HEAT RECOVERY FROM COMPOSTING

A Step-by-Step Guide to Building an Aerated Static Pile Heat Recovery Composting Facility

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EXECUTIVE SUMMARY

Until recently, conversations involving energy recovery from waste, whether on-farm, municipal, or industrial, involved anaerobic digestion. While this waste management strategy is appropriate for many types of high moisture content feedstocks, it is less suitable for semi-solid and solid waste, limiting energy recovery to individuals with the right feedstocks and the capital to construct an anaerobic digester. However, the last decade has seen an increase in commercially-viable technologies capable of extracting the thermal energy (heat) from the composting process, allowing energy recovery to occur from drier feedstocks not typically used in anaerobic digestion. A detailed review of 45 different compost heat recovery systems (CHRSs) by the authors of this report also verified that recovering heat from the composting process is finally beyond the prototype stage, and is ready for widespread commercial use. In their review, they found that commercial scale CHRSs recovered an average of 194,200 BTU/hr, while mid-scale systems recovered 19,000 BTU/hr (Smith et al. 2016). With one gallon of oil being equivalent to roughly 138,500 BTUs, CHRSs are capable of displacing large volumes of fossil fuels used for domestic heating. Current uses for CHRSs include:

- Farm, residential, and commercial space heating
- Warm greenhouses and high tunnels for extended growing season
- Maintain temperature of anaerobic digester tanks
- Warm drinking water for dairy cows in the winter (increases milk yield)
- Heat water for cleaning equipment
- Dry biosolids to reduce landfill costs
- Warm outdoor pools and showers

With CHRSs proving to be commercially viable, the authors of this report found it necessary to document how to construct a heat recovery composting facility from the ground up. The basis for this report came from the detailed review on CHRSs, along with four years of designing, building, and managing the University of New Hampshire Heat Recovery Composting Facility in Lee, New Hampshire.

The objective of this report is to describe the process of building a heat recovery composting facility using the aerated static pile (ASP) method and Agrilab Technologies Heat Transfer System. The heat recovery composting facility, constructed at the University of New Hampshire (UNH) Organic Dairy Research Farm, serves as a case study. The report begins with a technology review, followed by detailed information on facility design, specific materials used, cost, and cost-saving strategies/considerations for those wanting to install this type of system at their site. While the facility was built on a university organic dairy farm to process agricultural wastes, a majority of the structural designs, materials list, and cost-saving strategies will be the same for any farmer (dairy, equine, poultry, etc.) or compost operator wanting to build this type of facility on their site. More specifically, this type of system is suitable for any type of semi-solid to solid waste being composted aerobically, whether animal, biosolid, digestate, municipal, yard, food, etc.

The ultimate goal of this report is to provide enough detailed information that compost operators can design their own ASP composting system, reducing the amount of time and money that would otherwise be spent on engineering and consulting costs. The step-by-step instructions from the planning phase through project completion, along with the materials and cost list (Appendix 1) also provide guidance to operators on

how to construct and purchase large portions of the system themselves, leading to substantial cost savings. This report can also be used to answer many technology and cost questions that are pertinent to policy makers and investors who may be considering supporting this type of venture. The reader is encouraged to reference this report to expedite the often timely design and funding phases that exist for these types of projects.

CHAPTER 1 INTRODUCTION TO THE TECHNOLOGY

AEROBIC HEAT PRODUCTION VS. ANAEROBIC BIOGAS PRODUCTION

An important point to make is that this technology involves composting, in which heat, not biogas (methane - CH_4), is being captured and utilized. In this type of aerobic system, CH_4 production from insufficient oxygen (anaerobic) is an economic loss, representing material that could have generated heat for capture through composting. Because anaerobic microbes are not as metabolically efficient, there is only a partial breakdown of the starting organic material, with a tremendous amount of chemical energy being left in the bonds of the CH_4 compound. Unless the end goal is anaerobic digestion with biogas production/capture, this situation poses problems for compost operators wanting to extract heat from composting feedstocks. These problems may include:

