farm, consisting of 200 lactating cows, 20 dry cows, 170 heifers, and 45 calves, will be used to analyse farm practice impacts. Each farm of this size
produces 3 million gallons of liquid manure and 1,700 tons of solid manure a year. They also manage 1000 acres of crops included 750 of which currently receive manure applications. A 1000 animal dairy farm will also be considered for scale. The current manure disposal practices consists of field application. Both liquid and solid manures are collected and spread on fields in the area without treatment.

1.1 Question to be Addressed

The county is concerned about the impacts of dairy farm waste and traditional manure spreading on the drinking water supply and would like to analyze if a composting process would be environmentally, economically, and socially beneficial to farms in the area. Farm goals require a minimum nutrient content for each farm that will need to be available after composting for desired yield. Other restrictions involve federal and state regulations, including zero discharge of manure or wastewater. This report will address the economic, environmental, and social impacts of using a compost procedure at a dairy farm in comparison with current practices.

2.0 Background

2.1 The Effect of Nitrate on Groundwater Quality

Groundwater quality is of great concern for rural farmland counties in Wisconsin, such as Pepin County. Nitrate contamination is often attributable to agricultural processes such as fertilization and manure handling. As a main source of ground contamination in rural counties of Wisconsin, nitrate provides evidence of how land usage affects the well water in farmland communities (Margaret McCasland, Nancy M. Trautmann, & Keith S. Porter, n.d.). The groundwater quality is assessed by measuring the nitrate concentration of a groundwater sample. Nitrate, an inorganic compound with the chemical formula NO\(_3^-\), is a measure of the relative nitrogen content in a groundwater sample. Water quality criteria, set by the Environmental Protection Agency (EPA), has a health standard concentration of 10 mg/L in safe drinking water (United States Environmental Protection Agency, n.d.).
Risks associated with contaminated water consumption at or above the health standards are much greater for infants than adults. A relative high water consumption-to-body weight ratio for an infant compared to an adult ultimately leads to a greater toxicity of the contaminated water (Margaret McCasland et al., n.d.). It can cause blue baby disease, or methemoglobinemia, which causes a lack of oxygen to travel through the bloodstream (U.S. National Library of Medicine, n.d.).

2.2 Groundwater Quality in Pepin County, Wisconsin

The WI Well Water Quality 2008 report from the University of Wisconsin concluded that 22% of wells in Pepin County measured above the Health Standards maximum nitrate concentration. Parts of Durand, the most populous city in the county and depicted by the star in Figure 2, have an average concentration of 14 mg/L. Durand also had a well located on a farm which measured 39.7 mg/L, the highest concentration reported in Pepin County. Overall, Pepin Country has an average groundwater nitrate concentration of 6.1 mg/L (University of Wisconsin, n.d.).
Figure 2: Nitrate concentration levels illustrated throughout Pepin County, WI. Data samples taken from 1985-2004 and made available by the State of Wisconsin (“Protecting Groundwater in Wisconsin through Comprehensive Planning—Pepin County,” n.d.).

2.3 Existing Manure Management

Pepin County farmers currently hold all liquid dairy manure in a storage facility. Manure is aggregated from several livestock barns and mixed with waste generated at the milking parlor. This facility, which has an estimated capacity of 7 million gallons, is an earthen structure with concrete liner that protects the surrounding environment from the liquid manure. The manure is agitated once during the spring and fall to alleviate any build up that occurs while in storage. The application process is done by pumping the manure through a hose connected to a tractor with tillage equipment. The tractor then draglines the composted manure across the crop field (Andrea Hicks, 2019).
2.4 Proposed Manure Management Rotary Compostor

Composting is the process of using microorganisms to decompose organic material. This process is dependant on the nutrient content, carbon to nitrogen ratio, oxygen availability, temperature, moisture, pH, and time in addition to the presence of microorganisms (Massachusetts Department of Agricultural Resources, n.d.). In order to accelerate the composting process, the use of in-vessel composting, specifically a rotating drum composter will be evaluated.

Rotary drums serve primarily as a mixing procedure to aerate the compost material. An air supply allows oxygen to be incorporated into the material during mixing to decompose materials (R.V. Misra, R.N. Roy, & H. Hiraoka, 2003). Material is loaded into one end of the drum and is removed from the opposite end after sufficient composting time. Pure animal manure has a lower carbon nitrogen ratio then is optimal for composting. Therefore, organic materials such as crop waste will need to be added into the material. This will also reduce the water content of the manure mixture to within the optimal range (Wicks & Keener, n.d.). The amount of organic material added to the compost should be determined by the farmers based on the specifications of their rotary drum. It is assumed that this input is of no cost to farms. Other important requirements for the manure before input into composting involves storing manure in sufficiently small piles to prevent densification and keeping the manure free from large amounts of sand. Maintenance will include monitoring temperature and moisture content to make changes to the compost input as needed. The process will result in a loss of N, but P and K quantities will not be reduced (Wicks & Keener, n.d.).

The specific model used in analysis is the Bedding Master by DariTech. A 6-20 size was selected for an input of 375-600 cows, while the 6-32 size was selected for the 1000 cow farm. The Bedding Master features a separator, feed auger, rotating barrel, and an exit shute. Insulation and coating prevents heat loss or water intrusion. The product of the Bedding Master can be animal bedding or fertilizer, and thus can be utilized by dairy farmers in several ways.

The electricity consumption of the Bedding Master is an estimation based on the number of cycles completed by the Bedding Master each year. The number of cycles is determined by
how often the cow bedding is changed and composted manure is applied to the cropland. The assumption made for this analysis is the Bedding Master will run continuously throughout the year, totaling 365 cycles per year. A DairyTech representative provided information on the motors powering each component of the Bedding Master 6-20, summarized in Table 1 below. The system energy usage is 322 kWh per cycle, which leads to a total annual energy usage of 117,530 kWh.

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<th>Energy Use/cycle</th>
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<tr>
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<td>E-series mix pump</td>
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<td>17 kWh</td>
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*Table 1*: Summary of complete Bedding Master system components and their motor/energy use statistics.

### 3.0 Methods

#### 3.1 Environmental Evaluation

An Environmental Life Cycle Assessment will be conducted on the dairy farm to evaluate current and future environmental impacts following the change to Pepin County’s practices of manure management. One method to conduct this assessment is through a software tool developed by the U.S. Department of Agriculture known as The Dairy Greenhouse Gas Model, or DairyGHG.
This software will take into account the major processes of feed allocation, animal intake and production, and manure production and handling, and simulates these factors over a 15 year span to determine daily and long-term annual emissions (“Dairy Greenhouse Gas Model,” n.d.). This software will be critical in determining the most efficient manure handling practices based on the future recommendations for manure management. A second tool that will be used to determine the dairy farm’s life cycle assessment is the Economic Input-Output Life Cycle Assessment, which can further determine the environmental emissions acquired from the farm (“EIO Life Cycle Assessment,” n.d.).

In addition to an Environmental Life Cycle Assessment, a Water Quality Impact Assessment (WQIA) will be implemented for the farm property and surrounding water sources on and near the property. This will be used to identify impacts of land disturbance, The following WQIA will be modeled off of a WQIA used in Gloucester County in Virginia (United States Environmental Protection Agency, n.d.), and will be implemented in a designated Resource Protection Area (RPA) on the farmland:

Figure 3: A sample WQIA that was used in Gloucester County, Virginia

3.2 Economic Evaluation

An economic evaluation of a composting procedure and current practices will be conducted. The economic metrics used for any recommended equipment will be provided by quotes from company representatives. Metrics assessed will include payback period, cost benefit ratio, and present value, with the use of environmental economics.
Payback period will provide the amount of time it will take for revenue to recover the initial investment cost using equation 1. This will help Pepin county determine how long it will be before they see net profit from a possible solution.

\[
Payback \ Period = \frac{Initial \ Cost}{Annual \ Benefit}
\]  

(Equation 1)

Benefit-cost ratio is another method to evaluate the monetary benefit of a project. Using equation 2, a ratio can be found. A ratio of larger than 1 means the project is profitable.

\[
B/C = \frac{\sum \text{Benefits in Present Value}}{\sum \text{Costs in Present Value}}
\]  

(Equation 2)

Present Value will be used to assess the net present value of a method for farms with equation 3 for fixed cost and equation 4 for annual costs. It will represent the value for the community now given all of the future costs and benefits, accounting for how interest rates affect the value of money over time.

\[
PV = \frac{FV}{(1+i)^n}
\]  

(Equation 3)

\[
PV = \frac{A}{(1+i)^{-n}}
\]  

(Equation 4)

3.3 Social Impact Evaluation

In order to assess the social impacts of introducing manure control methods to Pepin County farms, a subjective opinion about the potential social benefits will be discussed. Impacts will be evaluated for the community of Pepin County. Topics that will be analyzed include community involvement, education, and impacts. How the community responds to the project, their drinking water quality, and sustainability will be hypothesised. Social attitude studies from similar regions may be used as evidence. Interfarm collaboration and demonstration farm potential will be discussed as a potential benefit for farms that implement a composting solution. Additionally, job market changes and public health changes in Pepin County will be evaluated. Assumptions will be made in this qualitative analysis about how the community will respond to new manure composting practices.
4.0 Results

4.1 Environmental Evaluation

When evaluating environmental impacts of the Bedding Master over Pepin County’s current manure management systems, it is critical to examine the Bedding Master’s core functionality. DariTech’s BeddingMaster’s slogan, “Quit paying for bedding, own it!”, explains that dairy farms will no longer require the need to purchase timber products to be used for sawdust and shavings, which are common forms of bedding for cows. By removing the need to purchase these timber products, less timber consumption could take place in Pepin County and reduce the emissions that would result from the life cycle of the required timber.

This was further determined after running an Economic Input-Output Life Cycle Assessment, specifically determining greenhouse gas concentrations. This was conducted through the use of Carnegie-Mellon’s Economic Input-Output Life Cycle Assessment with the following assumptions: the model was based off of a US 2002 Benchmark within the industry sector of milk production. Economic activity was set to $25 million, as this was representative of Pepin County’s gross regional product (GRP) described in Figure 1. Under typical production a total of 107,000 t CO2 e, which includes 60,400 CH4 t CO2 e and 21,600 N2O t CO2 e would be produced (Carnegie Mellon University Green Design Institute, 2019). By reducing the amount of timber input this would have an effect on the sub category of cattle ranching that makes up 4490 t CO2 e of the total ghg emissions seen in Figure 4.
Additionally, this process of composting results in a loss of nitrogen, as it is released as ammonia gas in production. This ultimately lowers the risk of eutrophication and the potential of nitrates leaching into the soil (Wicks & Keener, n.d.). It is important to note though that this can decrease plant nutrient value. Composting also provides nutrients and organic matter that can improve soil tilth, water holding capacity, cation exchange capacity, and act as mulch for erosion control (Wicks & Keener, n.d.).

Given the data and specifications on Pepin County’s dairy practices that was made available for this analysis, it has been determined that there is not sufficient enough data to properly conduct a Water Quality Impact Assessment (WQIA). Some of these uncertainties in data include access to a scaled drawing of the RPA, location and nature of any encroachments, and a detailed inventory of all flora present.

The Dairy Greenhouse Gas Model was also found to not provide sufficient data, as the program did not offer metrics to compare emissions reductions when timber products were not used as well as emission changes when using an in-vessel composter.
4.2 Economic Evaluation

An economic evaluation was conducted to compare the viability of the proposed composting system and the existing systems in Pepin County. Costs associated with the upgraded rotary drum system include the initial purchase of the Bedding Master equipment and the cost for electricity to power the system. Profits from increased crop production and alleviation of environmental burden were not considered because the proposed system will not have an effect on current metrics associated with these benefits. Cost savings from the improved system come from avoided costs of the current cow bedding material used in the barns, which can be a significant cost to dairy farmers. American dairy farmers responded to a 2013 survey reporting cow bedding material costs to be $100 per cow a year (M.M. Smith, C.L. Simms, & J.D. Aber, 2017).

Costs and energy usage information for the 6-20 model of the Bedding Master were provided by the DairyTech representative; for this reason, only this model will be investigated. The initial cost of the DairyTech Bedding Master 6-20 is $182,600, which includes the complete system and installation. The cost associated with the electricity consumption is determined using Alliant Energy’s residential rate for Wisconsin. At $0.11663/kWh, the annual electric bill based on the energy demand of the system is $13,668.74 (Alliant Energy, n.d.). Annual savings from the avoided purchase of cow bedding material are estimated at $50,000. The cash flow of the proposed manure composting system is displayed in Figure 5. The annual value of $36,331.26 is calculated by subtracting the annual costs, the electric bill, with the annual benefits, avoided purchase of cow bedding.
Figure 5: Cash flow diagram for proposed composting system.

Further analysis was conducted to evaluate the project based on payback period, present value, and the benefit-cost ratio as discussed in section 3.2 of this report. The payback period was calculated to be 5.03 years; any year after year 5 will result in a profit for the farmer. Over a 10 year period with an interest rate of 4%, the present value of the cash flow is $175,771.55. The benefit-cost ratio was calculated to further assess the feasibility of the project. The ratio was equal to 3.66, which means the annual benefits greatly outweigh the annual costs. Based on these results, it is determined that the upgraded composting system is an economically viable purchase that Pepin County farmers should consider.

4.3 Social Evaluation

Social benefits to composting include positive changes to labor and work environments in Pepin County. The introduction of rotating drums will require operator training and an operator, increasing local skilled labor and providing agriculture jobs with less variable working conditions. Furthermore, farm odors will decrease, benefiting workers and neighbors.
Potential social benefits may include stakeholder collaboration. This composting system encourages farmers to use inputs from other industries in their feedstock including commercial and municipal wastes. This will foster local collaboration to help make the composting process efficient and profitable for all parties. Composting farms often compost for their neighbors, increasing the sense of community on a small scale. Case studies from Cornell saw that cooperating with neighbors in processing composted insured community support (Eileen E. Fabian & Tom L. Richard, n.d.). Furthermore, the county government's initiative in requesting this report shows an opportunity for farms and government to collaborate on a composting system, improving that relationship.

Additionally, a composting initiative by local farms, with the goal of improving sustainability, may begin changing cultural attitudes in Pepin County. These composting facilities provide an educational opportunity for schools, particularly high school students interested in agriculture, to teach about responsible farming practices and broader environmental issues associated with sustainability. Historically, managing natural resources and the environment has been a key component of agricultural education in the midwest (Foster, 1995). These farms could also serve as demonstration sites for other county farms or as a site for academic studies about agricultural composting or sustainability practices. Sustainability initiatives can resonate with the community and encourage other businesses or community members to make better environmental choices.

5.0 Conclusion

In sum, a Bedding Master composting system will offer many social, environmental, and economic benefits to the dairy farms of Pepin County. The introduction of rotating drums will require a trained operator, increasing local skilled labor and providing agriculture jobs with less variable working conditions. Farm odors will be decreased, benefitting workers and neighbors. In addition, these composting facilities provide an educational opportunity for schools, particularly high school students interested in agriculture, to teach about responsible farming practices and broader environmental issues associated with sustainability. Since this system encourages
farmers to use inputs from other industries in their feedstock, it may facilitate community collaboration.

The Bedding Master offers many environmental benefits, as composting results in a loss of nitrogen, as it is released as ammonia gas in production. This ultimately lowers the risk of eutrophication and the potential of nitrates leaching into the soil. It also allows removes the need to purchase products to be used for sawdust and shavings, which are common forms of bedding for cows. By removing the need to purchase these timber products, less timber consumption could take place in Pepin County and result in reduced emissions. This process can also improve soil tilth, water holding capacity, cation exchange capacity, and act as mulch for erosion control.

It also proves to be an economically viable purchase. With a net annual benefit of just over $36,000, the investment will pay itself back in 5 years. The benefit-cost ratio is also greater than 1, indicating that the project will turn an annual profit.

These benefits offer a rewarding solution to the county’s concern about the impacts of dairy farm waste and traditional manure practices affecting their water resources. If put into practice, this system would help continue sustainable growth and longevity to the land and people of Pepin County.
Works Cited


Massachusetts Department of Agricultural Resources. (n.d.). *Guide to Agricultural Composting*.


# TABLE OF CONTENTS

List of Figures ..................................................................................................................3

List of Abbreviations .........................................................................................................4

Executive Summary ...........................................................................................................5

1. Introduction ...................................................................................................................6
   1.1 About Pepin County ...............................................................................................6
   1.2 Defining the Problem ............................................................................................7
   1.3 Data Provided by Client .......................................................................................8

2. Background and Literature Review ..........................................................................9
   2.1. WPDES Permit Standards ..................................................................................9
   2.2. NPK ....................................................................................................................9

3. Background on Farming in Pepin County ................................................................10
   3.1 Composting ........................................................................................................10
   3.2. Manure Piling ..................................................................................................11

4. Proposed Solution for Pepin County .......................................................................12
   4.1 Windrows Manure Piling ...................................................................................12
   4.2 Turning ................................................................................................................13
   4.3 Addition of Carbon .............................................................................................14
   4.4 Water Content .....................................................................................................15

5. Environmental Considerations and Analysis ..........................................................15
   5.1 Greenhouse Gas Emissions ...............................................................................16
      5.1.1 Current Conditions .....................................................................................16
      5.1.2 Proposed Conditions ..................................................................................17
   5.2 Water Quality .....................................................................................................18
      5.2.1 Current Conditions .....................................................................................18
      5.2.2 Proposed Conditions ..................................................................................19
5.3 Environmental Conclusions

6. Economic Considerations and Analysis

6.1 Economic Analysis

6.2 Annualized Value

6.3 Economic Conclusion

7. Social Considerations and Analysis

7.1 Social Analysis

7.1.1 Legal Implications

7.1.2 Economic Implications

7.1.3 Environmental Implications on Health

7.1.4 Smell Implications

7.2 Social Conclusion

8. Conclusion and Recommendations

Project Contribution of Team Members

References

Appendices

Appendix A

Appendix B

Appendix C

List of Figures

1. Figure 1: Map of Pepin County

2. Figure 2: Location of Pepin County within Wisconsin

3. Figure 3: Manure Lagoon on Dairy Farm

4. Figure 4: Inputs and Outputs of Composting Process

5. Figure 5: Composting Process Byproducts

6. Figure 6: Plan View of Proposed Windrows Design
List of Abbreviations

CAFOs - Concentrated Animal Feeding Operations
C/N - Carbon to Nitrogen ratio
CO₂ - Carbon Dioxide
DNR - Department of Natural Resources
EIO-LCA - Economic Input-Output Life Cycle Analysis
EPA - Environmental Protection Agency
Eq - Equivalents
Ft - Feet
GHG - Greenhouse Gas
H₂S - Hydrogen Sulfide
K - Potassium
Kg - Kilogram
NH₃ - Ammonia
NPK - Nitrogen, Phosphorus, and Potassium
P - Phosphorus
Executive Summary

Pepin County is in the western part of Wisconsin and is the smallest county in Wisconsin with an area of 249 square miles and largely consists of farmland. Currently farmers are depositing their manure derived from their farms in lagoons and using it as fertilizer on their crops. The county is therefore, inquiring what the environmental and economic impacts of selling excess manure is. The county is requesting feasibility analysis of both 500- and 1000-unit dairy farms, both a 1000- and 2000-acre assessment for the 1000-unit farm, with the requirement of meeting federal and state WPDES permit standards. Composting is the aerobic degradation of organic waste into organic raw materials, minerals and water, which accumulates in the compost pile. The degradation occurs due to microorganisms that break down the waste with water and oxygen. The current composting method of piling the waste materials, generate large areas of anaerobic degradation, which slows down the process and produces unwanted byproducts. As an alternative to the current method of composting done by farmers, windrow composting would increase the productivity of the composting by creating a better environment for the compost process to take place. Furthermore, to optimize the degradation process it is necessary to add additional carbon to the windrows in the form of plant material, as well as adding water to make sure moisture levels are kept at an optimum. Composting the manure and plant materials also create liquid waste that is harmful to water sources it might come in contact with. It is therefore important that waste runoff is lead to a containment pond where it can be held until it can be properly treated. Furthermore, the impact of the generated carbon dioxide from the windrows have to be accounted for, with consideration for the emissions of greenhouse gasses from the current composting process. When assessing the economic impact of the possible change in composting, it is vital to assess it from a cost benefit point of view, to ensure the economic feasibility of the new composting processes, as there will be initial costs connected with the transition. These costs will be offset by the income generated with the composted materials generating fertilizer that will be sold to consumers. When transitioning from one composting process to another and increasing the composting, it is bound to generate social implications. These implications will be addressed within the local community as well as the rest of the world.
As the composting process might generate various harmful substances, Ammonia, Volatile Organic Compounds, and Hydrogen Sulfide amongst others, it is important to assess how these compounds might impact the community, along with the possible increased standard of living.

1.0 Introduction

1.1 About Pepin County

Pepin County, located on the far west edge of Wisconsin, is home to nearly 7,500 people. The county is the smallest county in Wisconsin, consisting of a total area of 249 square miles, where 17 square miles are water (“Pepin County, Wisconsin,” 2019). An aerial map of the county is depicted in Figure 1 and was retrieved from Google Maps. Pepin County’s location within Wisconsin is shown in Figure 2.