1. Reduced compost quality – many intermediate compounds that remain from only a partial breakdown of biomass are phytotoxic to plants (Epstein 2011, Misra et al. 2003). This is especially true for fatty acids.
2. Foul odors – originate from intermediate compounds and some end products [volatile fatty acids, ammonia (NH_3), and hydrogen sulfide (H_2S)] (Chiumenti et al. 2005, Wright 2001, Rynk et al. 1992)
3. Corrosion - H_2S and fatty acids (Chen et al. 2010).
4. Elevated greenhouse gas emissions - CH_4 is 21 times more potent as a greenhouse gas than carbon dioxide (CO_2) (US EPA 2013).
5. Reduction in compost sterilization – inefficient low heat composting will not destroy weed seeds and pathogens within the composting mix (Misra et al. 2003).
6. Heat recovery suffers – more energy leaving the system as CH_4 results in less heat production for recovery.

HEAT PRODUCTION FROM COMPOSTING

The bio-oxidation of organic material that occurs during composting is an exothermic reaction that continually releases heat, and can be represented by the general equation in (Figure 1).

$$\text{Organic Material} + H_2O + O_2 \xrightarrow{\text{Microbial Metabolism}} \text{Compost} + CO_2 + H_2O + NH_3 + NO_3^- + \text{Heat}$$

Figure 1: Basic Formula for Aerobic Composting

In a compost pile, temperatures will go from ambient → mesophilic → thermophilic → mesophilic → ambient (Epstein 2011). While the exact range for what is qualified as mesophilic or thermophilic varies in the literature, a general range is 50-110ºF for mesophilic and > 110ºF for thermophilic. Following pile formation, temperatures will often increase sharply, and reach thermophilic temperatures within a few days (Figure 2).

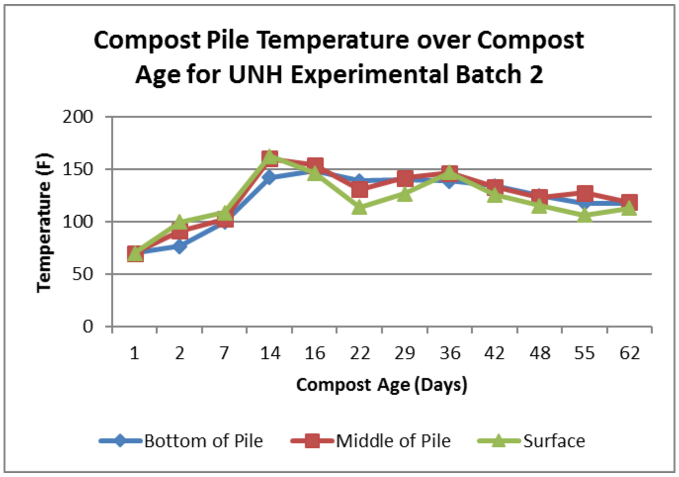

Figure 2: Compost Pile Temperature by Compost Age for UNH Experimental Batch 2

If heat is not removed, temperatures will increase to the point where the microbes start dying off (> 160ºF). In this thermophilic stage, oxygen demand and heat production are highest, as the microbes target and metabolize the most easily digestible materials first (starches, sugars and fats) (Epstein 2011, Rynk et al. 1992). During this stage, the amount of aeration needed for heat removal can be more than ten times the requirement of microbial oxygenation (Rynk et al. 1992). As the composting process continues, the quantity of easily digestible compounds decreases, leaving more difficult substances to consume (proteins, cellulose, and lignin). At this point, the cumulative metabolic rate (and microbial population) plateaus and begins to decline. As the microbial population declines, so does the pile temperature (Epstein 2011, Chiumenti et al. 2005). With heat extraction as a goal, maintaining pile temperatures between 130-150ºF and prolonging the point of plateau and temperature decline are two strategic goals for the operator. Although one may think that maintaining pile temperatures in excess of 160ºF would increase heat recovery from the system, that method would actually subject the microbes to inhibitive temperatures they could not survive. While the heat exchange system would perform well during this short phase, long-term heat recovery would likely suffer. Achieving maximum heat production requires the provision of an optimal microbial living environment, where they can thrive and reproduce.