![Figure 1: Satellite Map showing Pepin County outlined in red. Pepin County is surrounded by the Mississippi and Chippewa Rivers (“Google Maps,” n.d.).](image1)

![Figure 2: Location of Pepin County within Wisconsin (“Pepin County, Wisconsin,” 2019).](image2)
1.2 Defining the Problem

There are many farms in the county, with many of the farmers currently practicing some type of composting. The average farm consists of a 500-animal unit or a 1000-animal unit. Currently, dairy manure is typically being situated in lagoons on farms. These lagoons are pits that are filled with manure with sawdust particles on top of it. An image showing what a typical manure lagoon looks like is depicted in Figure 3. The current methods for manure use are effective, but the farms are inquiring about methods that are more economical and environmentally friendly. The farms want to consider composting their manure and selling excess as a fabricated fertilizer.

![Figure 3: Typical Manure Lagoon on a dairy farm](image)

It is assumed that there are existing manure pits on each farm and that they can hold 7,000,000 gallons of liquid manure.

Ideally, the county would like to determine if composting is better for business and the environment. To assess this, the country would like a rough design for a composting facility for each farm with a cost-benefit analysis and an analysis on groundwater impacts. The county also would like a compost feasibility analysis for both farms. For the 1000 animal unit, the county would like an analysis done for 1000 acres and 2000 acres, with an emphasis on considering the 1000-acre farm for facility design and impact to water quality. In order to meet federal and state WPDES permit standards, the farm must be a zero-discharge facility. To do so, one must look at the average data provided by the client, consider the impacts of composting within the environmental, economic, and social realms, and evaluate the tradeoffs with for the alternative.
1.3 Data Provided by Client

For a 500-animal unit dairy farm, the average farm typically consists of 200 lactating cows, 20 dry cows, 170 heifers, and 45 calves. Typically, the land is around 1000 acres, where there are around 200 acres of alfalfa, 50 acres of new alfalfa seeding, 250 acres of corn silage, and 500 acres of corn for grain. Manure is applied to the land used for corn silage and grain, accounting for around 750 acres. All 1000 acres; however, could be composted.

The farm produces a large quantity of manure, generating 3 million gallons of liquid manure each year and 1,700 tons of solid manure each year. Liquid manure is incorporated within 72 hours of application. Nutrient analysis for liquid manure shows nitrogen, phosphorus, and potassium, or also known as NPK values of 8.6-4.6-20.7 and dry matter to be 5.5%, whereas for dry manure, nutrient analysis shows an NPK of 3-3-6 and dry matter to be 33%. The Finchford loamy sand is the soil type. It has a 2-6% slope, around 2.6% organic matter, a pH of 6.7, a P level equal to 50, a K level equal to 120, and a water table at a depth of 40 ft. Ideally, the farm would yield 25 tons/acre of silage with an NPK of 140-50-115 and yield 190 bushel/acre of grain with an NPK of 140-40-0.

The 1000-animal dairy farm is quite similar. It typically consists of 1000 cows. It includes around 400 lactating cows, 40 dry cows, 340 heifers, and 90 calves. For this project, the client would like to consider two land sizes for the 1000 animal dairy farm. The first option would include 1000 acres, where there are 200 acres of alfalfa, 50 acres of new alfalfa seeding, 250 acres of corn silage, and 500 acres of corn for grain. Around 750 acres of this land, land used for corn silage and grain, has manure applied and all 1000 acres could be composted. This option is to be given priority over the second option. The second option would include around 2000 acres, where there would be around 400 acres of alfalfa, 100 acres of new alfalfa seeding, 500 acres of corn silage, and 1000 acres of corn for grain. Around 1500 acres of this land, land used for corn silage and grain, has manure applied and all 2000 acres could be composted.

The farm produces an excessive amount of manure, double that of the 500-animal unit farm. It generates 6 million gallons of liquid manure each year and 3,400 tons of solid manure each year. The manure characteristics and uses are the same as the 500-animal unit farm. The soil is also Finchford loamy sand with the same characteristics as the 500-animal unit farm. Ideally, this farm would have the same yield and NPK goals.
2. Background and Literature Review

2.1 WPDES Permit Standards

Agricultural businesses have the potential to discharge pollutants into waterways, as they typically produce large amounts of manure and wastewater streams. Every farm in Wisconsin must meet certain standards to prevent pollution into lakes, rivers, groundwater, etc. ("Agribusiness, CAFOs and other farms—Wisconsin DNR," n.d.). The state of Wisconsin regulates the storage of waste and manure application at large farms as Concentrated Animal Feeding Operations, or abbreviated as CAFOs, to comply with the EPA’s Clean Water Act, which monitors pollutant discharge through the WPDES program ("Agribusiness, CAFOs and other farms—Wisconsin DNR," n.d.). Farms in Pepin County produce, store, and spread manure, which must comply to WPDES standards. The farms must be zero discharge facilities in order to meet federal and state WPDES standards.

The discharge of pollutants into waterways is monitored and regulated by the DNR through the WPDES. There are special reports, compliance schedules, and monitoring requirements within wastewater permits issued for a five-year period ("Wisconsin Pollutant Discharge Elimination System (WPDES) permits—Wisconsin DNR," n.d.). To prevent contamination within waterways, manure and wastewater has to be collected. WPDES permits are issued by the DNR for wastewater discharges. The farms in Pepin county currently follow these standards. The general WPDES permits are designed to cover several farms under one permit when they perform similar operations and produce the same kind of wastewater. Being that these farms conduct the same kind of operations and produce similar wastewater streams, they usually employ similar wastewater treatment operations and have similar effluent limitations and monitoring requirements from WPDES ("Wisconsin Pollutant Discharge Elimination System (WPDES) permits—Wisconsin DNR," n.d.). To meet these standards on farms in Pepin County and to prevent pollution of surface and groundwater, all manure and process wastewater has to be gathered and regulated.

2.2 NPK

Plants need nutrients to grow and be healthy. NPK is often used for farming and fertilizer applications. It stands for "Nitrogen, Phosphorus, and Potassium.” Nitrogen typically is responsible for the growth of leaves on a plant, Phosphorus is responsible mainly for the growth of roots, flowers, and fruit, whereas potassium is mainly responsible for the overall functions of a
The right fertilizer is typically selected based on the NPK values given on the labels of a product. These three nutrients are represented by a series of three numbers, which represent the value of the three macronutrients used by plants. The higher the representing value, the higher the concentration of the nutrient in the material, whether that is fertilizer, soil, or another material (“NPK Values: What Do The Numbers On Fertilizer Mean,” n.d.). The NPK is often used when applying fertilizer to the soil (“Labeling of fertilizer,” 2019). To calculate how much fertilizer needs to be applied to the soil to equal one pound of the desired nutrient, 100 can be divided from the given value for that nutrient (“NPK Values: What Do The Numbers On Fertilizer Mean,” n.d.). For example, 10-10-10 means 10 pounds of fertilizer is needed to add 1 pound of the nutrient to the soil (“NPK Values: What Do The Numbers On Fertilizer Mean,” n.d.).

3. Background on Composting in Pepin County

Many of the farms located in Pepin County contain both cropland as well as space for dairy cows. While these are both very economically important resources, these farmers are not necessarily doing everything possible to maximize profit, minimize environmental impact, and focusing on social concerns. As stated by the client, a small farm in Pepin County would contain an approximately 500 animal unit dairy farm as well as managing 1000 acres of cropland which includes alfalfa, corn silage, and corn grain. Similarly, a large farm contains an approximately 1000 animal unit dairy farm and manages 2000 acres of cropland. One of the main issues these farmers deal with is waste from both the dairy cows and croplands. To manage this waste the farmers simply pile up the manure from the cows and take the excess crop waste and put it in the same pile.

3.1 Composting

This method of piling up waste forms a rather primitive method of composting. Composting is basically recovering materials to be used as fertilizer through the decomposition of organic matter. Composting is a biological process conducted under aerobic conditions with oxygen (“What is Composting; Composting is nature’s way of recycling organic waste,” n.d.). Raw materials, such as organic materials, minerals, and water are accumulated in a compost pile. Microorganisms, such as bacteria and fungi, break down the matter with the help of oxygen and water. The inputs are then converted into heat, carbon dioxide, and ammonium (“Compost,” 2019). The process required carbon for energy, nitrogen to grow and reproduce more
microorganisms to oxidize the carbon, oxygen to oxidize the carbon within the decomposition process, and water to maintain activity ("Compost," 2019). The inputs and outputs for the composting process are depicted in Figure 4. Creating this fertilizer from compost can repurpose the waste into something that will provide nutrients for the farmers cropland in the future. This fertilizer can also be sold to other local farmers for economic gain.

![Figure 4: The Inputs and Outputs of the Composting Process.](image)

**Figure 4:** The Inputs and Outputs of the Composting Process. Organic matter, minerals, water, oxygen, and microorganisms are needed for the decomposition process. Water, heat, and carbon dioxide are produced along with the finished compost product, which consists of organic matter, minerals, water, and microbes. Rich in nutrients, the finished compost can be applied to fields as a fertilizer supplement ("Compost," 2019).

### 3.2 Manure Piling

While many of the farmers in Pepin county currently practice some form of composting, as previously mentioned, this is a relatively primitive method of doing so. By throwing manure and hay in large piles like a landfill these farmers are producing compost, however, this process can be significantly improved with careful planning. Figure 5 depicts the composting process using manure. With the current method of stacking all the manure in one big pile, it is true that there is enough heat generated to start the composting process, however, the problem arises with the fact that the bacteria responsible for composting are aerobic and require oxygen (more than 5% by volume) to function ("Composting Animal Manures: A guide to the process and management of animal manure compost—Publications," n.d.). With a pile this big, the center
portions are almost entirely anaerobic and thus do not support composting of any kind. Simply breaking up their piles into smaller ones may sound like a good plan, however, it needs to be carefully thought out because these aerobic bacteria need temperatures between 113-160 degrees Fahrenheit to begin thermophilic decomposition which is responsible for the composting process (“Composting Animal Manures: A guide to the process and management of animal manure compost—Publications,” n.d.).

Figure 5: The composting process from the input of raw manure. This process produces gasses such as Ammonia, CO₂, Methane, and Nitrous Oxide along with a finished compost material (Kuo, Ortiz-Escobar, Huế, Hummel, & Pandalai, 2004).

4. Proposed Solution for Pepin County

In order to improve the efficiency and effectiveness of current composting process employed by farmers in Pepin County, it is first important to understand how composting works. With the background information stated above, it is possible to design a new composting system that will produce this natural fertilizer at a much faster pace. This will also provide farmers with economic, environmental, and social benefits which will be explained in further detail later in this report.

4.1 Windrows Manure Piling

In order to solve the problem of anaerobic conditions within the composting piles it is recommended to move to smaller sized piles that are more spaced out. The method that was chosen to best accomplish this goal is what is known as windrows manure piling. These windrows are piles of manure which are specifically designed to create the perfect conditions for
composting. Specifically, these are manure piles that are 10-12 feet wide with a height between 4-6 feet (“Composting Animal Manures: A guide to the process and management of animal manure compost—Publications,” n.d.). These windrows are large enough to generate the heat required for the composting bacteria, while also not too big as to not let oxygen into the center of the pile. Windrows of this design can be placed in long lines, depicted in Figure 6 and Figure 7, which can maximize the efficiency of the space used for composting purposes.

![Plan View](#)

**Figure 6: Plan View of Proposed Windrow Design**

![Profile View](#)

**Figure 7: Profile View of Proposed Windrow Design**

### 4.2 Turning

Another important aspect of composting with windrows is that these piles need to be turned over on a relatively consistent basis. There are a couple of different reasons for this, the first of which is to provide oxygen to areas of the pile that may not be receiving enough. Keeping the piles well-mixed ensures equal distribution of oxygen and therefore equal composting rates throughout. Another benefit of mixing is that it homogenizes that pile and breaks up any clumps present within the compost. This again allows for an equal rate of composting for the entire manure pile. Finally, perhaps the most important benefit of turning is the fact that this allows the bacteria responsible for composting to have more contact with the manure (“Composting Animal Manures: A guide to the process and management of animal manure compost—Publications,”)
n.d.). Keeping these microbes evenly dispersed throughout the manure pile speeds up the composting process and provides the most efficient method for creating compost.

In order to provide this constant rotation of the windrows, a machine known as a turner will be required. Turners can be mounted to the front of a tractor and provide a mixing motion that provides all the functions for the compost pile as previously mentioned. Turners can range in size anywhere from 6 feet to 20 feet wide, however, for this project a recommendation is a turner of around 10 feet in width (“Composting Animal Manures: A guide to the process and management of animal manure compost—Publications,” n.d.). Turners of this size can mix up to 1,500 yards of compost per hour and move at a rate of about 20 feet per minute to ensure proper turning of the pile (“Composting Animal Manures: A guide to the process and management of animal manure compost—Publications,” n.d.). An image of a tractor pushed turner can be seen in Figure 8.

**Figure 8:** Tractor Mounted Turner (“TG 301 (GB),” n.d.)

### 4.3 Addition of Carbon

Management of carbon content is another aspect of windrows composting that is essential. It is known that the approximate carbon/nitrogen (C/N) ratio should be between 20-1 (20 parts carbon to 1 part nitrogen) and 40-1, however, maintaining these ratios is a difficult process (“Composting Animal Manures: A guide to the process and management of animal manure compost—Publications,” n.d.). The microbes responsible for composting have a C/N ratio between 5-1 and 10-1, however this needs to be increased due to the fact that approximately 50% of their metabolized carbon is released as carbon dioxide (“Composting Animal Manures:
A guide to the process and management of animal manure compost—Publications,” n.d.). With too high of a C/N ratio (above 40-1) will immobilize the nitrogen in the system and slow the composting process. Too small of a C/N ratio (below 20-1) can lead to loss of nitrogen and release a smell of volatizing ammonia (“Composting Animal Manures: A guide to the process and management of animal manure compost—Publications,” n.d.). In order to achieve the perfect C/N balance it is necessary to add carbon in the form of plant matter. Given that the NPK of solid waste from dairy cows is 3-3-6, it is determined that for every 33.33 pounds of manure there is one pound of nitrogen. Furthermore, an average value of 50% carbon in biomass (“Forests and Climate Change,” n.d.) allows for crop waste and manure be mixed in the windrows in a ratio of 2:1 respectively in order to obtain a C/N ratio around 30-1.

4.4 Water Content

One final aspect of the manure piles that needs to be considered is the water content of the pile. For composting it is important to have 40-65% of the pore space contain water for the microbes to be the most efficient at composting the manure. This water content can be achieved through the addition of plant matter, which is high in water content. After the appropriate addition of plant waste added to the windrows as stated above the water content can be monitored through water sensing probes inserted into the piles. If too much water is present at that time the pile can be turned to evaporate excess water. If too little water is present, slightly more plant material can be added to increase the water available in the pile while being careful to not exceed a C/N ratio of 40-1.

5. Environmental Considerations and Analysis

Environmental impacts must be considered in the composting process the boundaries for this analysis must be identified. The environmental considerations that will be discussed in detail for both the current composting system in Pepin County as well as the proposed composting system will be greenhouse gas emissions and water quality impacts. The manufacturing of equipment, transportation of equipment, and emissions from equipment use were not used in the analysis of environmental impact because they were assumed to be negligible compared to the sources being analyzed. The scope of what will be considered as well as what is outside the environmental scope can be seen in Figure 9 and Figure 10 respectively.
5.1 Greenhouse Gas Emissions

Dairy cows themselves are responsible for approximately 70-120 kilograms of methane production every year from the gases they release from their rumen, a part of the cow’s digestive system that contains methane producing bacteria (“Study shows potential for reduced methane from cows,” n.d.). However, this source of methane will be considered constant between the current and proposed system for the sake of this report and instead the methane generation within the composting piles will be considered. By looking at average amounts of methane produced from various studies for different composting techniques it is possible to determine an estimate of how much methane would result from the current methods and the proposed methods of composting. Methane is important to study for this report because it is by far the largest contributor to greenhouse gas emissions from dairy cows. This is mainly because methane as a greenhouse gas is 25 times as effective at retaining heat in the atmosphere than carbon dioxide (Flaherty, n.d.). Methane also persists in the atmosphere for a shorter time frame than other greenhouse gases, so any reductions in methane will lead to a more climate change benefits in the short-term (Flaherty, n.d.). By analyzing the current conditions and the proposed conditions in the following sections with the methodologies previously stated, it will be apparent that proper compost management can significantly reduce methane production, and therefore, greenhouse gas emissions.

5.1.1 Current Conditions

As previously mentioned in Section 3 of this report, farmers currently place manure from dairy cows and excess crop waste in a large pile on their property to sit there and partially compost. This is considered an unturned composting system in the sense that the pile is always
static and is never rotated or mixed. This is an environmentally unfriendly method of composting due to the nature of methane production within this static pile. While the outermost portions of the pile are under aerobic conditions and capable of composting the manure and crop waste, the innermost portions of this large pile will be anaerobic (no oxygen present). The reason anaerobic issues are a concern is because methane producing bacteria can only operate under these conditions. In fact, a study done by the University of Purdue estimated that every pound of solid manure produced by dairy cattle can produce 3 cubic feet of methane under anaerobic conditions (“AE-105,” n.d.). Even if we assume only half of the manure pile under static composting is under anaerobic conditions at any given time there is still a total of 850 tons, or 1,700,000 pounds of manure produced by these cows annually. This equates to 5,100,000 cubic feet of methane production per year for the small farm and 10,200,000 cubic feet of methane for the large farm. In a study done by the nonprofit organization Sustainable Conservation, in California, around half of man-made methane emissions come from dairy cows. Of this, 45% comes directly from the manure management process (Flaherty, n.d.). It can be assumed that methane emission numbers from dairy cows are similar in proportion in Pepin County. From these numbers of methane emissions, it is clear to see that the methane production from anaerobic manure piles is far from inconsequential. Therefore, finding a superior method of composting can directly result in methane reductions.

5.1.2 Proposed Conditions

Described in Section 4 of this report, the newly proposed method of composting for the farmers of Pepin County is a turned windrows design. The main benefit of this system from a greenhouse gas perspective is that it produces almost completely aerobic conditions in the pile. This both means that more of the manure and crop waste can be composted compared to the static pile, but also that the methane producing bacteria that require anaerobic conditions cannot function. In the study conducted by Sustainable Conservation, it was estimated that through the process of turning a compost pile, methane emissions can be reduced by up to 71% compared to an unturned pile (Flaherty, n.d.). If the approximate of 5,100,000 cubic feet of methane produced annually is considered as the base case, then in this new method will produce approximately 1,479,000 cubic feet of methane annually for the small farm and 2,958,000 cubic feet of methane for the large farm. On top of the 71% methane reductions, all the methane is also released during the turning process as opposed to being released while being spread onto the fields like what
happens with the current methods (Flaherty, n.d.). This means that the methane emissions are much more concentrated and predictable so it would be possible to capture much of the methane escaping from the compost pile with the proper equipment. Adding methane capturing equipment would be an expensive and time-consuming process, so it is assumed that this would only be done by farmers who are concerned with the environment. While this proposed method will take more work and capital input from the farmers in order to turn their piles as well as lay them out in the dimensions stated in Section 4, it is clear that this extra work would have substantial benefits for the greenhouse gas emissions of their composting piles.

5.2 Water Quality

Production of nitrate leachate is the main water quality concern associated with dairy cow manure. This leachate from the cow’s liquid waste can be turned into runoff due to high quantities of it being produced or from storm events washing away the nitrate within the pile. Leachate runoff can find its way into surface water or groundwater, both having serious environmental implications. From a surface water perspective, if too much nitrate enters the water system, algae and other bacteria can grow at an overwhelming pace depleting all the oxygen in the system and creating a hypoxic zone in which fish and other animals cannot survive (“Water Research Center—Nitrogen effects on surface and groundwater quality,” n.d.). Looking at the impacts on groundwater, nitrate is easily soluble in water and can enter the water table. Since groundwater takes hundreds if not thousands of years to replenish, this contamination can have serious side effects, such as blue-baby syndrome or impacts on hemoglobin, to the people who drink groundwater contaminated with nitrates (“National look at nitrate contamination of Ground Water,” n.d.).

5.2.1 Current Conditions

Under current conditions, of an unturned compost pile which contains relatively high levels of liquid manure, there is a lot of nitrate leachate being produced. In the study done by Sustainable Conservation, they concluded that an unturned composting pile can emit up to 260 grams of nitrate leachate per ton of liquid manure present (Flaherty, n.d.). Much of this leachate is produced because the liquid manure is not given a chance to evaporate due to it being locked within the compost pile. As mentioned above, this leachate will eventually find its way to either a surface water or groundwater source and impact the environment in a negative way. If it is assumed that 3 million gallons of liquid manure is produced per year and the NPK of this is 8.6-
4.6-20.7, then using the methods described in Section 2, it is possible to determine that for every approximately 11.6 units of liquid manure, there will be one unit of nitrogen produced. Again, if it is assumed that half of all the nitrogen in the system is turned into nitrate leachate, then this system would produce 129,310 gallons of nitrate annually for the small farm and 258,620 gallons of nitrate for the large farm.

5.2.2 Proposed Conditions

In the same research done by Sustainable Conservation, it was stated that a turned pile of compost will emit around 142 grams of nitrate leachate per ton of liquid manure present (Flaherty, n.d.). This is approximately 55% as much as the current conditions would produce. These reductions occur when the pile is turned and the liquid manure within the compost can escape and evaporate from the compost. Taking the final values of nitrate production from the current conditions and multiplying them by the percent reduction from turning, it is seen that the small farm will produce around 71,121 gallons of nitrate annually and the large farm producing 142,241 gallons of nitrate annually. These reductions in nitrate can be seen immediately from the two different methods of composting, but there are also other benefits to proper turned windrows composting compared to static pile composting. One of these benefits is that proper composting produces temperatures high enough to kill pathogens like fecal coliform and Salmonella which could potentially be taken with runoff into local water sources, while static composting would not kill these pathogens everywhere in the pile (Flaherty, n.d.). One final benefit from this improved composting method is that the nitrogen nutrients get spread out more evenly throughout the compost, therefore protecting water sources from high levels of nitrate inflow (Flaherty, n.d.).

5.3 Environmental Conclusions

From the greenhouse gas and water quality analysis shown above, from an environmental standpoint the turned windrows method of composting is superior to the static pile composting method that is currently used by farmers in Pepin County. As shown in Figure 11 below, if methane from the unturned pile can be considered 100%, then the turned pile has a much lower value of 29%.
Figure 11: Potential methane emissions comparing the current unturned conditions compared to the turned windrows proposed conditions with the unturned case being considered 100% emissions.

Looking at the water quality benefits of the proposed turned windrows design compared to current conditions in Figure 12 below, it is also clear that the new design is environmentally superior to the current method of composting.

Figure 12: Comparison of nitrogen losses through leachate of the current composting method compared to the proposed composting method.

Comparing the main environmental concerns of methane emissions and nitrate leachate, the proposed design is superior from an environmental standpoint. A summary of the environmental aspects of composting can be seen below in Figure 13. It should also be noted that while the recommended turned windrows composting method is better for runoff than current
static pile composting, there will still be runoff that should be collected in a containment pond on-site that has an impermeable liner to prevent infiltration into the groundwater. Moving forward in this report, the economic and social aspects of these two conditions will be examined to arrive at a final recommendation for the farmers of Pepin County.

**Figure 13:** Flow chart of inputs and outputs of composting process from and environmental standpoint.

6. **Economic Considerations and Analysis**

Economic impacts must be considered in the composting process and the boundaries for this analysis must be identified. The economic considerations included the cost of composting systems in previous case studies, cost of turning methods, transportation of manure vs. compost material, and an estimated annualized value, as shown in Figure 14. Not included in this analysis was the cost of manufacturing of transportation materials, the NPV, and the cost to buy new equipment, as shown in Figure 15. Also, labor costs and the cost to turn piles will be included in the estimated annualized cost, shown in Figure 16.
Looking at previous case studies within one study, there were three studies which touch upon the windrow composting and in three different ways. A study by Daniel Dreyfus in 1990 describes manure piling and turning using a farm tractor with a 1 cubic yard front loader, this resulted in a turning price per ton of $1.75, and with a total turning time of 106.25 hours for the 1700 tons of manure (“Agricultural Composting: A Feasibility Study for NY Farms,” n.d.). Although these numbers are based on composting leaves, why this might not be entirely accurate when comparing with cow manure, as the density of the two materials are very different which might impact turning time. A study by Tom Richard in 1991 describes the turning of 100 tons of manure using a 40-horsepower tractor with 1/3 cubic yard bucket (“Agricultural Composting: A
Feasibility Study for NY Farms,” n.d.). This resulted in a turning price per ton of $2.25, and a turning time of 291.6 hours to turn the entire 1700 tons of manure. The last case study considered by Gary Tennant in 1991 described the use of a $50,000 tractor with a loading attachment and a specialized windrow turner (“Agricultural Composting: A Feasibility Study for NY Farms,” n.d.). This resulted in a turning price per ton of $0.35 and a total turning time of 19.4 hours for the entire 1700 tons of manure. These rates are including both equipment and labor costs, therefore it is assumed that the equipment costs also includes fuel, maintenance etc. (“Agricultural Composting: A Feasibility Study for NY Farms,” n.d.). As these studies are all more than 25-years old, it is rather likely to assume that the realistic turning times and prices are closer, if not better, than what Gary Tennant describes, as the technology used has greatly improved since then (“Agricultural Composting: A Feasibility Study for NY Farms,” n.d.). The costs and time can be seen in Table 1, as well as the total cost of turning the windrows both for the 500 and 1000-cow scenario.

Then comes the transportation of the manure, after it has been composted and is ready to either be sold to local farms or residents or used as fertilizer on the farmers own farms. With the decrease in weight and volume that happens during the composting process, between 50% to 80% percent according to a scientific article (“Mass and Nutrient Losses During the Composting Of Dairy Manure Amended with Sawdust or Straw: Compost Science & Utilization: Vol 12, No 4,” n.d.). Therefore, the cost of transportation would decrease drastically from transporting direct manure, although, the costs would be the same for all the different scenarios, as to why it has not been included in the calculation of costs, as it would add the same amount to every scenario and therefore not help differentiate between the scenarios.

6.2 Annualized value

Then to estimate the annualized value of the different turning processes, it is important to know how many times the windrows need to be turned. According to a composting guide, the manure should be composted after 3-5 turns, although according to The National Organic Program, it is required that the compost reaches at least 131 degrees for 15 days, and is turned at least 5 times (“Composting Animal Manures: A guide to the process and management of animal manure compost—Publications,” n.d.). Therefore, it is assumed that the manure windrows are turned 5 times with a two-week interval, after which it is completely composted. This would result in the annualized value of for turning the entire 1700 tons of manure to be $15,406.25 in
accordance to the method described in Daniel Dreyfus in 1990, $20,497.32 with the method described in the study by Tom Richard in 1991, and $2,944.64 with the method described by Gary Tennant in 1991. These values can also be seen in Table 1.

**Table 1:** Cost for small and large farms based off values from different studies.

<table>
<thead>
<tr>
<th></th>
<th>500 cows</th>
<th>1000 cows</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Turning time (hours)</strong></td>
<td>106.25</td>
<td>291.60</td>
</tr>
<tr>
<td><strong>Cost per turning ($)</strong></td>
<td>3,081.25</td>
<td>4,099.46</td>
</tr>
<tr>
<td><strong>Annualized value ($)</strong></td>
<td>15,406.25</td>
<td>20,497.32</td>
</tr>
</tbody>
</table>

Although all this new compost, would not only be an expense as it would also be possible for the farmers to sell their compost to other local farmers or residents. An average sales price for 40lbs bags of compost was found to be $4.72 ("Doing the Dirty Work | Waste360," n.d.).

Assuming the different turning methods all achieve fully aerobic compost, and that there is no loss, with an average loss of 65% in weight and volume, this would result in in a total amount of final compost to be 595 tons ("Mass and Nutrient Losses During the Composting Of Dairy Manure Amended with Sawdust or Straw: Compost Science & Utilization: Vol 12, No 4," n.d.). Assuming all 595 tons of compost is sold in 40lbs bags at an average price of $4.72 per bag, the total revenue generated from that would be $140,420.00. This would lead to no personal usage of the compost as fertilizer for the farmers themselves, but a large monetary gain. Although selling of only 87 tons of compost at the estimated price, would be enough to offset the expenses found using the method described by Tom Richard in 1991. The needed amount of sold compost would then only be less to offset the expenses when comparing with the other methods, as they both had lower expenses related to the turning of the windrows.
In order to estimate this annualized value of the turning of these windrows, assumptions have to be made for the costs included and also assumptions in regard to what is not included. As to what is included, the costs are derived from previous studies. The costs not included in this assessment is the manufacturing cost of the transportation vehicles, the NPV, and the cost of acquiring new equipment. The manufacturing of the transportation vehicles are not included, as these most likely are not bought by the individual farmers themselves, but are rented on “delivery-to-delivery” basis, which is why the cost of transporting the manure itself is included, but not the manufacturing of said vehicle. The NPV is not included as the net present value shows the difference between the cashflows in and out over a certain period. This is a useful tool to utilize when assessing profitability of future investments, but as there is no need for new investments, the yearly outflows of cash would be constant as no loans would need to be paid off, and the only expenses are from labor and machine usage. This in addition to the potential revenue made from selling the compost, makes the NPV no necessary. Lastly the cost of purchasing new equipment is not included, as it is assumed that the farmers already has the necessary equipment needed to create the compost windrows and to turn them the 5 times needed to fully compost the manure. This does create a scenario that might not be entirely corresponding to how it is, but the outcome will be representative to the extent that a decision can be made.

6.3 Economic Conclusion

Through this economic analysis of these three different methods of turning the manure windrows, in order to achieve a fully aerobic composting of the dairy manure, it was found that the most economically viable method, is to use a tractor with specialized windrow turner. The cost of this method was 5 times lower than the second lowest scenario; this does however require the acquisition of a specialized windrow turner if the farmer is not already in possession of one. These can be rather expensive, but with the potential income from the selling of compost, and the fact that farmers can come together and purchase one, which then gets shared between them whenever the use of the machine is needed. This would greatly reduce the individual cost of acquisition. Therefore the method of using the specialized windrow turner is greatly preferred.
7. Social Considerations and Analysis

With the option to increase composting in Pepin County, there is a need to evaluate the social implications that are associated with it. In order to do so, one must consider the economic and environmental impacts from composting, as they play a role in the outcome of social impacts. For this analysis, social impacts will be considered within the surrounding community and the world more broadly. The boundaries for this analysis include permit requirements, soil quality, air quality, human health, and smell. This analysis considered residents, workers, businesses, farmers, and society more broadly. This analysis did not include the standard of living, worker’s rights, working conditions, the quality of life, and business ethics, as it was difficult to quantify these from previous composting practices on farms. All scope boundaries are shown in Figure 18.
Figure 18: Boundaries for Social Consideration and Analysis. This figure includes the scope of social considerations, who was included in the social considerations, as well as what was not included in the social considerations.

The proposed composting method involving turning could have some social impacts regarding health and smell. For this analysis, air quality and soil quality were looked at in connecting with human health, as shown in the map of flows in Figure 19. Smell was also considered in this analysis, as it could play a role in human health and lifestyle, which is depicted in Figure 20.

Figure 19: Map of flows from composting process from a social standpoint on air and soil quality affecting human health.
Figure 20: Map of flows from composting process from a social standpoint on smell affecting human health.

7.1 Social Analysis

There can be legal implications for composting, such as laws to follow or quantitative limitations for composting practices. Published data from the Institute for Local Self-Reliance, the Wisconsin Department of Natural Resources (DNR), and the Wisconsin State Legislature will be used to determine social effects for the proposed composting alternative in relation to what is currently being done. The Institute for Local Self Reliance (Platt |, 2018), DNR, and Wisconsin State Legislature all deal with standards, laws, regulations, and legislation regarding composting processes.

Economic and environmental implications play a role in social impacts as well. When a community flourishes, it can affect the lives and well-brings of residents, workers, farmers, and businesses. Soil and air quality play a role in human health. Published data from the Sustainable Conservation (Flaherty, n.d.), the Institute for Local Self-Reliance (Platt |, 2018), and as well as research paper (Schiavon et al., 2017), will be used to determine social effects for the composting alternative in comparison to the field application of un-composted manure.

Smell can play a role in the daily lives of farmers and residents of Pepin County. An analysis of how smell can affect human health will shed some light as to if there will be any health implications from odors, and if the smell will have any dramatic impact as from what is being done currently. Research paper (Schiavon et al., 2017) will be used for this analysis.

For the most part, social aspects will be assessed qualitatively for the purpose of this analysis; however, some quantitative data will be utilized to highlight the social effects from soil and air quality when comparing un-composted manure and composted manure.
7.1.1 Legal Implications

According to the Institute for Local Self-Reliance, there are composting regulations for Wisconsin to ensure the quality of the compost as well as to minimize possible nuisances from mismanagement of materials through Wisconsin’s Department of Natural Resources (DNR) (“Wisconsin—Composting Rules,” n.d.). Certain licensing is necessary for various composting facilities. In this analysis, the assumption that composted material will not be sold and instead will be applied to farmland is made, as permits are typically not required for on-farm composting and licensing for selling compost product are needed. Depending on the size of the farm, certain requirements might need to be met. For instance, for large-scale manure composting, a local DNR agricultural runoff specialist should be contracted, so it is assumed that these farms do not fall into the large-scale category (“Farms and composting—Wisconsin DNR,” n.d.).

First, the DNR does not typically require licensing regulations for on-farm composting, as there is no constraint on volume of composting farm crop residue and manure generated on-site (“Wisconsin—Composting Rules,” n.d.). On-site farmers need to meet performance standards in NR 502.04(1), which require that the process is operated in a manner that does not cause environmental harm to the surrounding area (“Wisconsin Legislature: NR 502.04,” n.d.). These performance standards are included in Appendix A for additional review. In addition to performance standards, license exemption for farm manure composting exists provided the abidance of standards NR502.12, included in Appendix B (“Wisconsin Legislature: NR 502.12,” n.d., p. 50). According to these standards, the farm must be operated in an environmentally sound way, manure for the compost must be used from a commonly owner, adjacent, or managed farm on the property of one of those agricultural operations, the composted material must be used for agricultural land-spreading at the same farm or another farm following standards from NR 518.04(1), (b), or (i), and source-separated compostable material other than farm crop
residue and manure can be accepted off-site if certain conditions are met (“Wisconsin Legislature: NR 502.12,” n.d.). Also, for manure composting, a confined animal feeding livestock operation requires a Wisconsin Pollutant Discharge Elimination System (WPDES) wastewater discharge permit that can be administer by the DNR under NR 243.15(8), listed in Appendix C (“Farms and composting—Wisconsin DNR,” n.d.). Smaller farms that combine manure for composting can be treated as a combined animal feeding operation as well.

If the farm decides to receive material generated off-site for composting, there is a threshold limit to remain exempt from licensing and regulations of 10,000 cubic yards at one time on-site. The threshold limit was calculated taking into account collected feedstocks, the composting process, and the finished compost for the final sum and is based on the combined volume of farm crop residue, manure, yard waste, and clean chipped wood on-site at one time (“Wisconsin—Composting Rules,” n.d.). The compostable material then must meet local criteria and minimum operational and design standards, the farm must measure temperature of piles frequently at the turning of piles, and the farm must inspect the stormwater control measures used on-site during storm events (“Farms and composting—Wisconsin DNR,” n.d.).

Second, there are many economic benefits for farmers, businesses, and communities through the sale of finished compost. The State of Wisconsin requires licensing and regulations if farmers decide to sell their compost product. Compost is a value-added product and can provide additional revenue for farmers and other composters, thus there is a policy that incentivizes growing markets for compost products through the State of Wisconsin (“Wisconsin—Composting Rules,” n.d.). Wisconsin allows licensed facilities to sell all their compost without restriction if safety and quality standards are met (“Wisconsin—Composting Rules,” n.d.).
Assuming farms in Pepin County use on-site manure and materials to generate compost and do not sell it, there should be minimal regulations or licensing to abide by. If the decision is made to sell the material or acquire off-site material for the compost, additional regulations and licensing may apply. These regulations can affect the social impacts on Pepin County, as regulations may make the composting process more challenging and time-intensive; however, the economic benefit of selling might make the process worth it. Economic, environmental, and social considerations can assist with decision making. Things to consider might be the cost of labor, cost to produce, cost to follow regulations, transportation costs, GHG emissions from transportation travel, the environmental impact on groundwater outside of Pepin County, how selling compost could affect the lives of workers, how the challenge of following permits would affect farmers and laborers, and so on.

7.1.2 Economic Implications

Properly composted manure is much lighter and has less volume than improperly composed manure, which could bring to light an economic advantage to the community and farmers that could result in a social impact. The economic potential to produce, sell, and transport composted manure is much greater than typical manure. Due to the lightness of composted material, transportation is cheaper and can be done farther from the source compared to manure. A study found that uncomposed manure can travel up to 10 miles whereas composted material can travel 30-50 miles (Flaherty, n.d.). Figure 21 shows the mileage radii of the two materials from a randomly selected farm in Pepin County.
Figure 21: Transportation of Manure (Red) vs. Composted Material (Yellow) from a Pepin County Farm.

Figure 21 shows that the transportability of composed material is much greater than manure, which can mean selling it might be an economically productive option. Economic productivity can potentially lead to profits for farmers and the community, which could improve social standards, such as how people live their lives, the ease of life, etc. More research on types of transportation methods, cost of labor, and price to sell materials would need to be evaluated in order to determine if selling composted material is an effective service at specific farms. Farms also would have to consider the cost and regulations associated with of permits needed to sell material.

7.1.3 Environmental Implications on Health

There are health implications that can arise from composting. Soil quality can affect health. Land spreading of manure compost has been shown to improve the soil health after nutrients have been depleted from extensive agricultural activity (Flaherty, n.d.). In fact, according to the institute for local self-reliance, composting is the best way to add organic matter to soils, which enhances the soil and protects watersheds (Platt |, 2018). Figure 22 depicts the biological, chemical, and physical characteristics of the soil can benefit from composting (Platt |, 2018).
Figure 22: How Composting Can Increase Soil Quality. This figure lists the benefits that can come to soils from utilizing composted material from land-spreading (Platt |, 2018).

Composting can replenish nutrients in the soil, increase the soil’s retention of water, decrease the bulk density, increases soil organic matter, increases fertility and biological activity, as well as adds carbon sequestration (Flaherty, n.d.). This means the farm’s water irrigation demand could decrease, compaction of soil could decrease, water storage capacity of the soil could increase, and carbon in the atmosphere could decrease.

Compost can be better for the soil compared to applying traditional manure. According to a study, composted manures can reach temperatures that kill weed seeds and pathogens, where un-composted manure does not (Flaherty, n.d.). Also, composted manures do not have as high of inorganic nitrogen levels as un-composted manure, but they do have higher levels or organic nitrogen, which means there is more long-term nitrogen availability with a smaller risk of leaching or nitrogen runoff using compost over manure (Flaherty, n.d.).

Agriculture poses health implications as is; however, composting poses some health risks as well. Composting can result in the production of substances such as Ammonia (NH₃), volatile organic compounds (VOCs), hydrogen sulfide (H₂S), and possibly even heavy metals and other toxins in the waste (Schiavon et al., 2017). These substances pose a threat to the health of workers, the community, and the public in general. Long-term exposure can even increase the risk to develop cancer over a lifetime (Schiavon et al., 2017). Air quality can also be affected by composting. Not only can these substances be hazardous to human health, these substances can
be detrimental to the ozone layer, which can affect the quality of life and standards of living. VOCs have been shown to contribute to global warming (Schiavon et al., 2017).

Soil can act as a carbon sink. When land is converted from natural land to cropland, soil organic carbon (SOC) reduces 30-40% (“Carbon sequestration,” 2019). This depletion is mainly due harvesting, as plants in the soil contained carbon. Using manure or manure-based compost as fertilizer can add carbon back into the soil. According to the Institute for Local Self-Reliance, a research project found that applying only 0.5 inches of compost to rangelands can sequester the equivalent of 1 metric ton of CO$_2$/hectare over just three years (Platt |, 2018).

Also, cow manure can lead to the emission of two criteria pollutants defined by the Clean Air Act, ammonia (NH$_3$) and volatile organic compounds (VOCs). Ammonia can end up taking the form of ammonium sulfate or ammonium nitrate aerosols in the atmosphere (Flaherty, n.d.). These aerosols can increase the concentration of fine particular matter, which can eventually lead to respiratory health issues as well as lead to the acidification of soil and the eutrophication of water. According to a study, cows un-composted manure produces up to 26% of NH$_3$ emissions during manure storage and application (Flaherty, n.d.). 42.5% of NH$_3$ is released during storage and 57.5% during land application (Flaherty, n.d.). Composted manure; however, releases 100% of NH$_3$ during storage and turning, which means less chance to release NH$_3$ at application and better potential to control during the storage process (Flaherty, n.d.). While composting releases more ammonia than un-composted manure, all of the ammonia from composted manure is released during the production phase rather than the application phase, which makes managing the gas for air quality easier. The proposed compost turning method would be superior to static piles, as static piles would require ammonia mitigation tactics during the production and application stages rather than just the production stage (Flaherty, n.d.). VOCs can react with nitrogen oxides (NO$_x$) and sunlight to form ground-level ozone, which can lead to air quality and asthma issues (Flaherty, n.d.).

**7.1.4 Smell Implications**

The substances produced with composting can also be associated with distinct smells that many do not favor. VOCs have been shown to cause odor nuisance (Schiavon et al., 2017). These odors might affect communities and individuals. Due to the biodegradation of organic materials, composting can pose a chance towards the formation of odors. If aerobic conditions are met, composting should not produce an overwhelming smell; however, if anaerobic
conditions are implemented, the smell could be stronger due to the production of ammonia and methane. The nuisance of smell has potential to decrease the quality of life or potentially even drive down the values of surrounding properties, as it is undesirable, but this is unlikely. Exposure to odors have even been shown to increase symptoms, such as headaches, respiratory problems, excessive tiredness, and nausea; although, is controversial as to whether health effects come from odor emissions (Schiavon et al., 2017). However; considering the composting project would include the composting of manure, it is likely that there already is an existing smell associated with the farms due to the mass amounts of manure produced year-round, which could mean the composting process should not affect the smell much. This means the quality of life and property values may not change due to increasing composting practices. Also, the social cost of odor is likely much smaller than the cost of shutting down farming operations or not optimizing potential efficiencies, profits, and environmental benefits from farm materials generated, such as excess manure and nutrient-rich waste products.