Basic Guidelines for Composting

1. Organic material – feedstocks are thoroughly mixed and have a combined carbon-to-nitrogen (C: N) ratio of 27:1 - 30:1 (Epstein 2011)
2. H_2O – maintain pile moisture content between 50-60% (Epstein 2011)
3. O_2 – maintain compost pile oxygen content between 10-18% during the active phase (Epstein 2011) and 1-5% during the maturation phase (Chiumenti et al. 2005). It is also important to reduce preferential airflow that can form from large pits and mounds on the pile, or cracks that run from the bottom to the top of the pile (both will be discussed in detail later).
4. Temperature - maintain pile temperatures under 150ºF through aeration and/or turning (Epstein 2011)
5. Porosity - free air space should be 35-50% (Chiumenti et al. 2005)
6. pH – maintain between 5.5 – 8.0 (Chiumenti et al. 2005)
7. Material size - no larger than 1-3'' (Chiumenti et al. 2005)
8. Contaminants - Absence of materials toxic to microbes
9. Drainage – compost leachate is drained away from the pile to prevent an anaerobic base from forming

Individuals interested in more specific details concerning the science of the composting should reference Epstein (2011), Chiumenti et al. (2005), Haug (1993) and Rynk et al. (1992).

HEAT RECOVERY FROM COMPOSTING

Numerous compost heat recovery systems (CHRSs) have been tested over the years, and are described in great detail in Smith and Aber (2016). In their review, three primary mechanisms of how to extract heat from a composting pile were described. The first method originated in ancient China 2000 years ago, and involved growing crops above a composting mass, which supplied heat to the root zone of crops through convection (Brown 2014). This system was further advanced in France during the 1600s, where acres of glass-enclosed hotbeds were used for crop production (Aquatias 1913). As with the Chinese system, a trench was filled with composting manure and was capped with topsoil for crop growth. As the manure composted, heat rising through convection warmed the roots of the crops, allowing for several months of season extension in the spring and fall. This system lost favorability in France in the early 1900's, when the primary composting feedstock (horse manure) was no longer in large supply, due to the replacement of the horse with the automobile. A version of this method made a short comeback from the 1940s – 1970s by English and Dutch farmers, who used decomposing straw bales to extend the growing season of tomatoes, cucumbers and lettuce (Loughton 1977).

While convection is the simplest and least costly method in extracting heat during the composting process, it is also the least efficient and is limited to horticultural applications. The second approach to recover heat from composting is conduction-based, which offers a substantial advance in both heat recovery and utility. This method was pioneered by Jean Pain in the 1970's at his farmstead in France. In his system, a 55-ton pile of chipped brushwood, with hundreds of feet of coiled tubing located within the composting mass, was used to heat water from 50°F to 140°F at a rate of one gallon per minute for six months. The water was used to warm a high tunnel and to heat a farmhouse (Pain and Pain 1972). What made this system a substantial leap forward was the ability to use the thermal mass of the composting pile to warm water that could be used for any purpose. This method is still used today and is described in detail in Brown (2014).

Although warming water through conduction of composting feedstocks is more efficient than convection-based systems, this method is more suitable for backyard operations, where the time and labor consuming aspects of installing and removing the pipe during pile formation and breakdown can be absorbed by an enthusiastic homeowner. This method is typically not suitable for commercial operations, where revenue is the goal and labor/time is accounted for. Problems can also arise if too much heated water is removed from the pile, and/or the replacement water is too cold (Smith et al. 2016). This scenario can inhibit microbial growth and even crash the microbial population, causing rancid conditions. However, if managed properly, conduction-based CHRSs can be a successful option for small-scale operations.

An improvement to using pipe embedded within the composting mass is to install the recirculating heat exchange pipe within concrete below the composting feedstocks. This type of system is more suited for commercial operations, as the time and labor aspects of installing and dismantling the pipe are avoided. While the addition of concrete increases the cost of the operation, it is a more realistic option for commercial operations processing large quantities of biomass. A commercial composting facility in New Brunswick, Canada uses this type of system to prevent snow and ice from freezing GORE^{TM} compost covers to the ground (Allain 2007). However, as with the within-pile heat recovery systems, one has to be careful with how much heated water is extracted, in addition to carefully monitoring the temperature of the makeup water. These details were not considered at a separate Canadian composting facility when trying to extract heat from water-filled pipe below composting fish waste. The plant operators circulated the heat exchange liquid too fast, removing heat until it caused the compost pile to cool down and crash. The result was putrefaction of the feedstocks and odor complaints from adjacent neighbors that resulted in the facility shutting down. If less water were pulled from the system, this approach should have worked. However, there is risk when extracting heat from a within-slab system, as the slab is part of the thermal mass of the pile. Pulling too much heat from one section of the pile (in this case the bottom) risks anaerobic and odorous conditions.

The final approach to recover heat from the composting process is to extract the thermal energy from the exhaust vapor using an aeration system. By mechanically moving air through the pile, the aerobic microbes receive needed oxygen, while removing excess heat that can inhibit their growth and reproduction (Epstein 2011, Rynk et al. 1992). Importantly, heat recovery does not interfere with the composting process like conduction-based recovery systems. The simplest method under this approach is to use the heated compost vapor directly. These systems usually involve placing perforated PVC pipe below composting feedstocks and forcing air through the composting pile (positive aeration) with a fan. As air is forced through the decomposing material, hot compost vapor is forced out. Because of high levels of NH_3 and VOCs in the compost vapor stream, a biofilter is necessary to reduce these odorous and potentially harmful gases. Early research utilizing this technology came from the New Alchemy Institute, where a winter greenhouse was warmed through compost vapor, which had been sent through a biofilter (Fulford 1986). More recently, Adams (2005), explored the use of compost vapor to heat greenhouses in Vermont.

While positive aeration systems serve as a valuable tool for season extension and reduced heating costs for greenhouse and high tunnel growers in cooler climates, it has limited applications, due to the difficulty in capturing the diffused heat across the pile. The amount of available heat in the air is also limited, with a study by Themelis (2005) finding that only 13.4% of the heat generated within a compost pile is contained in the air. Composting systems using positive aeration also risk corroding any type of building or structure they are housed in, as highly corrosive vapor is being blown into the airspace.

A more effective method of capturing heat from composting is through negative aeration, where air is pulled through the composting mass and into a single chamber where the heated vapor can be directed. In some systems, this heated vapor is sent through a biofilter, where the contaminants are scrubbed and the heat and CO_2 are diffused into a greenhouse (Smith et al. 2016). However, a more efficient system is to direct the heated vapor into a chamber containing an air-to-water heat exchanger. By using a heat exchanger, the thermal energy contained within the water molecules of the vapor stream can be extracted. This is important, as a majority of the energy balance within a composting pile is contained in the water vapor. Themelis (2005) found that 63% of the thermal energy within a composting pile was in the water vapor. Furthermore, if an air-to-water heat exchanger is used, heat recovery does not influence the composting process and the heated water can be used for more than just horticultural applications. Agrilab Technologies Inc., developed such a system, by using Acrolab's Isobar® Heat Pipe technology and the ASP composting method (Agrilab Technologies is a U.S.A. based vendor of the Acrolab Isobar system).

ACROLAB'S ISOBAR® HEAT PIPE TECHNOLOGY

Acrolab's Isobar Heat Pipe is a two-phase, super-thermal conductor that provides thermal uniformity across the pipe by immediately transferring heat evenly across the entire unit (Acrolab 2013). The heat exchanger uses an extremely high-grade stainless steel evacuated pipe filled with a working refrigerant. When heat is applied to the evaporator side of the pipe, the refrigerant inside heats up and vaporizes. That vapor travels the length of the pipe and condenses on the cooler side, releasing the latent heat of condensation. After condensing, the condensate is returned to the warm end of the pipe through capillary action in a metallic wick contained within the isobar (Acrolab 2013). The beauty of the system is that there are no mechanical parts within the isobar (Figure 3).

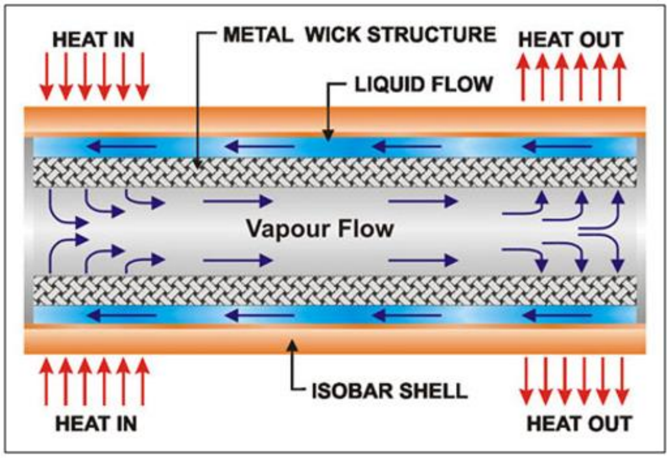

Figure 3: Internal Workings of Acrolab's Isobar Heat Pipe (Acrolab 2013)