7.2 Social Conclusion

Some studies have shown that composting doesn’t change the VOCs present in existing manure and VOCs from cow manure are less likely to form ozone that other types of manure (Flaherty, n.d.). More research needs to be done; however, to determine whether composted manure or un-composted manure has a better or worse impact with VOCs. From what was found during the social analysis; however, that compared to traditional field application of un-composted manure, that composted manure poses as a great alternative to what was currently being done. Composting field application poses greater benefits to the soil and air, which can benefit human health and economics. Adding nutrients in the soil, can mean the farm can spend less money on water irrigation and compaction, as demand could decrease from using composted manure (Flaherty, n.d.). With compost, there is higher potential for carbon sequestration, which could benefit the health of humans with less toxic GHGs potentially in the atmosphere (Flaherty, n.d.). Also, the smaller risk of leaching or nitrogen runoff using compost over manure poses a positive to the health of humans and animals. This could mean less toxic groundwater for ingestion, and less nutrients that will travel down the Mississippi River to the Gulf of Mexico. Currently, the hypoxic zone is a dead zone nearly 6,000 to 7,000 square miles in the Gulf of Mexico with less than 2 parts per million (ppm) of dissolved oxygen (“The Gulf of Mexico Dead Zone,” n.d.). This dead zone occurs mainly from the nutrient enrichment of nitrogen and
phosphorous brought to the Gulf from the Mississippi River. Watersheds from many farming states make their way into the Mississippi River, taking nitrogen from farmlands with it. Algal blooms develop from the nutrients and with too much nitrogen or phosphorous, these blooms can alter the food chain and deplete the dissolved oxygen (“The Gulf of Mexico Dead Zone,” n.d.). Using compost over manure for land application can lead to less nitrogen runoff, thus potentially decreasing the amount of nutrients carried to the Gulf of Mexico, and potentially helping the lives of plants, animals, and humans.

Social analysis has brought to light the many benefits of manure compost for field application compared to traditional un-composted manure application. Although this analysis assumed that the composted material was not going to be sold, the economic benefit from selling compost and its transportation capabilities suggest it might be a good utilization of the manure generated on farm sites in Pepin County. The analysis on smell suggests that under the proposed windrow turning method, aerobic conditions could be met, thus not creating an intense odor. Any additional smells coinciding with the proposed composting solution are assumed to be minor in comparison to the smell the dairy farm is presumed to have currently. Overall, from a social perspective, the proposed solution deems itself to have positive impacts on human health, the environment, and economy.

8. Conclusion and Recommendation

As shown in the previous analysis sections, it is believed that the turned windrows composting method is superior to the current method of static pile composting. Environmentally, methane emissions and nitrate leachate are reduced. From an economic standpoint, while this method is more expensive up-front, there are returns on being able to sell compost as fertilizer. This trade-off is believed to be worth the initial investment a farmer would have to put in. Finally, from a social aspect, air quality and soil health are improved from the current conditions. There are also added benefits of reduced smell and a greater ease of transportation of the lighter and smaller composted manure. This turned windrows composting solution provides farmers with a relatively easy to understand and perform process that will greatly improve the current method of composting. By allowing farmers the option of using their current equipment, or to invest in new equipment, it gives them the freedom to decide how in depth they want to implement this new composting technique. In the future, it is recommended that further look into methane collection on site be considered to both protect the environment from greenhouse gases
as well as being a profitable byproduct from the composting process.

**Project Contributions of Team Members**

1. Introduction
2. Background and Literature Review
3. Social Considerations and Analysis
4. Analysis/Research
5. Creation of figures, graphs, tables, etc.
6. Sources
7. Review of Proposal

**Review of Proposal**

1. Executive Summary
2. Economic Considerations and Analysis
3. Analysis/Research
4. Creation of figures, graphs, tables, etc.
5. Review of Proposal

**Explanation of Current Conditions**

1. Explanation of Current Conditions
2. Explanation of Alternative
3. Environmental Considerations and Analysis
4. Analysis/Research
5. Creation of figures, graphs, tables, etc.
6. Review of Proposal
References

AE-105. (n.d.). Retrieved December 8, 2019, from
https://www.extension.purdue.edu/extmedia/ae/AE-105.html

Agribusiness, CAFOs and other farms—Wisconsin DNR. (n.d.). Retrieved December 3, 2019,
from https://dnr.wi.gov/topic/AgBusiness/CAFO/

Agricultural Composting: A Feasibility Study for NY Farms. (n.d.). Retrieved December 8,
2019, from http://compost.css.cornell.edu/feas.study.html#cost


Compost. (2019). In Wikipedia. Retrieved from


Farms and composting—Wisconsin DNR. (n.d.). Retrieved December 7, 2019, from
https://dnr.wi.gov/topic/Recycling/Farms.html


Forests and Climate Change. (n.d.). Retrieved December 5, 2019, from
http://www.fao.org/3/ac836e/AC836E03.htm

Google Maps. (n.d.). Retrieved December 2, 2019, from Google Maps website:
https://www.google.com/maps/@43.0675726,-89.4074148,3308m/data=!3m1!1e3


Mass and Nutrient Losses During the Composting Of Dairy Manure Amended with Sawdust or Straw: Compost Science & Utilization: Vol 12, No 4. (n.d.). Retrieved December 8,

National look at nitrate contamination of Ground Water. (n.d.). Retrieved December 8, 2019,
from https://water.usgs.gov/nawqa/nutrients/pubs/wcp_v39_no12/


See how a manure lagoon works and why farmers want to build even more of them—YouTube. (n.d.). Retrieved December 3, 2019, from https://www.youtube.com/watch?v=oSEYfs1V1JY


APPENDICES

Appendix A

NR 502.04  **General requirements.** All facilities regulated under this chapter shall comply with the following requirements:

(1) Performance standards.

(a) Unless an exemption is granted by the department under par. (b), no person may establish, construct, operate, maintain or permit the use of property for any facility regulated under this chapter, or any non-commercial soil borrow source designated to be used in the construction of a specific facility regulated under this chapter, within an area where there is reasonable probability that the facility will cause any of the following:

1. A detrimental effect on any surface water.

2. A significant adverse impact on wetlands as provided in ch. [*NR 103*](#).

3. A detrimental effect on groundwater quality or will cause or exacerbate an attainment or exceedance of any preventative action limit or enforcement standard at a point of standards application as defined in ch. [*NR 140*](#). For the purposes of design, the point of standards application is defined by s. [*NR 140.22 (1)*](#).

4. A take of an endangered or threatened species or other activity prohibited under s. [*29.604*, Stats.](#)

5. The migration and concentration of explosive gases in any facility structures, excluding any leachate collection system or gas control or recovery system components or in the soils or air at or beyond the facility property boundary in excess of 25% of the lower explosive limit for such gases at any time.

6. The emission of any hazardous air contaminant exceeding the limitations for those substances contained in s. [*NR 445.07*](#).

(b) Exemptions from the requirements of par. (a) 4. to 6. may be granted by the department only upon demonstration by the applicant of circumstances which warrant the exemption. Exemptions from compliance with par. (a) 3. may be granted only according to the procedures in ch. [*NR 140*](#).
Exemptions from compliance with par. (a) 2, may be granted only in accordance with the standards in ch. NR 103. Exemptions from compliance with par. (a) 1, may not be granted.

(2) Initial site inspection.

(a) Any person intending to establish or expand a solid waste facility listed in subds. 1 to 8, which is subject to locational criteria under this chapter or a soil borrow source listed in subd. 9, shall submit a written request to the department for an initial site inspection for the purpose of evaluating compliance with the performance standards listed in sub. (1) and the applicable locational criteria contained in this chapter:

1. Noncontainerized storage facilities.

2. Transfer facilities.

3. Processing facilities.

4. Incinerator facilities.

5. Air curtain destructor facilities.

6. Woodburning facilities.

7. Composting facilities.

8. Municipal solid waste combustor facilities.

9. Non-commercial soil borrow source designated to be used in the construction of a specific solid waste facility listed in subds. 1 to 8.

(b) The written request for initial site inspection shall comply with s. NR 500.05 (5) to (8) and shall contain a cover letter identifying all of the following:

1. The applicant and authorized contact.

2. Type of facility and operation proposed.

3. Property ownership.

4. Location by quarter — quarter section.

5. Present land use.
6. All potential conflicts with the performance standards listed in sub. (1).

(c) The written request for initial site inspection for solid waste facilities listed in par. (a) 1. to 8. shall contain all of the following additional information:

1. Identification of any known potential impacts to endangered and threatened species in accordance with s. 29.604 (4), Stats., and the federal endangered species act or historical, scientific or archeological areas in accordance with s. 44.40, Stats., including any prior studies or surveys conducted at the proposed site.

2. An enlarged 7.5 minute USGS map or other base map having a minimum scale of 1" = 500 feet. The map scale and contour intervals shall be revised as necessary to sufficiently show relief, surface waters, floodplains, existing land use conditions and all water supply wells and residences located within one mile of the property boundaries of the proposed facility.

Note: One copy of the information required by pars. (b) and (c) shall be submitted to the department's field office responsible for the area in which the facility is proposed to be located, and one copy shall be submitted to the department's solid waste management section in Madison.

(d) The department shall conduct an initial site inspection within 22 business days of receipt of a written request which complies with the requirements of this subsection. Depending on the season, follow up inspections may be necessary to identify any obscured features of the proposed property such as wetlands. Within 22 business days of completing the inspection, the department shall render a preliminary opinion regarding the suitability of the site location and identify any additional studies or information that is to be submitted to determine if a proposed solid waste facility or soil borrow source complies with the performance standards listed in sub. (1) and the applicable locational criteria contained in this chapter. A favorable opinion from the department under this paragraph does not guarantee that performance standards or locational criteria will be met.

(3) Closure. Except as otherwise specified in this chapter or in a department issued approval, the owner or operator of any facility regulated under this chapter, or any person who permits the use of property for such purposes, shall at a minimum complete all of the following:
(a) Within 5 calendar days after ceasing to accept waste at the facility, remove all putrescible waste and containerize, properly utilize or dispose of all other waste.

(b) Within 60 days after ceasing to accept waste at the facility, remove all waste.

(c) Unless otherwise specified in a department issued approval, the following minimum requirements shall also be met by the owner or operator of a facility for which a plan of operation is required under this chapter:

1. At least 60 days prior to ceasing to accept waste at the facility for an extended period, the department shall be notified in writing and a sign shall be posted in a prominent location notifying users of the date on which the facility will cease to accept waste. In the case of ceasing to accept waste for an extended period due to unplanned and unforeseeable circumstances, such as fire or equipment failure, department notification and sign posting shall be completed as soon as practical. Alternatives to posting a sign may be implemented with department concurrence for facilities which are not open to the general public.

2. Within 60 days of ceasing to accept waste, the facility shall be closed in accordance with the approved plan of operation.

Note: Fees for plan review, license and other applicable items are charged in accordance with ch. NR 520. Licenses for facilities regulated under this chapter are transferrable.

(4) Environmental review. The department may require an applicant for an initial license or for approval of expansion of an existing solid waste facility listed in the following pars. (a) to (f) to submit information with the plan of operation report as specified by the department to determine the need for an environmental impact report or environmental impact statement:

(a) Noncontainerized storage facilities.

(b) Transfer facilities.

(c) Processing facilities.

(d) Incinerator facilities.

(e) Composting facilities.

(f) Municipal solid waste combustor facilities.
(5) Environmental monitoring. The department may require the owner or operator of any facility for which a plan is required under this chapter, or any person who permits the use of property for such purposes, to conduct environmental monitoring in accordance with ch. NR 507 and plans approved by the department, including surface water, groundwater, unsaturated zone or gas monitoring. The department may require monitoring after closure of the facility.

(6) Financial responsibility. The department may require the owner or operator of any facility for which a plan is required under this chapter to provide proof of financial responsibility for the cost of closure of the facility. The department may require the owner or operator to submit closure cost estimates for removal, transport and ultimate disposal of the wastes. If proof of financial responsibility is required by the department, it shall be submitted prior to licensing of the facility, or as otherwise specified by the department.

**History:** Cr. *Register, January, 1988, No. 385*, eff. 2-6-88; r. and recr. *Register, June, 1996, No. 486*, eff. 7-1-96; CR 05-020: r. and recr. (1) (a) 4., rn. (2) (c) 1. and 2. to be (2) (c) 1. and r. and recr., renum. (2) (c) 3. to be (2) (c) 2. *Register January 2006 No. 601*, eff. 2-1-06; correction in (1) (a) 6. made under s. 13.92 (4) (b) 7., Stats., *Register March 2017 No. 735*.

**Appendix B**

**NR 502.12  Yard, farm, food residuals and source-separated compostable material composting facilities.**

(1) General. No person may operate or maintain a composting facility for yard residuals, farm crop residue, farm animal manure, animal carcasses, food residuals including vegetable food residuals, or source-separated compostable material except in accordance with the requirements of this section or s. NR 243.15 (8).

**Note:** Pursuant to s. NR 243.15(8), the Department may choose to regulate composting facilities associated with livestock operations that are subject to the requirements of ch. NR 243 under that operation's Wisconsin Pollution Discharge Elimination System permit instead of under s. NR 502.12. Facilities for composting waste types other than yard residuals, farm crop residue, farm animal manure, animal carcasses, food residuals or source-separated compostable materials are regulated under s. NR 502.08. Local ordinances may apply to facilities regulated under this section.
(2) Household exemption. Facilities for composting only source-separated compostable material from a single family or household, a member of which is the owner, occupant or lessee of the property where the facility is located, are exempt from all requirements of this chapter, provided the facility is operated in a nuisance-free and environmentally sound manner.

(3) Limited exemption for source-separated compostable material composting facilities with capacity of 50 cubic yards or less. Facilities for composting source-separated compostable materials that do not exceed 50 cubic yards at one time, including collected raw materials and compost being processed but excluding finished compost, are exempt from the requirements specified in s. NR 502.04 (2) to (6), locational criteria, plan of operation submittal, licensing and all other requirements of this chapter provided the following are met:

(a) The performance standards specified in s. NR 502.04 (1) and the minimum operational standards specified in sub. (10).

(b) The facility is operated in a nuisance-free and environmentally sound manner.

(4) Limited exemption for farm crop residue or manure composting facilities. Facilities for on site composting of farm crop residue or manure, except deer or elk manure, directly from agricultural operations are exempt from the requirements of s. NR 502.04 (2) to (6), locational criteria, plan of operation submittal, licensing and all other requirements of this chapter, provided all of the following requirements are met:

(a) The performance standards in s. NR 502.04 (1).

(b) The facility is operated in a nuisance-free and environmentally sound manner.

(c) All the farm crop residue and manure composted are generated from agricultural operations either under common ownership, common management or located adjacent to each other, and the composting occurs on the property of one of these agricultural operations.

(d) The compost is utilized for agricultural landspreading, at the same farm or at another farm, in accordance with s. NR 518.04 (1) (b) or (i).

(e) Source-separated compostable material other than farm crop residue and manure may be accepted from off site for use in the composting process if the following requirements are met:
1. The locational criteria in sub. (8), unless the offsite material consists exclusively of yard material, clean chipped wood, or both.

2. The minimum operational and design standards in subs. (10) and (11).

3. The recordkeeping requirements of sub. (15) (a) 3. and the discharge inspection requirements in sub. (15) (a) 4.

4. The combined volume of farm crop residue, farm animal manure, and source-separated compostable material on site at one time may not exceed 10,000 cubic yards, including collected raw materials and compost being processed but excluding finished compost. The volume of food residual inputs to the composting process may not exceed 25 percent of the total combined volume of raw material inputs. Inputs shall be mixed to achieve an initial carbon to nitrogen ratio of at least 20 to 1.

**Note:** Composting facilities that accept manure or are located at a livestock operation may be subject to additional state requirements in chs. NR 151 and 243 and in ch. ATCP 51, as well as local regulations for manure storage and shoreland and floodplain zoning. Public distribution of the compost may be regulated by the department of agriculture, trade and consumer protection (DATCP). Other local ordinances may apply to facilities regulated under this section. The following landspreading operations are exempt under s. NR 518.04 (1) (b), (h) and (i), respectively, provided the material is applied as a soil conditioner or fertilizer in accordance with accepted agricultural practices and the facility is operated and maintained in a safe, nuisance-free manner:

- Farms on which only nonhazardous agricultural residuals resulting from the operation of a farm, including farm animal manure, are landspread.

- Landspreading of uncomposted yard residuals.

- Landspreading of composted source-separated compostable material.

(5) Limited exemption for on site farm animal carcass composting facilities. Facilities for on site farm composting of animal carcasses other than deer or elk are exempt from the requirements in s. NR 502.04 (2) to (6), locational criteria, plan of operation submittal, licensing and all other
requirements of this section, provided they are in compliance with s. 95.50 (1), Stats., and all of the following:

(a) The performance standards in s. NR 502.04 (1).

(b) The minimum operational and design standards in subs. (10) and (11), excluding the size reduction requirements in sub. (10) (c).

(c) Only animal carcasses, farm animal manure, farm crop residue, yard residuals and clean chipped wood are composted at the facility.

(d) All the farm wastes composted are generated from agricultural operations either under common ownership, common management or located adjacent to each other, and the composting occurs on the property of one of these agricultural operations.

(e) The compost is utilized for agricultural landspreading, at the same farm or at another farm, in accordance with s. NR 518.04 (1) (b) or (i), except that compost made using ruminant animal carcasses may not be utilized at another farm.

(f) If yard residuals or clean chipped wood are accepted from off site, the following requirements shall be met:

1. The yard residuals or clean chipped wood shall be mixed with farm wastes to increase the carbon to nitrogen ratio and porosity of the composting process.

2. The combined volume of animal carcasses, farm animal manure, farm crop residue, yard residuals and clean chipped wood on site at one time may not exceed 10,000 cubic yards, including collected raw materials and compost being processed but excluding finished compost.

6. Limited exemption for yard residuals composting facilities. Facilities for composting yard residuals and clean chipped wood that do not exceed 20,000 cubic yards at one time, including raw materials and compost being processed, but excluding finished compost, are exempt from the requirements in s. NR 502.04 (3) (c), (4), (5), and (6), plan of operation submittal and all other requirements of this chapter, provided all of the following requirements are met:

(a) The performance standards and closure requirements in s. NR 502.04 (1) and (3) (a) and (b).
(b) For new or expanded facilities, compliance with the locational criteria in sub. (8). New or expanded facilities with a capacity greater than 1,000 cubic yards shall comply with the initial site inspection requirements in s. NR 502.04 (2).

(c) The minimum operational and design standards in subs. (10) and (11), the recordkeeping requirements of sub. (15) (a) 3., the discharge inspection requirements in sub. (15) (a) 4., and the reporting requirements in sub. (15) (b).

(d) An operating license for the facility is issued by the department.

(e) The compost is applied to land, either on site or off site, in accordance with s. NR 518.04 (1) (i), or is otherwise used for horticultural, landscaping, or erosion control purposes.

(7) Limited exemption for source-separated compostable material composting facilities of 5,000 cubic yards or less. Facilities for composting source-separated compostable material that exceed 50 cubic yards but do not exceed 5,000 cubic yards at one time, including raw materials and compost being processed, but excluding finished compost, are exempt from the requirements in s. NR 502.04 (3) (c), (4), and (5) and subs. (12) and (14), and the monitoring requirements of sub. (15) (a) 1. and 2., provided all of the following requirements are met:

(a) The performance standards and closure requirements in s. NR 502.04 (1) and (3) (a) and (b).

(b) For new or expanded facilities, the initial site inspection requirements in s. NR 502.04 (2) and the locational criteria in sub. (8).

(c) The minimum operational and design standards in subs. (10) and (11), the plan submittal requirements in sub. (13), the recordkeeping requirements of sub. (15) (a) 3., the discharge inspection requirements in sub. (15) (a) 4., and the reporting requirements in sub. (15) (b).

(d) An operating license for the facility is issued by the department.

(e) For facilities that use animal manure as a raw material, the testing requirements of sub. (15) (a) 1.

(f) The compost is utilized for landspreading applied to land, either on site or off site, in accordance with s. NR 518.04 (1) (i), or is otherwise used for horticultural, landscaping, or erosion control purposes.
(8) Locational criteria for composting facilities.

(a) Unless exempt under sub. (2), (3), (4), or (5) from compliance with locational criteria, new or expanded compost facilities regulated under this section may not be located in any of the following areas unless an exemption has been granted in writing by the department under par. (c):

1. Within a floodplain.

2. Within 5 feet of the seasonal high groundwater table.

3. Within 250 feet of any private water supply well, or within 1,200 feet of any public water supply well.

4. Within 250 feet of any navigable river or stream.

5. Within 1,000 feet of the nearest edge of the right-of-way of any state trunk highway, interstate or federal aid primary highway or the boundary of any public park or state natural area under ss. 23.27 (1) and 23.28 (1), Stats., unless the facility is screened by natural objects, plantings, fences or other appropriate means so that it is not visible from the highway, park or state natural area.

6. Within 10,000 feet of any airport runway used or planned to be used by turbojet aircraft or within 5,000 feet of any airport runway used only by piston type aircraft or within other areas where a substantial bird hazard to aircraft would be created. This criterion is applicable only when the facility will be used for handling putrescible waste.

(b) In addition to the restrictions in par. (a):

1. Facilities exempt under sub. (6) or (7) may not be located within 250 feet of any navigable lake, pond, or flowage, or within 100 feet of land owned by a person other than the owner or operator of the facility.

2. Facilities not exempt under sub. (2), (3), (4), (5), (6), or (7) may not be located within 500 feet of any navigable lake, pond, or flowage, or within 250 feet of land owned by a person other than the owner or operator of the facility.
(c) The department may grant exemptions from par. (a) 2. to 6. only upon demonstration by the applicant of circumstances which warrant the exemption. Exemption from compliance with par. (a) 1. may not be granted.

**Note:** Compost facilities associated with livestock operations that are required to have a wastewater discharge permit under the Wisconsin Pollution Discharge Elimination System and that handle manure, animal feed or other agricultural materials may be subject to additional locational requirements in chs. NR 151, NR 243 or ATCP 51.

(10) Minimum operational standards for composting facilities. Unless exempt under sub. (2) or (4), no person may operate or maintain a composting facility regulated under this section except in accordance with the following minimum operational requirements:

(a) Raw materials accepted for composting shall be source separated at the point of generation so that they have not been mixed or otherwise contaminated with nonapproved waste types, particularly materials which are not readily compostable. Prior to incorporation into the composting process, the raw materials shall be sorted as needed to ensure that materials which are not readily compostable are removed unless alternate operational methods are used in conjunction with equipment to produce a compost product virtually free of physical and chemical contaminants.

**Note:** Compost product which contains physical or chemical contaminants such as plastic, glass, metal scraps or regulated concentrations of heavy metals or organic compounds, may require controlled disposal under an approved landspreading plan or at a landfill.

(b) Raw materials in noncompostable bags shall be debagged within 24 hours of receipt at the facility. Raw materials, other than leaves and brush, in compostable bags shall be processed such that the contents of the bags are exposed to air within 24 hours of receipt at the facility. Stored waste shall be managed in accordance with the requirements applicable to the composting process. The following operational standards shall also be met for the wastes specified:

1. Grass clippings and food residuals from canned, frozen or preserved fruit or vegetable processing operations shall be incorporated into windrows or another composting process within 72 hours of receipt at the facility, unless odor becomes a problem at the facility in which case these materials shall be incorporated within 24 hours.
2. Animal carcasses, fish harvesting and processing residuals, manure and food residuals which are not from canned, frozen or preserved fruit or vegetable processing operations shall be incorporated into windrows or another composting process on the same operating day as received at the facility. Upon initial incorporation of these residuals, composting windrows or piles shall be covered with a minimum 6 inch layer of compost, high carbon material such as wood chips, or other suitable material to control odor and vectors.

3. All animal carcasses and food residuals shall be managed to prevent access by dogs and wild animals.

(c) Compost raw materials shall be size reduced if necessary to provide adequate particle surface area for effective composting.

(d) Materials within the composting process shall be thoroughly mixed as appropriate to the composting method and aerated as frequently as necessary. Windrow height, structure and porosity shall be designed and maintained to ensure that adequate oxygen is available at all times within the windrow or pile to prevent the process from becoming anaerobic.

Note: To maintain aerobic composting and prevent odor, aeration is needed whenever the process temperature rises to 150°F or more. Windrows consisting primarily of leaves and wood waste are likely to require turning at least monthly from spring through fall.

(e) Materials shall be mixed into the composting process to provide a minimum initial carbon to nitrogen ratio of 20:1.

Note: For aerobic composting, the optimum carbon to nitrogen ratio ranges from approximately 20:1 to 40:1.

(f) Maximum windrow size and minimum windrow spacing shall match the capability and requirements of the equipment utilized at the facility.

(g) Material within the composting process shall be wetted as needed to control dust and maintain a moisture content conducive to efficient composting.

Note: For aerobic composting, the optimum moisture content is 50 to 60% by weight.

(h) Materials resulting from composting shall be:
1. Stabilized to reduce pathogenic organisms and to ensure that the materials do not reheat upon standing.

2. Free of sharp particles which could cause injury to persons handling the material.

3. Free of toxins and pathogens in amounts or concentrations that could cause detrimental impacts to public health or the environment.

**Note:** Pathogens are defined in ch. NR 204 as “disease causing organisms, including but not limited to certain bacteria, protozoa, viruses and viable helminth ova.” Appropriate methods for pathogen reduction during composting are specified in 40 CFR, Part 257, Appendix II, Section B:

1. For in-vessel or static aerated pile composting, maintain a continuous minimum temperature of 55°C, or 131°F, for a minimum of 3 consecutive days.

2. For windrow composting, attain a minimum temperature of 55°C, or 131°F, on a minimum of 15 days, which are not required to be consecutive, and turn the windrow a minimum of 5 times during the high temperature periods.

(i) Compost product storage time shall be minimized to maintain the quality of the compost and the product shall be marketed as necessary to prevent excessive stockpiling.

(j) The facility shall be operated in a nuisance-free and environmentally sound manner.

**Note:** Landspreading of composted leaves, grass, brush and other source-separated compostable material is exempt from department landspreading regulations under s. NR 518.04 (1) provided the material is applied as a soil conditioner or fertilizer in accordance with accepted agricultural practices and the facility is operated and maintained in a safe, nuisance-free manner. Public distribution of the compost may be regulated by the department of agriculture, trade and consumer protection (DATCP).

(11) Minimum design standards for composting facilities. Unless exempt under sub. (2) or (3), no person may construct or maintain a composting facility regulated under this section except in accordance with the following minimum design standards:
(a) Run-off from the composting area shall be discharged to a gently sloping vegetated area of sufficient size to prevent erosion and any discernible confined and discrete discharge of liquids or suspended solids to surface water or wetlands from the composting area.

(b) Slope, vegetation and surface water containment ditches, retention basins, compost berms or socks and other best management practices shall be used at the facility as needed to minimize erosion, prevent pollutant discharges from storm water runoff and maintain diffused surface drainage.

(c) Composting shall take place on an area sloped sufficiently to prevent ponding, and measures such as berms or ditches shall be used to prevent storm water run-on.

(d) If inspections performed under sub. (15) (a) 4. indicate improvements in storm water controls are needed to meet the requirements of pars. (a) through (c), the owner and operator of the facility shall make the needed improvements as soon as practicable and update the storm water pollution prevention plan, if applicable.

Note: Under ch. NR 216, new or expanding facilities with one acre or more of land disturbance are required to obtain a construction site storm water permit. In addition, the department may require a composting facility to obtain an industrial storm water discharge permit if it does not maintain compliance with a separate department permit or approval which includes storm water control requirements that are at least as stringent as those required under ch. NR 216, resulting in the discharge of pollutants to waters of the state or constituting a significant contribution of pollutants to the waters of the state.

(e) The overall composting facility shall be of sufficient size to allow processing of materials as necessary to avoid nuisance conditions, and shall have adequate room for material stockpiles, windrows of manageable dimensions for maintaining aerobic conditions, curing piles, staging of finished compost, and equipment.

Note: Composting facilities that accept manure or are located at a livestock operation may be subject to additional state requirements in chs. NR 151 and 243 and in ATCP 51, as well as local regulations for manure storage and shoreland and floodplain zoning. Other local ordinances may apply to facilities regulated under this section.
(12) Additional operational and design standards for nonexempt composting facilities. Unless exempt under sub. (2), (3), (4), (5), (6), or (7), new or expanded composting facilities regulated under this section shall comply with the following additional operational and design standards:

(a) All run-off that contacts materials being composted or raw materials staged for composting shall be managed as leachate and shall be directed to either a collection basin or a tank. Leachate may be used in the composting operation for moisture addition. All other leachate shall be treated at an onsite or offsite wastewater treatment facility permitted to accept it.

(b) All composting, and all storage of uncomposted raw materials other than leaves, clean chipped wood, clean sawdust and other raw materials with initial carbon to nitrogen ratios greater than 30:1 shall take place on a low-permeability pad constructed of asphalt, concrete, recompacted clay or other material approved by the department.

(c) At a minimum, the leachate collection capacity shall be designed for a 25 year, 24 hour storm event as defined in s. NR 205.05.

(13) Plan submittal requirements for nonexempt and certain exempt composting facilities. Unless the facility is exempt under sub. (2), (3), (4), (5), or (6), applicants for all new or expanded composting facilities regulated under this section shall submit a plan of operation report and obtain department approval of the plan of operation report prior to construction of the new or expanded facility. Unless an exemption is granted by the department in writing, the plan shall be submitted in accordance with s. NR 500.05, except that facilities exempt under sub. (7) need not comply with s. NR 500.05 (4). The plan shall provide a design which complies with subs. (10) and (11) and, as applicable, sub. (12), and contain the following minimum information:

(a) The location of the property where the facility is proposed to be located.

(b) A brief description of the project, including the area served, an estimate of the annual tonnage and volume of material to be processed and identification of the materials to be used in the compost process.

(c) A description and drawing of the proposed facility, including location and size of windrows, or other composting process, on site traffic and process flow, the property boundaries, routes to
transport feedstocks and finished compost to and from the facility and present land use within 1/4 mile of the facility.

(d) A description of the procedures for processing the material prior to incorporation into the windrow, or other composting process, such as de-bagging or size reduction.

(e) For each raw material proposed to be composted, either laboratory or literature data documenting the carbon, nitrogen, and moisture content and pH.

(f) A proposed raw material mix for composting, with calculations or laboratory data documenting the carbon, nitrogen, and moisture content and pH of the mix.

(g) A specification of the maximum size, including volume, height and width, for staging piles, composting windrows or other composting processes, curing piles, and finished compost storage. If the materials on site at any one time will exceed 40,000 cubic yards of yard residuals and clean chipped wood, 10,000 cubic yards of source-separated compostable materials other than yard residuals and clean chipped wood, or 5,000 cubic yards of food residuals, an estimate of closure costs shall be provided with the plan of operation report, and prior to licensure, proof of financial responsibility in accordance with ss. NR 520.06 through 520.13 shall be provided for the closure costs, including the removal, transport and ultimate disposal of all waste material and compost at the site.

(h) A specification of the methods of measuring critical parameters within the windrow and other composting processes, and a description of methods that will be used to ensure the critical parameters are met. Critical parameters addressed shall include carbon to nitrogen ratio, temperature, moisture content, oxygen content, pH and stability. The specification shall describe methods to be used for maintaining aerobic conditions during the composting process, including turning equipment and frequency for passive ventilation, and equipment and residence time for mechanical ventilation, as well as actions to be taken in response to odors and composting process upsets.

(i) A description of the type of vehicles used for transporting feedstocks and finished compost to and from the facility, and a description of the type of equipment for turning or mixing and screening.
(j) A discussion of potential markets for the compost and material specifications necessary to be met for these markets, such as nutrient content, pH, particle size, appearance, moisture holding capacity or other pertinent specifications.

(k) Identification of any noncompostable waste, such as bags, which will be generated from the composting operation, and the name and location of solid waste disposal facilities at which any waste generated from the composting operation will be disposed of.

(L) Specification of the design, construction and documentation to be used for the low permeability pad, including materials, thicknesses and testing.

(m) A description of the planned sampling frequency and testing parameters for the finished compost.

(n) A storm water pollution prevention plan that meets the requirements of s. NR 216.27.

(o) Identification of local zoning and permit requirements that apply to the proposed facility.

Note: Under ch. NR 216, new or expanding facilities with one acre or more of land disturbance are required to obtain a construction site storm water permit.

(p) Proposed procedures for amending the plan in the event changes to the approved plan are needed.

(14) Construction documentation for nonexempt composting facilities.

(a) For facilities other than those exempt under sub. (2), (3), (4), (5), (6), or (7), the department may require owners and operators of new or expanded composting facilities regulated under this section to submit a construction documentation report to the department and obtain department approval of the construction documentation report prior to operation of the facility.

(b) Unless an exemption is granted by the department in writing, the construction documentation report shall be prepared in accordance with the department's plan approval and the requirements in s. NR 500.05. The construction documentation report shall be approved by the department prior to obtaining a license and prior to accepting waste at the facility.

(15) Monitoring, recordkeeping and reporting.
(a) Unless exempt under sub. (2), (3), (4), (5), (6), or (7), owners and operators of composting facilities regulated under this section shall complete monitoring and reporting in accordance with the plan of operation approval and the following requirements:

1. Samples of the finished compost that is ready for sale, distribution or use shall be collected every 2,000 tons or 4,000 cubic yards, with a minimum of one sample per year, or, alternatively, in accordance with the testing frequency specified by the United States Composting Council's Seal of Testing Assurance program, unless a different frequency is approved in writing by the department, and tested for the parameters in Tables 1 and 2.

Note: Only class A compost under sub. NR 502.12 (16) is subject to the limits in Tables 1 and 2. “Test Methods for Evaluation of Compost and Composting” (2002) and a list of laboratories certified under the Seal of Testing Assurance program are available from the United States Composting Council, 5400 Grosvenor Lane, Bethesda, Md 20814 (301) 897-2715, www.compostingcouncil.org.

a. Samples shall be collected, handled and analyzed in accordance with methods listed in “Test Methods for Evaluation of Compost and Composting” published in 2002 by the United States Composting Council or other methods approved in writing by the department. Samples shall be tested at a laboratory certified under the United States Composting Council's Seal of Testing Assurance program or at another laboratory approved in writing by the department.


b. Test results shall be made available upon request to the department, potential users of the compost, and to the general public.

2. Unfiltered leachate samples shall be taken from the collection basin or tank, and tested quarterly for the first 4 quarters and annually thereafter for BOD5, COD, field pH, field conductivity corrected to 25°C, nitrate-nitrite-nitrogen, and total dissolved solids.
3. Compost pile turning frequency and temperature readings as appropriate to the composting method used shall be documented and maintained to demonstrate pathogen reduction and odor control activities.

4. The facility shall be visually inspected by the owner or operator quarterly to evaluate storm water discharge quality and performance of discharge controls, and twice per year to identify non-storm water discharges if present.

(b) Unless exempt under sub. (2), (3), (4), or (5), the owner or operator of a composting facility regulated under this section shall prepare and submit an annual report to the department by March 1 on forms supplied by the department. The annual report shall include at least the following information:

1. Name and address of the facility.

2. Calendar year covered by the report.

3. Annual quantities and types of raw materials received and compost produced, in tons. Tonnage estimates may be based on volume records where scale weights are not available.

4. Annual quantity of compost sold, distributed or used, in tons, and quantity of class A compost sold, distributed or used.

5. Copies of laboratory analyses of composted material.

6. Any additional information required as a condition of the plan of operation approval.

Note: Copies of the annual reporting form may be obtained from the department of natural resources, bureau of waste and materials management, 101 South Webster Street, P.O. Box 7921, Madison, Wisconsin 53707-7921, (608) 266-2111, DNRwastematerials@wisconsin.gov, or online at http://dnr.wi.gov/topic/Recycling/regs.html.

(16) Class A compost. Finished compost may be designated and distributed as class A compost if it meets all of the following requirements:

(a) The compost is composed entirely of materials meeting the definition of “source-separated compostable materials” in s. NR 500.03 (219m).
(b) The compost is produced by one of the processes to reduce pathogens described in subd. 1. to 3., with temperature and retention time monitored and recorded each day until the temperature and retention time criteria are met:

1. Windrow method consisting of an unconfined composting process utilizing periodic aeration and mixing. Aerobic conditions shall be maintained during the composting process. A temperature of 55°C, or 131°F, shall be maintained in the windrow for at least fifteen days. The windrow shall be turned at least five times during the high-temperature period.

2. Mechanically aerated static pile method consisting of an unconfined composting process utilizing mechanically forced aeration of insulated compost piles. Aerobic conditions shall be maintained during the composting process. The temperature of the compost pile shall be maintained at a continuous minimum of 55°C, or 131°F, for at least three consecutive days.

3. In-vessel method consisting of a confined compost process utilizing mechanical mixing of compost under controlled conditions. The minimum retention time in the vessel shall be 72 hours with the temperature maintained at 55°C, or 131 °F.

(c) The compost is tested in accordance with sub. (15) (a) 1. a. and b.

(d) The compost does not exceed any of the limits specified in Tables 1 or 2.

Table 1.
Test parameters for nonexempt compost facilities and class A compost - See PDF for table

Table 2.
Maturity and stability testing for nonexempt facilities and class A compost - See PDF for table

History: Cr. Register, January, 1988, No. 385, eff. 2-1-88; r. and recr., Register, June, 1996, No. 486, eff. 7-1-96; CR 05-020: am. (8) (a) 7. and (9) (a) 7. Register January 2006 No. 601, eff. 2-1-06; CR 10-128: am. (title), (1) (intro.), r. (1) (a) to (f), am. (2), (3) (title), (intro.), (a), (4) (title), (intro.), (c), (e) (intro.), r. and recr. (4) (e) 1. to 3., cr. (4) (e) 4., am. (5) (title), (intro.), (b), (c), (d), (e), (f) (intro.), 1., 2., (6) (title), (intro.), (b), (c), (e), (7) (title), (intro.), (a), (b), (c), r. and recr. (7) (e), (f), am. (8) (title), (a) (intro.), r. (8) (a) 4., 6., renum. (8) (a) 5., 7., 8. to be 4., 5., 6.,
r. and recr. (8) (b), cr. (8) (c), r. (9), am. (10) (intro.), (a) to (e), (h) 1., 3., (11) (intro.), (a), (b), r. and recr. (11) (d), cr. (11) (e), am. (12) (a), (b), (13) (title), (intro.), (b), (e), (f), (g), (h), (k), cr. (13) (m), (n), (o), (p), am. (14) (a), r. and recr. (15), cr. (16), r. and recr. Table 1 and Table 2 Register May 2012 No. 677, eff. 6-1-12; correction in (13) made under s. 13.92 (4) (b) 7., Stats., Register July 2015 No. 715.

Appendix C

R 243.15 Design, submittal and approval of proposed facilities or systems.

(8) COMPOSTING FACILITIES. The department shall determine if the design and operation of a manure or animal carcass composting facility that is part of the production area is more appropriately approved under this section or ch. NR 502. This determination shall be based on factors such as the type of materials mixed with the manure or animal carcass and the amount and source of the materials, the method of composting and the characteristics of the final composted material. If the department determines that design and operation requirements for a composting facility are appropriately reviewed and approved under this section, the department may still apply additional design and operation requirements contained in ch. NR 502 as needed to protect water quality and shall apply additional design and operation requirements as needed to meet the requirements in ss. NR 243.13 and 243.14 (9).
Pepin County Dairy Manure: The Economic, Social, and Environmental Impacts of Composting

Client: Pepin County
Team Members: 
Course: CEE 421 - Environmental Sustainability Engineering
Instructor: Professor Andrea Hicks
Date: December 10, 2019
Table of Contents

Table of Contents 1
List of Tables 3
List of Figures 4
List of Abbreviations 5
1. Introduction 7
  1.1 Regulations 9
  1.2 Design Parameters 9
2. Background on Impacts on the Sustainability Paradigm 11
  2.1 Social Impacts 11
    2.1.1 Human health 11
    2.1.2 Complaints 12
  2.2 Economic Impacts 12
  2.3 Environmental Impacts 13
    2.3.1 Water resources 14
    2.3.2 Air pollution 15
    2.3.3 Greenhouse Gases (GHGs) 15
    2.3.4 Soil quality 16
3. Questions and Scope 16
  3.1 Guiding Questions 17
  3.2 Proposed Scope 17
4. Methods of Analysis 17
  4.1 Life Cycle Assessment 17
    4.1.1 Goal and Scope Definition 18
    4.1.2 Inventory 20
    4.1.3 Impact Assessment 20
    4.1.4 Interpretation 20
  4.2 Net Present Value Analysis 22
  4.3 Social Impact Analysis 23
5. Life Cycle Assessment 24
  5.1 Goal and Scope 24
5.2 Inventory

5.2.1 Current Manure Management Method

5.2.2 Composting Method

5.2.2.1 Carbon and Nitrogen

5.2.2.2 Moisture Content

5.2.2.3 Temperature

5.2.2.4 Cleaning

5.2.2.5 Method of Compost Sitting and Turning

5.2.2.6 Composting Land Selection

5.2.2.7 Emissions

5.3 Impact Assessment

5.3.1 Current Method

5.3.2 Concrete Pad

5.3.3 Cleaning Water

5.3.4 Fuel

5.3.5 Organic Matter

5.4 Environmental Impact Results

6. Economic Impact Assessment

6.1 Composting System

6.1.1 Concrete

6.1.2 Cleaning Water

6.1.3 Fuel

6.1.4 Organic Waste

6.1.5 Windrow Turner

7. Social Impact Assessment

7.1 Social impacts of raw manure management

7.2 Social impacts of compost management

8. Conclusion

Project Team Contributions

Works Cited
List of Tables

Table 1. Inputs to be used in the EIO LCA of the current manure management method.
Table 2. Manure Composting inputs. This data will be used in the EIO LCA.
Table 3. The environmental impact of the current method.
Table 4. The environmental impacts of the proposed composting method.
Table 5. The NPC values of composting and current method over a 20 year period.
Table 6. Pathogen species found in raw cattle manure and their associated diseases or symptoms.
List of Figures

**Figure 1.** Imagery of Pepin county’s agricultural soil breakdown. Political Township is a majority of the land in Pepin County, followed by Prime Agricultural Land, Water Bodies, and Incorporated Boundaries (Pepin County Farmland, 2016).