The Isobar Composting and Thermal Energy System developed by Agrilab Technologies, uses this technology, by utilizing the metabolic heat generated by microbes during the composting process for heat exchange. The system uses 6-12 Isobars, 30-60' in length, contained within a single unit with a vapor chamber and a highly insulated bulk storage tank of water (number and length of Isobars depend on monthly feedstock tonnage). The Isobars run the length of the unit, with roughly ten feet contained within the sealed tank of water, serving as a thermal battery (Figure 4).

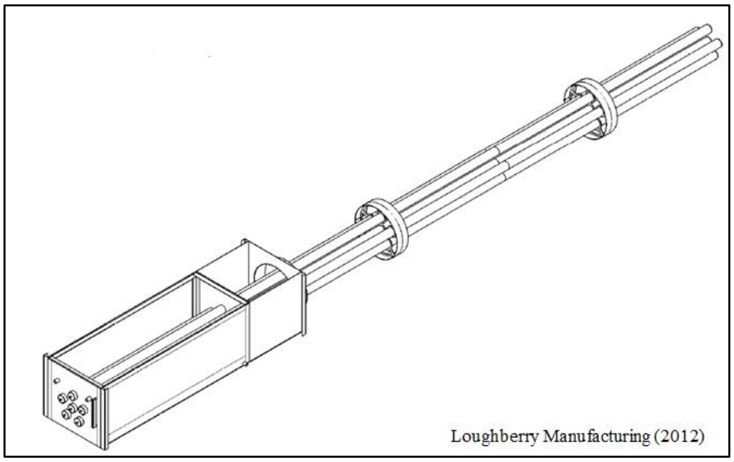

Figure 4: UNH Isobar Heat Exchange System (Loughberry Manufacturing 2012)

The system operates by pulling heated vapor from composting feedstocks through the aeration network and into the vapor chamber containing the array of Isobars. When the 120 – 165°F vapor condenses on the cooler Isobar surface, it transfers the latent heat condensation to the pipe, which is used to vaporize a refrigerant. The vapor within the Isobar travels up the pipe into the section of the unit contained within the highly insulated storage tank of water. The cooler water in the tank causes the vapor within the pipe to condense, once again transferring the latent heat of condensation, only this time it is transferred from inside the pipe to the water (Figure 5). The heated water (typically 100-140ºF) can then be used for any application requiring hot water (radiant floor heating, aquaculture, greenhouse, preheater for an anaerobic digester, preheater for a standard hot water system, etc.). Current uses for this type of system can be found in Appendix 2.