**Figure 2.** Ownership of Pepin County Farms. The majority of farms are owned by individuals or families, at 85.8% or 394 of all farms (Pepin County Farmland, 2016).

**Figure 3.** Net Present Value equation with variables provided. This equation will be used to calculate the economic value of each alternative.

**Figure 4.** A diagram displaying the flow and process of aerobic compost, including both the solid and liquid manure.

**Figure 5.** A windrow turner rotates the compost to allow oxygen to reach the mixture (Division of Waste and Hazardous Substances, 2016).

**Figure 6.** Testing of the GHG found in both active and passive composting found that active composting produced higher emissions (Hao et. al. 2001).

**Figure 7.** The GHG potential of both the composting method and current method.

**Figure 8.** The eutrophication potential of the current method and proposed composting method.

**Figure 9.** Comparing the environmental impacts of each factor in the composting method.

**Figure 10.** The NPC analysis comparing the composting and current method.
List of Abbreviations

C                Carbon
CH4              Methane
CO2              Carbon Dioxide
CO2e             Greenhouse Gas Potential
EIA              Energy Information Administration
EIO              Economic Input Output
EPA              Environmental Protection Agency
ft               Feet
GHG              Greenhouse Gas
gph              Gallons per Hour
kg               Kilograms
kGal             Kilogallon
L                Liters
lbs              Pounds
LCA              Life Cycle Assessment
m                Meters
MMI              Mucous Membrane Irritation
N                Nitrogen
N2O              Nitrous Oxide
Ne               Eutrophication impact
NIMBY            Not In My Back Yard
NO3-N            Nitrate Nitrogen
NPDES            National Pollutant Discharge Elimination System
NPK              Nitrogen-Phosphorus-Potassium
NPC              Net Present Cost
NPV              Net Present Value
<table>
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<tr>
<th>Abbreviation</th>
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</thead>
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<tr>
<td>ppm</td>
<td>Parts per million</td>
</tr>
<tr>
<td>R</td>
<td>Discount Rate (Time Value of Money)</td>
</tr>
<tr>
<td>T</td>
<td>Time Period</td>
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1. Introduction

Pepin County, is a small county located on the Western side of Wisconsin (WorldAtlas, 2019). As of the 2010 census, the county has a population of only 7,469 people (Quick Facts, 2010). This makes the county the 4th smallest county in Wisconsin, ahead of the smallest county, Menominee County, by 3,337 people (Wisconsin Census, 2000). Although Pepin County is miniscule compared to other counties, the population is rising much faster than other areas (Wisconsin Census, 2000). In 2017, the fertility rate was determined to be about 79.5 births per 1000 women (Wisconsin Census, 2000). This makes Pepin County the fifth highest fertility rate out of all Wisconsin counties, with no slowing down in site (Wisconsin Census, 2000). The population density of Pepin County is 31.1 people per square mile, which is well below the average population density in Wisconsin of 98.8 people per square mile (Wisconsin Census, 2000). With the area being low on population density, farms have begun to take over for agriculture (Wisconsin Census, 2000). According to the Pepin County Comprehensive Plan, farmland has become so prominent that over 89% of all land in Pepin County is used for agriculture (Pepin County Farmland, 2016). An image depicting the proportion of agricultural land in Pepin County is displayed in Figure 1.
Although the number of farms was estimated to increase from year to year, the opposite has occurred. The number of farms in Pepin County decreased from 501 in 2002, to 459 in 2012 (Lupac, 2016). A possible reason for the decrease is larger companies buying out the farmland. This assumption is supported by the market value of production of crops and livestock increasing by 34.8% from 2002 to 2012. The size of farmland has also increased by four acres in the same time period (Pepin County Farmland, 2016). Another interesting development with the agricultural lands is the reduced use of pastureland for animals. Pasture lands from 2002-2012 decreased by 26.6%, while the land in farmsteads (ponds, roads, facilities) increased by 47.9%. This suggests farmers in the area are moving towards a more industrialized approach, compared to the traditional methods. The main income from Pepin County farmland has come from the production of crops such as oats, soybeans, corn, and hay alfalfa (Lupac, 2016). Of these crops, soybean production has increased the most (almost 17% from 2009 to 2010). However, not just the crops have brought income in for Pepin County. The value of the farmland has dramatically increased year to year. From 2000 to 2013 the dollars per acre of agricultural land increased by 37.6%, to 4,209 dollars (Pepin County Farmland, 2016). By 2014, farming generated about $170 million in economic activity and provided over 1,000 jobs to the region (Pepin, 2014). The profit of farming in enticing to large corporations and companies, but farming lifestyle sticks with many families. The ownership of Pepin County farms is shown in Figure 2.
Figure 2. Ownership of Pepin County Farms. The majority of farms are owned by individuals or families, at 85.8% or 394 of all farms (Pepin County Farmland, 2016).

As an increasing number of Pepin County citizens turn to farming for income, efficiency of the farms is necessary. With farming, also comes several regulations that must be sustained.

1.1 Regulations

While farming continues to be a rising economic and social lifestyle in Pepin County, regulations must be upheld to continue work. The Environmental Protection Agency or EPA has regulations for farmlands that include aquaculture, chemical handling, and air emissions (Laws and Regulations, 2015).

The EPA covers pollution to water with a permit labeled the NPDES or National Pollutant Discharge Elimination System. When the Clean Water Act was implemented, it prohibited companies and people from discharging pollutants or chemicals into United States water (NPDES Permit, 2015). The NPDES permit however, tailors the discharging of material to each person or location. The permit specifies the level of the pollutant that is found in the discharge, regarding the toxicity and harmfulness to the environment.

This permit also applies to the pesticides used for crop enhancement. The permit relies on the location of the application and to what extent the application is performed. A license is necessary for use of pesticides on commercial crops and an annual license under section 94.703 of the Wisconsin State Legislation is $70 (Wisconsin Legislature, 2019).

1.2 Design Parameters

Farms can vary in their design parameters, depending on the location, owners, and size. The farm of interest in Pepin County has two facilities, one holding 500 animals and the other holding 1000 animals. From the 500 animal facility, 200 are lactating cows, 20 are dry cows, 170 are heifers (young female cows), and 45 calves. The 1000 animal facility is double all of the previous animal numbers. The farm is spacious with a total of 1,000 acres of land. The land is
divided up with 200 acres designated for alfalfa, 50 acres for new alfalfa seeding, 250 acres for corn silage, and 500 acres of corn for grain use. Of the 1,000 acres, 75% of the land has manure applied, intended to be fertilizer. However, all 1,000 acres are able to have compost applied to the land for crop growth. The current estimated generation of manure from the 500 animal farm is three million gallons of liquid manure per year. The nutrients of the liquid manure is done through a nutrient analysis. A NPK value describes the mass percentage of each element that the soil desires (Soil Nutrient Analysis, 2019). The NPK ratio of the liquid manure is 8.6-4.6-20.7. Of the three million gallons of manure, 5% or 150,000 gallons are dry matter. After 72 hours of application the liquid manure is then incorporated. The solid manure per year generated is 1,700 tons, and has an NPK ratio of 3-3-6. The dry matter of the solid manure is about 33%. The soil around and under the farm is Finchford loamy sand and has an average slope ranging from two to six percent. The pH of the soil is 6.7, with 2.6% of the soil being comprised of organic matter. The phosphorus of the soil is 50 parts per million (ppm) or 100 pounds per acre (lbs/acre). The potassium found in the soil was 120 ppm or 240 lbs/acre. The water table under the farm is 40 feet from the surface.

The farm has a yield goal for soilage of 25 tons/acre and recommends the NPK ratio to equate to 140-50-115. In comparison, the grain on the land is 190 bushel/acre and has an assumed NPK ratio of 140-40-0. In addition to doubling the animal numbers, the 1,000 animal farm also doubles the values of liquid and solid manure, and soil information from the 500 animal farm. In order to meet the WPDES permit standards and follow the regulations for a Wisconsin farm, the Pepin County farm is a zero discharge facility. Pepin county requests a feasibility analysis for composting on the 1,000 animal farm if it had the same acres as the 500 animal farm, and an analysis for the land if the acres were double the 500 animal farm. The farm in Pepin county is looking for a composting design that will ideally create business for the farm, while benefiting the environment.

One way that businesses create an economical and environmentally friendly design is through a Life Cycle Assessment or LCA. An LCA’s main purpose is to show how an action or object impacts the world in an environmental context (Complete Beginner’s, 2019). Multiple factors such as raw materials and production, go into determining the environmental impact of
the design (Complete Beginner’s, 2019). Almost everyone benefits from utilizing an LCA, but it is most commonly used in “product development and research development, supply chain management and procurement, marketing and sales, and executive level and strategic management” (Complete Beginner’s, 2019). An LCA is a technique that enables Pepin County to move forward on their project aspirations.

2. Background on Impacts on the Sustainability Paradigm

Manure composting and direct manure application to land are the practices that have the potential to cause many problems to the sustainability paradigm – society, economics, and environment – in each step. Therefore, the actual and potential impacts of each practice must be fully understood prior to the final decisions. In this section, potential impacts of uncomposted manure and manure compost management will be discussed and compared.

2.1 Social Impacts

NIMBY, an acronym for “Not In My Back Yard,” is an example of social aspects that one might have heard when considering the social impacts of some practices on their communities. Even though people have positive attitudes towards using animal excreta and compost as greener fertilizers, it is undeniable that these opinions might be changed when these practices are adopted in their neighborhoods due to smell and several pathogens in both animal dung and compost piles that may have the potential to affect human health and other outdoor activities in their daily routines.

2.1.1 Human health

Livestock waste contains a wide variety of bacteria, viruses, and protozoa, associated with several diseases and symptoms in animals and humans. The levels and types of pathogens vary with types of animals, food sources, ages of the animals, characteristics of manure, and manure storage practices. These factors control the lifetime and the spreading pattern of the pathogens. By applying raw manure directly to land farms, risks of being exposed to pathogens
in manure are increased, especially occupational risks to the workers. (Brooks et al., 2012) Although these risks are short-term, it is important to address this issue properly.

Unfortunately, shifting manure management from raw manure application to compost application does not eliminate risks on human health. Even though more than 99% of pathogens can be killed off by heat built up inside the compost piles (Larney et al., 2003; Albrecht et al., 2006; Manyi-Loh et al., 2016), several studies have reported health concerns and complaints. Therefore, risks of manure compost must be assessed prior to the final decision to prevent adverse health impacts on people in neighborhoods, although the application of compost to farmlands may receive lots of great reputations.

2.1.2 Complaints

Dust, odor, and potentials to contaminate water reservoirs in the neighborhoods are the major problems for either direct manure application or manure composting. Some articles (e.g., Porter, 3009) reported complaints from people living near a dairy farm about unbearable odor and dust from the manure piles, as well as worries about wastewater seeping into the neighbors’ lands and creeks.

Similar problems are found with the manure composting. The compost piles generate odors in the forms of ammonia and hydrogen sulfide. (Farm Safety Association Inc, 2002) There are some articles (e.g. Goldstein and Goldstein, 2005; Phelp, 2017) reported that odor management in composting facilities had become a concern to neighborhoods near the plants in many regions.

2.2 Economic Impacts

Manure has become one of valuable waste towards crop farmers all over the world as it provides additional nutrients, especially available nitrogen, to soils in their lands at low cost. However, in the perspective of cattle farms’ owners, they might not appreciate these wastes as much as the farmers since there are costs of manure management, such as collection, storage, and application of raw manure, they need to deal with. (O2Compost, n.d.) According to a study by
Bentley and Tranel (2015), their sample farm (188-lactating cow farm with 7000 gallons of liquid manure and 10.4 tons of solid manure) had invested $364.79 in manure storage per cow, and $147.45 in storage equipment. Additionally, they also had to invest up to $120.50 per cow annually for fuel, supplies, and labor. Moreover, the application to farmlands required additional costs up to $185.63 annually for equipment, maintenance, labor, taxes, insurance, and handling costs.

By changing from raw manure application to manure compost application, the investments by the cattle farms’ owners would be changed depends on the technology they decide to use. The system construction can cost from $100 (aerated static pile system) to $50,000 (on-grade or top-down system). Other costs include labor moving and turning the piles, equipment, maintenance, cleaning, and electricity (usually costs $5 to $10 per month). (O2Compost, n.d.) From the information shown herein, the cost of building a compost system seems to be expensive. Fortunately, the market for compost is in high demand. According to Sustainable Conservation (2017), bulk manure compost can be sold at $20 to $40 per ton (transportation and spreading cost not included) in California. Additionally, the cost of transportation and spreading to farmlands for manure compost is usually much cheaper compared to raw manure at the same amount due to different physical properties (e.g. moisture content).

To sum up, both raw manure application and manure composting require investments in system construction, maintenance, equipment, storage, and labors. The costs may vary depending on technology, the size of farms it applied on, and existing equipment available. (Sustainable Conservation, 2017) Therefore, the comparison of the initial cost and the breakeven point between raw manure management and manure composting must be compared prior to the final decision.

2.3 Environmental Impacts

Manure management and compost management are multiple-step processes involving complex interactions between four spheres of the Earth – hydrosphere, geosphere, atmosphere,
and biosphere. As Life Cycle Analysis summarizes social, economic, and environmental impacts of the current practices and pinpoints what steps should be improved to mitigate those impacts, several possible approaches may be suggested. However, one emission control procedure at one step might release other emissions of the same or other compounds at different steps. (Amon et al., 2001) Therefore, it is important to understand and weigh out the possible outcomes and trade-offs of each method prior to the final decision.

2.3.1 Water resources

Maintaining and improving the quantity and quality of water resources is the first priority mentioned in Pepin county land and water resource management plan 2011 – 2020. Poor groundwater quality is the main concern in Pepin county, where residents, businesses, agriculture, and industries rely on groundwater as the only source for drinking water. Similarly, surface water is also important as recreational activities for residents and visitors, and fish and wildlife habitats rely on good quality of surface water resources available in the county. As dairy is a key industry in the county, it is undeniable that there are risks of water quality degradation. Several studies have reported that dairy industries contribute to high levels of pollution (e.g., nitrates, and salts), as well as pathogen contamination, in groundwater. (Sustainable Conservation, 2017) These contaminations are a result of poor manure management or over-application of manure to improve soil nutrients. Basso and Ritchie (2005) investigated NO3-N leaching in soil treated with raw manure, compost, and inorganic fertilizers, and pointed out that, even though manure application may improve soil properties, it also increases the nutrient loading to groundwater and surface water without increasing crop yields. On the other hand, the same study reported a lower rate of nitrate leaching in lands treated with compost. The risk of pathogen contamination in water resources is also decreased when applying compost to lands instead of raw manure. As temperature builds up from the decomposition inside the compost piles, more than 99% of pathogens are killed off (Larney et al., 2003; Albrecht et al., 2006; Manyi-Loh et al., 2016). Therefore, less active pathogens can enter groundwater and surface water.
2.3.2 Air pollution

Air pollution is a risk associated with adverse health and environmental impacts. Ammonia emission is one of the actual air pollution-related problems occurring in manure storage or application. Ammonia is one of the important gases released from these processes. In fact, the storage and the application of manure are responsible for the ammonia emission. An intensive livestock operation, such as dairy, emits ammonia that can be transported far away from the source and can harm the environment in multiple ways (e.g., forming aerosols, ammonia deposition, soil acidification, eutrophication, vegetation damage, and plant biodiversity reduction)(McGinn et al., 2003; Sustainable Conservation, 2017). Another serious emission from manure management operation is volatile organic compounds (VOCs). These compounds can react with nitrogen oxide via photochemical reactions to generate ground-level ozone, resulting in worse air quality and adverse human health effects.

Ammonia emission in compost, unfortunately, seems to be more serious. Many studies reported that the level of ammonia emission in compost is much higher compared to raw manure storage and application. (e.g., Amon et al., 2001) However, the ammonia emission control in composting can be done easier as well. The ammonia emission from compost occurs only in the production; therefore, it is easier to mitigate the emission compared to raw manure that continuously releases ammonia before and after the application to lands.

2.3.3 Greenhouse Gases (GHGs)

Greenhouse gas (GHGs) emission is responsible for global and regional climate change. In the context of the emission from dairy industries, GHGs term usually refers to 3 major gases; methane (CH4), carbon dioxide (CO2), and nitrous oxide (N2O). Data from CARB (2016) reported that dairies were responsible for approximately 45% of the total CH4 emission in California. N2O is also important to impact of GHGs on the environmental aspect as it has a much greater warming potential than CO2 and CH4 even though it shares only a small percentage.
On the other hand, the production and the application of compost can reduce methane and nitrous oxide emissions. Aeration in the production process provides oxygen to the piles resulting in shifting from anaerobic fermentation, which generates methane, to aerobic digestion. Several studies have reported up to 71% reduction compared to a manure static pile, while almost no methane emission was observed after the application to lands. (Sustainable Conservation, 2017)

2.3.4 Soil quality

Better soil quality is a second goal Pepin county aims to achieve as stated in the Land and Water Resource Management Plan 2011-2020. Since agriculture is the backbone of Pepin county, it is important to find a way to improve soil structure without creating other impacts on the environment. Both raw manure and compost provide positive outcomes when being applying to the soils. Several studies have shown that, by adding either raw manure or compost to the farmlands, the soil properties are improved. The benefits of the addition of raw manure and compost to the soils are improved soil structure, better water storage capacity, greater bioactivities, a buffer to toxins, increased water retention, and decreased soil bulk density. (Sustainable Conservation, 2017) These improvements reduce the demand for irrigation, provide more support to root growth, and provide better air and water flows. However, compost has additional strong points compared to raw manure. It also reduces the risk of introducing new weeds or pathogens to crops and animals as up to 99% of pathogens are killed off by heat generated in the compost piles. Furthermore, during the composting processes, nutrients, especially nitrogen, are stabilized by transforming them into organic forms that have lower solubilities. Then, the nutrients are released slowly to the soils. Thus, it reduces the potential to leach into groundwater or surface water.

3. Questions and Scope

The rest of this project proposal will outline the guiding questions and scope of the project and the methods with which the project’s goals will be executed.
3.1 Guiding Questions

This project will be guided by a central question, developed in conjunction with the clients at Pepin County. How can Pepin County dairy farms best use their resources to maximize the positive economic, social, and environmental protection impacts these farms have on the county community?

3.2 Proposed Scope

To answer this question a thorough design alternative proposal and analyzation process will be completed. Two dairy manure management and use alternatives will be proposed and examined, along with an examination of current use practices. These use and management practices will be analyzed based on their economic, environmental, and social impacts. The methods for this three-part analysis will be discussed later in this proposal.

4. Methods of Analysis

This project will analyze the environmental, economic, and social impacts of different resource use and management alternatives in Pepin County. In order to complete this three-part analysis three different methods—one each for the environmental, economic, and social impact—will be used. These methods are each described in detail here.

4.1 Life Cycle Assessment

The environmental impacts of the current and alternative manure use strategies will be identified and analyzed through the completion of Life Cycle Assessments (LCA). Two LCAs will be completed—one the current manure management method and another for the proposed alternative. These LCAs will follow the four stages of a common life cycle assessment. These stages are as follows.
4.1.1 Goal and Scope Definition

The assessment begins with creating specific goals and a focused scope. This phase will answer a few important questions that will guide the rest of the assessment.

· What will be assessed?
  Is this assessment analyzing environmental impacts, or economic value? And what specific type of environmental impact? These questions help establish desired impact categories, which are necessary to narrow the scope of an LCA so it can be realistically completed.

· How much will be assessed?
  Is this assessment showing the effects of using manure to grow 1 ton of grain? Or to grow a season’s worth of soybeans? This question establishes the functional unit which gives the assessment realistic grounding and allows for easier comprehension and comparison.
  This question also leads one to ask for how much time will this system be analyzed? From its creation to disposal—cradle-to-grave? Or from creation until it is ready to be used—cradle-to-gate? This establishes an assessed product lifecycle that will set limits to the LCAs scope.

· What system will be assessed?
  Is this assessment looking at all the dairy farming in Pepin County? Or the impacts of one farm? This question sets system boundaries that inputs will enter and outputs will leave.

· And what will not be assessed?
  Will this assessment look at the impacts of cows creating manure? Will it then look at the impacts of growing and transporting the resources needed to raise that livestock? These assessment limits set how detailed the LCA will be.
For this assessment, the impact categories analyzed will be greenhouse gas emissions and eutrophication potential. Greenhouse gasses are major contributors to climate change and thus an important concern for any current environmental analysis. Eutrophication of water systems is a major regional environmental concern in the upper midwest and one of the most felt consequences of farming’s impact on the environment. A dairy farm’s potential impact and ability to decrease pollution that potentially may reduce eutrophication is another important concern for environmental analysis in this region.

The functional unit used in the study will be 3,000 gallons of liquid manure and 1.7 tons of solid manure. These are 1/1000 of the annual amounts of manure produced at the 500 animal unit farm. It provides a smaller and more manageable number for analyzation purposes while keeping the correct ratio of types of manure produced at the two different sized farms.

The product lifecycle used in this analysis will be cradle-through use. The analysis will consider the environmental impacts of creating these manure management systems along with the impact from using these management methods to process one functional unit’s worth of animal manure.

The system boundaries for this analysis will include manure collection, transportation, storage, and management but exclude land application and any manure-related activities that take place after application. A visual representation of this system boundary is located below:

The assessment limits of this analysis will focus the LCAs on only the manure management process. The assessment will not consider transportation of materials to the farm. It will not consider the impacts of livestock that is not directly manure-related. It will not consider the impact of the treated or raw manure once spread on fields. It will also not consider the impacts of disposal of elements of the manure management system after their useful life.
4.1.2 Inventory

Now the system is defined, desired impact type to be found is stated, boundaries are set, and detail limits are decided. The LCA knows its subject of focus and can begin collecting information about them. The inventory identifies and measures all materials, energy, and emissions that enter and leave the system. This collection and measurement of inputs and outputs creates the qualitative informational base to later determine the system’s environmental impact.

4.1.3 Impact Assessment

Now the system and all of its involved elements and required products and byproducts are identified. By evaluating the impact of each individual element, product, and byproduct the impact of the whole system can be assessed.

This phase takes each individual material, energy usage, and emissions needed to create one functional unit. It will then take these identified data points and find the monetary value of each item. This information will then be plugged into Carnegie Mellon’s Economic Input Output Life Cycle Assessment (EIO LCA) tool.

The EIO LCA estimates the materials and energy resources required for--and environmental impacts caused by--certain amounts of economic activity. It will provide a detailed estimation of the environmental impacts of the manure management system. Additional data from previous LCA analyses may be combined with the findings of the EIO LCA to determine more accurately the total environmental impact of the manure management systems.

4.1.4 Interpretation

Now the impact of the system has been calculated. What does this information mean? What will be done with this knowledge?

LCAs are a valuable exercise in breaking down systems and understanding their components, but they do not exist in a purely academic setting to inform people on how systems
work. They exist to make decisions that will make systems better. The LCA provides valuable insight about efficiency and impacts about a system. With that knowledge conclusions can be reached that help make systems efficient to save money, lower environmental impact, or reach any other goal. In the case of this analysis, the results will help dairy farms reach conclusions as to how to manage their manure in ways that will reduce greenhouse gas and eutrophication-related nutrient pollution.

While strong conclusions are often desired, the results of an LCA are often too complicated to make sweeping declarations about impacts and efficiencies. An LCA will show the impact of one or a few impact category. Most real-world issues are so multifaceted that a single assessment cannot fully encompass them. Addressing the limitations of the LCA is important in navigating the analysis’ results in ways that acknowledge the multi-faceted nature of issues compared to the simplified conditions of and results given by an LCA. By properly interpreting the information given by an LCA and examining the assessment’s context and limitations, more valuable conclusions can be reached.

The results of this LCA are limited by their range and accuracy. The scope of this analysis was created in a way that does not include the environmental impacts of transporting materials to the farms, spreading and potential runoff of raw or processed manure, or the impacts of disposal of this system at the end of its useful life. Additionally the EIO LCA takes its inputs in general economic categories. The environmental costs determined by the EIO LCA will thus be estimates and may vary in their accuracy. Additionally, the inputs and their quantities were determined through a research process that attempted to discover and quantify the materials, energy, and waste of a dairy farm of these sizes. This research process may have found data that is not completely accurate to this specific farm. Understanding these limitations will allow for more useful and applicable conclusions to be drawn.

By following these four phases accurately, valuable insight about dairy farming’s environmental impact in Pepin County will be determined.
4.2 Net Present Value Analysis

Dairy farms produce valuable economic benefits to the Pepin County residents and community. Farms have valuable resources on them—crops, cows, even their manure. Maintaining and operating these farms also require certain costs—constructing buildings, powering facilities, and feeding animals. This project will evaluate those costs and benefits for two proposed alternatives and the current manure use strategy in order to determine the economic value of each manure use strategy.

Economic benefit will be measured using Net Present Value (NPV) calculations. NPV evaluates the current value of a series of cash flows. Operating off of the principal of time value of money—that money loses value over time at a specified rate—a system’s current and future cash can be converted to a consistent time period. This consistent time period—the present—allows for equal comparisons between current and future costs and benefits. Done across each alternative, NPV allows for equal comparison of relative economic value for each dairy manure use strategy. Below is a general equation for calculating NPV.

\[
NPV = -C_0 + \frac{C_1}{1+r} + \frac{C_2}{(1+r)^2} + \ldots + \frac{C_T}{(1+r)^T}
\]

- \(C_0\) = initial investment
- \(C\) = cash flows
- \(T\) = time period
- \(r\) = discount rate (time value of money)

**Figure 3.** Net Present Value equation with variables provided. This equation will be used to calculate the economic value of each alternative.

In this project, determining the NPV and analyzing economic value will be a three-part process.

**Research**

Determine all applicable costs and benefits for each manure use strategy. Initial costs which entails construction costs, equipment procurement, and material acquisition among other
costs. Similar research will be completed to determine annual operating costs, periodic maintenance costs, salvage cost or benefit, and the profits expected to be created by each manure use strategy. This information will make up the cash flow for each alternative. Research will also determine the most accurate discount rate expected at this time to best represent the time value of money.

**Calculation**

With the component parts and respective values of current and future costs and benefits found, cash flows can be constructed for each manure use strategy. These cash flows contain a specified value and time for each cost or benefit. Each cost and benefit will be plugged into the NPV equation, seen above, in order to convert the whole cash flow to its value in current dollars.

**Evaluation**

With each manure use strategy’s economic value converted into equal and comparable values—their value in present dollars—they can be accurately compared. The alternatives with the higher values are generally more economically valuable. Limitations and assumptions used to complete this calculation will be assessed so that the comparison can be contextualized and properly evaluated. Using all this information a recommendation as to the economic value of the different manure use strategies will be made.

### 4.3 Social Impact Analysis

Dairy farms have environmental and economic impacts that combine to affect local communities. This analysis will identify the impacts of the three manure use strategies on the Pepin County community and examine the effects of those impacts.

This analysis will use information gathered in the life-cycle assessments and net present value analyses of the three manure use strategies. The environmental and economic impacts which will affect the Pepin county community at large will be identified and qualitatively
analyzed. Additional factors and impacts that This process will give a picture of how dairy manure can be used to positively impact the whole county community.

5. Life Cycle Assessment

A life cycle assessment will be conducted to aid the analysis of the environmental impact of dairy manure management systems. The life cycle assessment has four steps, which are described in detail in the previous section. This analysis is completed for the 500 animal unit farm. To obtain the inputs and results for the 1,000 animal unit farm multiply the data by two. The following sections will describe each step and the results of this analysis.

5.1 Goal and Scope

As described previously, the life cycle assessment will have a specific scope and goals. The manure management systems will be analyzed from cradle through use, determining impacts to set up the system and manage one functional unit’s worth of manure. The functional unit analyzed will be 1/1000 of the annual manure production at the 500 animal unit farm--3,000 gallons of liquid manure and 1.7 tons of solid manure. The boundaries of the system will include manure collection, transportation, and storage but not include the impact of raising cows or spreading the manure. The goal of the study is to determine the environmental impact of different manure management systems, and the life cycle assessment will show this impact in its impact categories--greenhouse gasses and eutrophication potential. Reference section 4.1.1 for more detail about goals and scope.

5.2 Inventory

The inventory of the LCA determines what is inputted into the system to process the functional unit of manure. This section will begin with background about each manure management method and then identify the inputs that will be considered for this life-cycle analysis.
5.2.1 Current Manure Management Method

Currently, this farm does not employ a manure composting or digestion system. In short, it collects raw manure, stores it during the off season, and spreads it onto cropland during spring and fall. Liquid manure is collected from livestock housing and milking parlors and stored in an earthen, concrete-lined lagoon. That liquid manure mix is agitated before application in the spring and fall. Solid manure collected from young stock housing and some barnyards to be applied on fields. This system requires inputs in the form of water and fuel. Water is used to clean barns, housing, and milking parlors. Fuel is used to power front-loaders and other vehicles that move and transport raw manure. The fuel costs can be assumed to be small enough to be insignificant in their environmental impact. The amount of water used in cleaning and clearing manure is given below.

Table 1. Inputs to be used in the EIO LCA of the current manure management method.

<table>
<thead>
<tr>
<th>Current Method</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>6168.5 Liters</td>
</tr>
</tbody>
</table>

5.2.2 Composting Method

Composting occurs when “oxygen-consuming bacteria and fungi feed on the mixed organic waste in a pile or windrow and convert the waste” (Thomas Bass et. al, 2017). A system flow diagram of the process is displayed in Figure 4.
5.2.2.1 Carbon and Nitrogen

In order for these fungi and bacteria to convert the manure to compost, the components water, oxygen, carbon (C) and nitrogen (N) are required (Thomas Bass et. al, 2017). The nitrogen provides the necessary protein synthesis that allows the microorganisms to multiply, while the carbon in the manure is the energy of the system (Guide to Agricultural, 2011). A carbon to nitrogen ratio by weight between 20:1 and 40:1 allows the decomposition of the manure to happen swift and efficient (Guide to Agricultural, 2011). According to a study done by Montana State University, the range of carbon and nitrogen ratios for dairy animals is 8:1 to 30:1.

Since bacteria and other microorganisms are known as aerobic, they require oxygen (Guide to Agricultural, 2011). To make sure that oxygen is at a suitable level for composting, turning of the windrow or adding organic waste is performed (Thomas Bass et. al, 2017). The
Desirable oxygen content of the mixture varies from 5-20 percent (Thomas Bass et. al, 2017). The oxygen content is satisfied as long as it turned consistently with a windrow turner.

The raw solid manure on this farm does not have the required characteristics for composting. With a C:N ratio of less than 20:1, organic materials--leftover corn stalks, waste alfalfa--will be added to maintain proper nutrient conditions. The environmental impact of these organic materials will later be analyzed.

5.2.2.2 Moisture Content

Moisture is another important element to the compost. Without the moisture in the mixture, the microorganisms cannot thrive and properly dissolve the nutrients (Guide to Agricultural, 2011). The moisture content for a successful compost is between 40 and 60 percent (Guide to Agricultural, 2011). Similar to nutrient content, the raw solid manure does not meet these characteristics needed for composting. The organic materials added to aide in the C:N ratio will also lower moisture content from about 77% to within the desirable range for composting of 40%-60%.

5.2.2.3 Temperature

The temperature of the compost represents the progress the microbes are doing and when the compost is about complete (Thomas Bass et. al, 2017). Using a compost monitor, the compost should give off heat in the range of 130 to 160 degrees Fahrenheit within the first couple days of generation (Thomas Bass et. al, 2017). Once the temperature begins to decrease, it signifies that the compost must be flipped over to allow new oxygen in (Thomas Bass et. al, 2017). Before curing, the compost should be flipped four to six times (Thomas Bass et. al, 2017). Typically the composting process takes about a few weeks, but if the optimum requirements are not met then it could take as long as a couple years (Guide to Agricultural, 2011).
5.2.2.4 Cleaning

As the manure and composting system is run through, a cleaning process needs to be established. The area where the manure is collected and the area where the solid and liquid manure is stored should be cleaned periodically to prevent the spread of diseases. According to an article by MDPI, the average cleaning water for a cow is 33.8 L per day. Within the restrictions of 500 animals at the Pepin County farm, the farm requires 16,900 L of water per day. Having a functional unit of 0.365 days, the farm requires 6,168.5 L per functional unit.

5.2.2.5 Method of Compost Sitting and Turning

The method of which the compost is laid is important for the quality and time it takes for the compost to be complete (Thomas Bass et. al, 2017). The method of storing compost used for this case study is windrows. Windrow composting consists of laying the compost down in long piles (Guide to Agricultural, 2011). Then the piles are typically rotated and turned over, allowing the compost to absorb more oxygen (Guide to Agricultural, 2011). The compost can be rotated with either a windrow turner or a front-end loader (Thomas Bass et. al, 2017). An example of this machine is shown in Figure 5.

![Figure 5](image_url)

**Figure 5.** A windrow turner rotates the compost to allow oxygen to reach the mixture (Division of Waste and Hazardous Substances, 2016).
A windrow turner is the desirable machinery for the compost turning. A study performed by GCM Enviro found that the turning process is overall more efficient than having a front-end loader. The turns per week is increased, the processing time is reduced, and the fuel consumed by the machine is reduced by 16.67% annually when switching from a front-end loader to a windrow turner (Solbrandt, 2018).

The size of the windrows depends on the proportion of the compost made, but it typically ranges from “6-10 ft high and 10-20 ft wide” (Guide to Agricultural, 2011 pg 8). The turning of the windrows occurs quite frequently during the composting process (Sweeten et. al., 2008). During the first week, the windrows should be turned about three times, followed by two turnings in the second and third week (Sweeten et. al., 2008). Lastly, the fourth and fifth week of the process should only have one turning per week (Sweeten et. al., 2008).

For this study the cross section of the windrows will be an 8’ high and 15’ wide semi circle. The length of the windrows is 33’ in length which allows space for machinery to navigate around the piles. There will be three windrows to fill the concrete pad with compost.

The creation of the windrows for Pepin County will be done with a windrow turner. The windrow turner type depends on the size of the farm, the amount of compost, and preferability. For this study, a CT718 compost turner was picked to examine specifications and environmental impact. According to the Vermeer website, the seller of the machine, the compost turner has a max fuel consumption of 29 gph. Assuming the compost is turned 5 turns per 8 weeks and the turning process takes about 30 minutes every session, the gallons required for the functional unit can be determined. The gallons required for the functional unit of 0.365 days is 0.474 gallons of fuel.

5.2.2.6 Composting Land Selection

The land that the compost will be placed on is important for groundwater contamination and efficiency of the process (Guide to Agricultural, 2011). A slight slope of about 1-3% for the land can prevent ponding of the moisture (Guide to Agricultural, 2011). Since the slope of the land on Pepin County is 2-6% then that requirement is fulfilled. The compost will be stored in
windrows at the Pepin County farm. The windrows will be placed on a 65’ x 40’ concrete pad which will then be placed on the farms soil. The concrete pad was selected to reduce the infiltration of contaminants into the ground, and to provide stability for the heavy machinery that may be driving over it. The concrete pad will be about 6” thick to allow for a buffer between the surface and the soil. The total concrete required for the composting pad is 1300 cubic feet.

To make the turning and curing of the compost zero-discharge, the concrete under the windrows will be slightly perforated. This will allow the excess liquid to discharge from the compost. A liquid capture zone located beneath the windrows could contain the excess water before it can seep into the ground. The slope of 2-6% allows the runoff to flow to a containment unit under the concrete pad. This means that the orientation of the windrows on the concrete panel must also be considered. When placing the windrows, the piles should go up and down the slope (Guide to Agricultural, 2011).

Covering of the windrows via tarp would also limit the outside access of the precipitation and further limit the runoff. The runoff coming from around the piles should also be diverted to avoid the compost. This can be achieved with “berms, diversion ditches, and grassed waterways” that are located uphill (Guide to Agricultural, 2011).

5.2.2.7 Emissions

When producing compost for a farm, a major concern is the contribution of greenhouse gases (GHG). Harmful emissions such as $CO_2$, $CH_4$, and $N_2O$ have all been known to be released from compost during the curing process (Hao et. al. 2001). A study performed by Xiying Hao (2001) tested the emissions that occurred between a windrow that was actively turned compared to a windrow that was only aerated beneath the pile via perforated pipe. The information regarding the greenhouse gas emissions of each experiment is displayed in Figure 6.
Cumulative greenhouse gas (GHG) emissions during feedlot manure composting (May–August 1997).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>CO₂–C</th>
<th>CH₄–C</th>
<th>N₂O–N</th>
<th>CO₂–C</th>
<th>CH₄–C</th>
<th>N₂O–N</th>
<th>CO₂–C</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive†</td>
<td>73.8b*</td>
<td>6.3a</td>
<td>0.11b</td>
<td>73.8</td>
<td>132.3</td>
<td>34.1</td>
<td>0.0</td>
<td>240.2b</td>
</tr>
<tr>
<td>Active‡</td>
<td>168.0a</td>
<td>8.1a</td>
<td>0.19a</td>
<td>168.0</td>
<td>170.1</td>
<td>58.9</td>
<td>4.4</td>
<td>401.4a</td>
</tr>
</tbody>
</table>

* Within columns, means followed by the same letter are not significantly different according to the Tukey test (0.05).
† Initial surface area of 162.1 m² windrow⁻¹ and weight of 9.55 Mg windrow⁻¹ were used in calculation.
‡ Initial surface area of 156.5 m² windrow⁻¹ and weight of 6.67 Mg windrow⁻¹ were used in calculation.
§ Using global warming potential of 1, 21, and 310 for CO₂, CH₄, and N₂O, respectively.
¶ Based on fuel consumption of 0.266 L turn⁻¹ Mg⁻¹ and CO₂–C emission rate of 2.73 kg C L⁻¹ diesel fuel.

**Figure 6.** Testing of the GHG found in both active and passive composting found that active composting produced higher emissions (Hao et. al. 2001).

The study was performed on windrows that were about 50 m² in area and 1.6 meters high (Hao et. al. 2001). The actively turned windrow was turned a total of 6 times over the course of 99 days (Hao et. al. 2001). The notable measurements from Figure X is the 160 kg CO₂ - C Mg manure for the active composting compared to the 73.8 kg CO₂ - C Mg manure (Hao et. al. 2001). This difference likely occurred due to the increased microbial activity from turning and increased gas diffusion rates of the turned windrow (Hao et. al. 2001).

### 5.3 Impact Assessment

The environmental impacts of the functional unit of 3,000 gallons of liquid manure and 1.7 tons of solid manure, will be evaluated using an EIO LCA tool. This tool is intended to
“estimate the materials and energy resources” (EIO-LCA: Free, Fast, n.d) that go into the composting and current method of manure application. The data for each input is shown in Table 2.

![Table 2. Manure Composting inputs. This data will be used in the EIO LCA.](image)

<table>
<thead>
<tr>
<th>Composting</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>6168.5 Liters</td>
</tr>
<tr>
<td>Diesel Fuel</td>
<td>0.474 Gallons</td>
</tr>
<tr>
<td>Concrete</td>
<td>1300 cubic feet</td>
</tr>
<tr>
<td>Organic waste</td>
<td>575 pounds</td>
</tr>
</tbody>
</table>

5.3.1 Current Method

The current method of manure use doesn’t include several factors that the composting method does. The concrete pad that is used for the windrows will not be necessary for the straight manure method. The necessary fuel for the windrow turner will also not be necessary for the current method. Lastly, organic matter is not necessary for the current method as the manure applied to the crops is typically in the range necessary for crop growth. The only input for the manure is the cleaning water for the process. The required amount of water for the manure is 6,168.50 L. In the EIO LCA, the US 2002 Producer model, and the Water, sewage, and other systems sector, was used to determine the environmental impact of the cleaning water. The impact of the cleaning water on the current method is 0.0087 tons of CO2e and 0.0007 tons Ne as shown in Table 3.
Table 3. The environmental impact of the current method.

<table>
<thead>
<tr>
<th>Current Method</th>
<th>tons CO₂e</th>
<th>tons Ne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>0.00869</td>
<td>0.000742</td>
</tr>
<tr>
<td>Total</td>
<td>0.00869</td>
<td>0.000742</td>
</tr>
</tbody>
</table>

5.3.2 Concrete Pad

The 65’ by 40’ concrete pad requires a total of 1,300 cubic feet of concrete. The EIO LCA tool was used with the US 2002 Producer model, and the Ready-mix concrete manufacturing sector. This resulted in concrete producing 0.0027 tons of CO₂e and 0.0004 tons Ne.

5.3.3 Cleaning Water

The required amount of water for the composting is the same as the current method at 6,168.50 L. Similar to the current method, the US 2002 Producer model, and the Water, sewage, and other systems sector, was used for the EIO LCA. The theoretical environmental impact of the cleaning water is 0.0087 tons of CO₂e and 0.0007 tons Ne.

5.3.4 Fuel

The EIO LCA tool was used with the US 2002 Purchaser model, and the Petroleum refineries sector. The diesel fuel required if the farm used a windrow turner would contribute to 0.0012 tons of CO₂e and 0.0001 tons Ne.

5.3.5 Organic Matter

To find the environmental impact of the organic matter used as a carbon amendment, an EIO LCA was performed using the US 2002 Purchaser model and the Grain farming sector. The organic matter has an environmental impact of 0.1080 tons of CO₂e and 0.0645 tons Ne.
Specific quantifiable inputs for the composting process were selected to be plugged into the EIO LCA tool. These are shown in Table 4 below.

**Table 4.** The environmental impacts of the proposed composting method.

<table>
<thead>
<tr>
<th>Composting Method</th>
<th>tons CO$_2$e</th>
<th>tons Ne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>0.0087</td>
<td>0.0007</td>
</tr>
<tr>
<td>Diesel Fuel</td>
<td>0.0012</td>
<td>0.0001</td>
</tr>
<tr>
<td>Concrete</td>
<td>0.0027</td>
<td>0.0004</td>
</tr>
<tr>
<td>Organic Waste</td>
<td>0.1080</td>
<td>0.0645</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>0.1207</strong></td>
<td><strong>0.0658</strong></td>
</tr>
</tbody>
</table>

### 5.4 Environmental Impact Results

The environmental impact of the current method and composting method vary widely. The total greenhouse gas potential of the current manure method is only 0.00869 tons of CO2e, while the greenhouse gas potential of the proposed composting method is 0.1207 CO2e. The comparison of the two methods is shown in Figure 7 below.

**Figure 7.** The GHG potential of both the composting method and current method.
The composting method’s potential of GHG is almost 14 times that of the current method’s potential. A reason for this large discrepancy between the two is due to the bounds of the study. The analysis of the GHG potential takes into account cradle-to-use of the manure. This means that the study analyzes the inputs and outputs that go into the process of making the manure or compost. By restricting the study to the process of creating the manure or compost, it negates the emissions that could potentially be occurring once the material is applied to the crops.

The eutrophication of both methods had a similar trend to the GHG. The total eutrophication potential of the current method is 0.000742 Ne, while the total of the composting method is 0.0658 Ne. A comparison of the two methods eutrophication potential is shown in Figure 8 below.

![Figure 8. The eutrophication potential of the current method and proposed composting method.](image)

The difference of eutrophication potential is much larger than the GHG, with the composting method having a potential over 80 times that of the current method. This large difference coincides with the previous sections explanation. Due to the bounds of the study only considering the making of the materials and not the effects the materials have afterwards, the impact of the composting material will be much larger than the current method.

The analysis of the four different inputs considered for the composting method showed an interesting trend. Almost all of the impacts had similar numerical values when it came to
environmental impact. However, organic matter had a much larger environmental impact compared to the others. This large difference is shown in Figure 9 below.

Figure 9. Comparing the environmental impacts of each factor in the composting method.

The organic waste having a much larger value than the other inputs was surprising. It was expected that the concrete or diesel fuel would have the larger environmental impact. A possible reason for this large value could be due to the EIO LCA inputs. Although the economic input is considered for the analysis, the bounds are a little vague. The Grain farming sector of the tool could take into account other factors that were not considered such as the machinery used to harvest this crop and the water required to sustain growth. For this reason the organic waste was noticeably larger than the others.
6. Economic Impact Assessment

An economic impact assessment for the composting and current manure method provides valuable information into which method is viable in respect to its economic costs. This analysis was completed for the 500 animal unit farm. The results for the 1,000 animal unit farm can be extrapolated by multiplying these results by two.

6.1 Composting System

The composting system consists of four areas that are considered for economic evaluation. The areas are concrete, cleaning water, fuel, and organic waste.

6.1.1 Concrete

The application of the concrete takes into account several factors. The average cost of concrete as of 2018 is $113.00 per cubic yard or $4.18 per cubic foot (Concrete Price Considerations, 2019). Reinforcement of the concrete is also recommended to prevent cracks. The price to reinforce the concrete slab is about $0.15 per square foot (Concrete Price Considerations, 2019). With the concrete being 1,300 cubic feet, this brings the total of the concrete application to $5,531.50.

6.1.2 Cleaning Water

The total amount of water required for cleaning is 6168.50 L per functional unit or 6,168,500 L annually. According to an article by the U.S Department of Energy (2017), the water rates for water utilities in the Wisconsin area is about $3.00/kGal of water. The total amount of money required for the cleaning water is $4.89 per functional unit, or $4,890.00 annually.
6.1.3 Fuel

Fuel is required to power the windrow turner. To determine the cost of the fuel the 29 gph of the CT718 compost turner was used, and it was assumed that the turning process occurs for 8 weeks at 30 minutes per turning session. This means that the total gas required for the functional unit of 0.365 days is 0.4739 gallons of diesel gas. According to the Energy Information Administration (EIA) (2019), the average cost of diesel gas in the U.S is $2.98 per gallon. The total cost of diesel gas for the functional unit is $1.41 and the total cost annually is $1413.04.

6.1.4 Organic Waste

The organic matter required for the carbon amendment and to reduce the moisture content, is 575 lbs (Animal Unit Months, n.d.). The organic matter required for composting is valued at $166.00 per ton (Animal Unit Months, n.d.). The total cost of the organic matter is $1.58 per functional unit or $1,575.34 annually.

6.1.5 Windrow Turner

For the compost method, the windrows must be turned by a windrow turner. If the Pepin County farm does not have a windrow turner then the cost of this machinery must be considered. An article by Montana State University (2017), found that the cost of a windrow turner can be anywhere from $20,000 for a used unit, to $60,000 for a new unit. For the sake of the economic analysis and assuming the farm wants to limit the cost, a $20,000 windrow turning unit is proposed.

6.2 Current System

Using the inputs previously identified during the life-cycle analysis, the current manure management method only has one significant cost to be accounted for. Water use, to clean stalls and barns of manure, is required at 6,168,500 L annually for a price of about $3.00/kGal. See section 6.1.3 for more details.
This system requires no startup costs, as it is currently in operation and the equipment and materials needed to begin the process have already been purchased. Those previous purchases are past sunk cost, with no economic bearing or costs to an economic analysis done now, so they will not be considered. This equipment is assumed to be in working order and to survive the 20 year analysis period.

6.3 Economic Analysis Results

The costs identified were made into cash flows in their appropriate time period and plugged into the net present value equation displayed in Figure 3. Because every cash flow is a cost, this calculation can be called net present cost, as it will be presenting the value of all of the costs for each alternative over a 20-year period. The discount rate in this equation was set to the estimated 2019 inflation rate (USInflation.org). The initial costs, annual costs, and calculated net present costs for each manure management method is displayed in Table 5 below.

Table 5. The NPC values of composting and current method over a 20 year period.

<table>
<thead>
<tr>
<th>Cost of Manure Management</th>
<th>20-year period</th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial Cost</td>
<td>Annual Cost</td>
<td>Net Present Cost</td>
<td></td>
</tr>
<tr>
<td>Current Method</td>
<td>$0</td>
<td>$4,880</td>
<td>$76,508</td>
<td></td>
</tr>
<tr>
<td>Composting</td>
<td>$25,532</td>
<td>$54,018</td>
<td>$872,419</td>
<td></td>
</tr>
</tbody>
</table>

The composting method has significantly higher initial costs, annual costs, and net present cost. It requires the purchasing of new equipment, building of new structures, and implementation of new processes. The difference between the cost of the manure management alternatives is shown visually in Figure 10 below.
As just mentioned, the compost method brings in a variety of new and significant costs. These costs bring no new economically quantifiable benefit to the farm. Without new benefits, the new system will be economically just an added cost to the farm. The benefits that the composting system does bring come in less economically-quantifiable categories like odor reduction and runoff reductions after field application. For the composting alternative to be worth its costs, the farm will have to value these benefits more than the significant cost of the system. These different benefits that are less quantifiable are discussed in the following section.

7. Social Impact Assessment

Social impacts of both raw manure management and manure compost management are complicated and have a broad effect on personnel working on-site and adjacent communities; therefore, it is important to set a clear scope of study prior to intensive researching and making the final decision. In this study, the scope of the social impact covers from manure collection to land applications, and will be limited to personnel working on-site and the communities around the farms. The topics that will be discussed and compared are mainly (1) health issues, and (2)
complaints about dust, odor, and other contaminations related to raw manure management and manure compost management inside the farms.

7.1 Social impacts of raw manure management

The main concerns of raw manure management (collection, storage, on-site transportation, and application to farmlands) are pathogens released from manure to the environment surrounding the farms. Livestock waste contains a wide variety of bacteria, viruses, and protozoa, associated with diseases and symptoms in humans. The levels and types of pathogens vary with types of animals, food sources, ages of the animals, and characteristics of manure. Table 6 shows the major pathogens in cattle manure, such as *Salmonella*, *Escherichia coli*, *Cryptosporidium*, *Campylobacter*, *Bacillus*, and *Giardia*. These pathogens can infect human directly and indirectly by consuming contaminated food and/or water, and inhalation. Children, the elderly, and people with weakened immune system are at higher risk than others.

Any manure management practices, from manure collection to land applications, add more an exposure risk to workers and communities surrounding the farms. Brooks et al. (2012) reported that the risk of being exposed to pathogens is increased, especially to the workers handling collection, storage, and land applications. However, the most concern is the risk during the land applications. Several studies and articles have reported a concern about detectable concentrations of pathogens in the lower air several miles away from where manure application taken place. (e.g., Beecher, 2016; Borchardt and Burch, 2016; Martel, 2017) Furthermore, the concern of manure-borne pathogens in residential groundwater wells and surface waters after land applications are often mentioned in some studies, reports and news. (e.g., Pandey et al., 2014; Wisconsin Department of Health Services, 2015; Wang et al., 2017) It is undeniable that manure management still cause worries to the communities no matter how safe it is described.

The second concern about raw manure management is odor and dust. Odor and dust are released during raw manure collection, storage, on-site transport, and land applications. Porter (2009) published an article about complaints from people living near a dairy farm in Eaton, Colorado. The complaints included unbearable levels of odor and dust from the manure piles.
The article also stated the worries about wastewater from raw manure management seeping into the neighbors’ lands and creeks, which led to complaint files, and fines. (Porter, 2009)

7.2 Social impacts of compost management

Compost management practices replacing to the raw manure management may cause less impacts on workers and the adjacent communities; however, the statement is valid only with a good performance. Similar to the raw manure management, the social impacts involve pathogens, dust, and odor released from the manure compost management processes (manure collection, composting, storage, on-site transportation, and land applications). By adopting manure compost management to the farmlands, the numbers of steps that have potentials to release pathogens, dust and odor have been increased.

Composting may reduce numbers of pathogens in the composted products compared to the raw manure; unfortunately, it does not guarantee that risks of being infected by these pathogens are reduced. Although more than 99% of pathogens could be killed off by heat built up inside the compost piles as reported in several studies (e.g., Larney et al., 2003; Albrecht et al., 2006; Manyi-Loh et al., 2016), there were some studies have reported health concerns and complaints. The pathogen community structure in composted manure can be shifted from manure-borne bacteria or viruses to manure-borne fungus, especially *Aspergillus fumigatus*. (United States Department of Agriculture, 2010) This fungus induces the development of allergic bronchopulmonary aspergillosis, causing fungus fibers, blood clots, and blood cells to form in the lungs or sinuses, along with a fever, chest pain, coughing blood, or difficulty breathing. (Revankar, 2019) Furthermore, the presence of endotoxins (i.e., products of gram-negative bacteria causing nausea, headache, and diarrhea) was reported in the same study.

During the composting process, the pathogens may be released from the piles to the air as a form of bioaerosols. Bioaerosols are airborne microorganisms (e.g., bacteria, viruses, protozoa, fungi, and microbial spores) containing allergens and living microbes emitted from the compost piles or facilities that can initiate symptoms and other diseases after being inhaled or digested. A
study on compost-related health issues by Kamper et al. (2012) reported that current and former workers in composting facilities in Germany suffered from mucous membrane irritation (MMI) (e.g., coughing and eye irritation), while spotting a small significant lung function impairment in their subjects. The same study also stated that the symptoms in the former workers were improved after quitting their jobs. Likewise, a similar study by Bünger et al. (2000) reported a higher occurrence of tracheobronchitis, MMI, sinusitis, and other diseases in compost workers. Furthermore, the airborne microorganisms can be transported during the work activities up to approximately 500 meters away from the compost facilities. (Albrecht et al., 2008)

Similar problems about dust and odor are also found with the manure compost management. The odor from compost piles created from the decomposition process is the main problem that compost facilities must prepare to face. Goldstein and Goldstein (2005) published an article about odor management in composting facilities reporting that odors from the facilities had become a concern to neighborhoods near the plants in New Jersey. Similar issues were also reported by Phelps (2017) when communities in Northborough, Massachusetts, did not appreciate having compost facilities in their neighborhoods due to odors and dust. One possible to mitigate the odor problem is an application of biofilters; however, it is not always effective in reducing the odors. (Albrecht et al., 2008)

<table>
<thead>
<tr>
<th>Species</th>
<th>Infection pathway(s)</th>
<th>Examples of diseases/symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Escherichia coli</em></td>
<td>Consuming contaminated food</td>
<td>Gastroenteritis, diarrhea, hemolytic-uremic syndrome, hemorrhagic colitis</td>
</tr>
<tr>
<td>(<em>E. coli</em> O157:H7)</td>
<td>Direct contact with livestock feces</td>
<td></td>
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<tr>
<td></td>
<td>Person-to-person transfer</td>
<td></td>
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<tr>
<td><strong>Organism</strong></td>
<td><strong>Transmission</strong></td>
<td><strong>Disease</strong></td>
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<td>----------------------------------------------------------------------------</td>
</tr>
<tr>
<td><em>Salmonella</em> sp.</td>
<td>Consuming contaminated food or water Direct contact with livestock feces</td>
<td>Salmonellosis, diarrhea, fever, abdominal cramps</td>
</tr>
<tr>
<td><em>Campylobacter</em> spp.</td>
<td>Consuming undercooked food products Consuming contaminated water</td>
<td>Campylobacteriosis, gastroenteritis, Guillain-Barré syndrome, joint inflammation, postinfectious irritable bowel syndrome</td>
</tr>
<tr>
<td><em>Listeria monocytogenes</em></td>
<td>Consuming contaminated food or water</td>
<td>Listeriosis, vomiting, diarrhea</td>
</tr>
<tr>
<td><em>Yersinia enterocolitica</em></td>
<td>Consuming contaminated food or water</td>
<td>Yersiniosis, lymphadenitis, acute enterocolitis,</td>
</tr>
<tr>
<td><em>Enterococcus</em> sp.</td>
<td>Direct contact with contaminated objects</td>
<td>Urinary tract infections, endocarditis, wound infection, intra-abdominal and pelvic infections, nosocomial infections</td>
</tr>
<tr>
<td><em>Mycobacterium</em> sp.</td>
<td>Inhalation Direct contact with contaminated soil</td>
<td>Paratuberculosis (chronic disease of the intestine), Crohn’s disease (chronic inflammatory bowel disease), coughing</td>
</tr>
<tr>
<td><em>Cryptosporidium</em> sp.</td>
<td>Consuming contaminated food or water Direct contact with livestock feces</td>
<td>Gastroenteritis, cryptosporidiosis</td>
</tr>
<tr>
<td><em>Giardia</em> sp.</td>
<td>Consuming contaminated food or water Direct contact with giardiasis patients</td>
<td>Giardiasis, diarrhea, abdominal cramps</td>
</tr>
<tr>
<td><em>Bacillus anthracis</em></td>
<td>Oral ingestion of contaminated soil Inhalation of bacterial spores Consuming contaminated food</td>
<td>Anthrax</td>
</tr>
</tbody>
</table>
8. Conclusion

Pepin country is a small county located in western Wisconsin. Due to low population density, a farming business has begun to take over the lands for agriculture, which promotes communities and economics in the county. However, by running a farming business, the natural resources in the county are being exploited and exposed to the pollution that has an impact on both regional and global scales.

Life Cycle Analysis (i.e., LCA) is a useful tool that helps entrepreneurs choose economical/environmental-friendly designs for their business. The steps of LCA include setting scope and goal, inventory analysis, impact assessments, and result interpretation. In this study, 500 and 1000 animal-unit farms were analyzed using LCA, resulting in the resultant data (environmental impacts, economic impacts, and social impacts) which provides easier comparisons and decision making. The purposes of this study are: (1) to analyze the impacts of adopting compost management to the croplands on three aspects of sustainability, compared to the raw manure management (current method), and (2) to make a recommendation on which method are suitable for the farms based on the results from the LCA. The 500 and 1000 animal-unit farms are located on Finchford loamy sand (501B soil map) area far away from any water body while raising lactating cows, dry cows, heifers, and calves, and growing alfalfa, alfalfa seeding, corn silage, and corn grains over 1000 acres of the land property. The scope of this study was set to cover manure collection, on-site transportation, and storage. The inventory analysis was studied accordingly. Economic Input-Output Life Cycle Analysis (EIO-LCA) tool was then used to analyze the environmental and economic impacts of both management methods.
with a functional unit of 3000 gallons liquid manure and 1.7 tons solid manure at the 500 animal-unit farm. The resultant data for the 1000 animal-unit farm can be obtained by multiplying results from the study on the 500 animal-unit farm by 2. Finally, the final decision on which management practices are suitable for both farms was made.

Raw manure management (current method) in the scope includes solid and liquid manure collection from stock housings and barnyards, stock housing cleaning, and manure storage. The environmental and economic impact assessments were analyzed using EIO-LCA tool. The results from the environmental impact assessment indicated that the environmental impact of the current method is associated with cleaning water use under two selected environmental impact categories: greenhouse gases (GHGs) emission, and eutrophication. For all the processes in the scope of the study, the current method generates GHGs approximately 0.00869 tons of CO₂ equivalent and releases roughly 0.00074 tons of eutrophication-related nitrogen. The economic impact assessment using the same tool indicated that the value of the current method used (raw manure management) over a 20-year period equals to $76,508. The value presented here was calculated from only cleaning water and annual operating costs. When considering the social impacts of the raw manure management, the main concerns are related to manure-borne pathogens, especially bacteria and protozoa, and odors released from each step of the management method, especially during the land applications.

Compost management, on the other hand, seems to have more impact. The compost management practice, a windrow system, adds additional steps, including the separation of solid and liquid fractions from liquid manure, composting, and composted product storage, to the scope of the study. These additional steps require machinery (e.g., loaders), fuel, and materials (concrete and reinforcement), resulting in more sources of GHGs emissions and eutrophication to be analyzed. The results from the environmental impact assessment indicated that, by adopting the compost management to the scope, the GHGs emission would be increased to approximately 0.1207 tons of CO₂ equivalent, and the management may release up to 0.0658 tons of eutrophication-associated nitrogen to the environment. The results also indicated that the major source of the environmental impact of composting is the organic waste required to meet the
proper C:N ratio of the composting process. Likewise, the economic impacts of the compost management method would be also increased as the results from the EIO-LCA tool revealed that the value of the compost management method over a 20-year period equals to $872,419. This number was calculated from the cost of concrete, reinforcement, cleaning water, diesel fuel for machinery, organic waste, and annual operating cost. Simply put, the value of the composting operation would be higher than the current method roughly 11 times. However, the social impacts seem unclear compared to those of raw manure management. The results showed that the risk of being exposed to manure-borne pathogens has been increased due to the composting step added to the scope. Although almost all manure-borne pathogens get killed off during the composting step, it does not guarantee that it can reduce the chances of personnel being infected as the pathogen community structure has shifted to fungi and endotoxins. Furthermore, several studies also stated communities’ concerns about odors and dust from the compost facilities in their areas even though compost management is believed to be a greener solution for agricultural soil improvement methods.

Based on the results from environmental, economic, and social impact assessments of both raw manure management and compost management, the suitable practice for the 500 and 1000 animal-unit farms in the Pepin county is raw manure management (the current method), which exploits less resources, less operating and maintenance costs, and causes less environmental and social impacts compared to the compost management.
# Project Team Contributions

<table>
<thead>
<tr>
<th>Section</th>
<th>Necessary Work</th>
<th>Contributor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>Introduction to Pepin County</td>
<td></td>
</tr>
<tr>
<td>Background</td>
<td>Background information on the three paradigms</td>
<td></td>
</tr>
<tr>
<td>Questions and Scope</td>
<td>What to answer and scope of assessment</td>
<td></td>
</tr>
<tr>
<td>Methods of Analysis</td>
<td>How the question will be answered</td>
<td></td>
</tr>
<tr>
<td>Life Cycle Assessment</td>
<td>Environmental impact of proposal</td>
<td></td>
</tr>
<tr>
<td>Economic Impact Assessment</td>
<td>The cost for the proposal</td>
<td></td>
</tr>
<tr>
<td>Social Impact Assessment</td>
<td>The social aspects that are considered with each method</td>
<td></td>
</tr>
<tr>
<td>Conclusion</td>
<td>Summarizing the project</td>
<td></td>
</tr>
</tbody>
</table>
Works Cited


US EPA, OW. (2015, September 23). NPDES Permit Basics [Overviews and
Factsheets]. Retrieved October 24, 2019, from US EPA website:
https://www.epa.gov/npdes/npdes-permit-basics

https://usinflation.org/us-inflation-rate/

Wang, J., Tyau, N. & Ybanez, C. R. (2019, January 9). *Farm communities face contaminated water from manure, nitrates, records reveal.* Retrieved from
https://www.oregonlive.com/pacific-northwest-news/2017/08/farm_communities_face_contamin.html

https://doi.org/10.2172/1413878


Wisconsin Department of Health Services (2015, September). *Manure Contamination of Residential wells.* Retrieved from

https://docs.legis.wisconsin.gov/statutes/statutes/94/701/3/c
About UniverCity Year

UniverCity Year is a three-phase partnership between UW-Madison and one community in Wisconsin. The concept is simple. The community partner identifies projects that would benefit from UW-Madison expertise. Faculty from across the university incorporate these projects into their courses, and UniverCity Year staff provide administrative support to ensure the collaboration’s success. The results are powerful. Partners receive big ideas and feasible recommendations that spark momentum towards a more sustainable, livable, and resilient future. Join us as we create better places together.