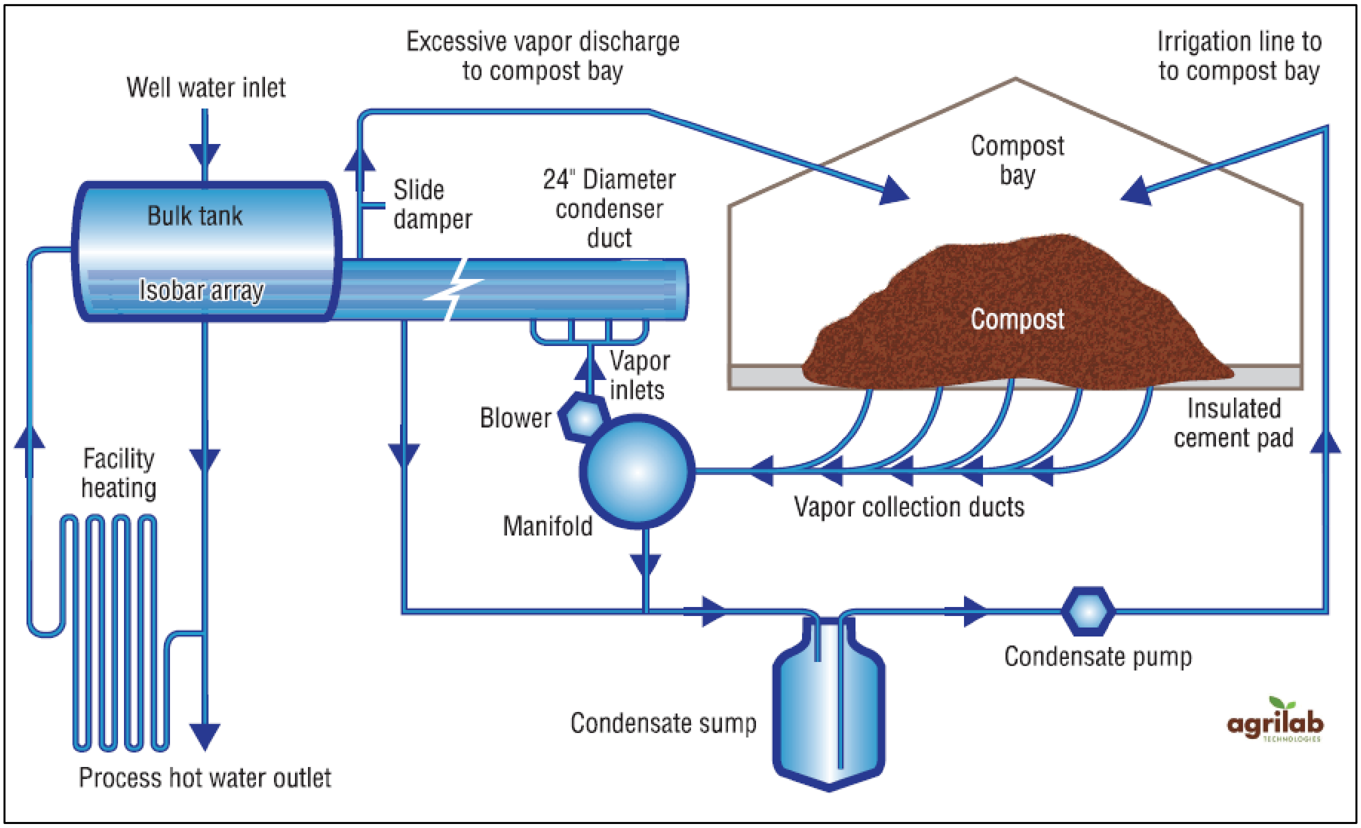

Figure 5: Flow Diagram of Heat Recovery System (Smith and Aber 2014)

HEAT RECOVERY POTENTIAL FROM AGRILAB'S ISOBAR SYSTEM

The heat recovery potential from one of Agrilab's systems is variable and depends on a number of factors including: biomass volume, feedstock biodegradability, heat exchanger type & size, and operational-specific variables (aeration schedule, duration of composting, pile watering, etc.). When looking at biomass volume, more biomass typically results in greater heat recovery because of the ability to have a shorter compost residence time. As illustrated in Figure 2, compost temperatures peak early in the process and gradually decrease over time. The ability to load material more frequently allows the operator to extract heat from the thermophilic phase of the composting process, when temperatures are highest. More biomass also allows the operator to make larger piles, which have a smaller surface area-to-volume ratio, meaning less heat is lost to conduction, convection, and radiation.

The amount of heat that can be extracted from one of these systems is also dependent on feedstock biodegradability. During the initial compost trials at the facility described in this report, the compost mixture was cow manure and spent animal bedding (eastern white pine). However, this particular mix was not very successful at producing compost vapor temperatures above 135°F, in part because eastern white pine has been found to be anti-microbial, which makes for great animal bedding, but very poor for composting. Haug (1993) also reported the low biodegradability of pine species, and the issues that can arise from its use in compost mixes. The solution to our biodegradability problem was to include horse manure and spent hay bedding in the mixture, both of which are highly biodegradable and provided more food for the heat-producing microbes. Vapor temperatures consistently exceed 150°F with the new mix (Figure 6).

With these variables in mind, the two largest Agrilab systems (Diamond Hill Custom Heifers and Sunset View Farm) have reported recovery rates of 200,000 BTU/hr during active aeration (Appendix 2). The much smaller heat recovery system at UNH has reported heat recovery rates of 34,500 BTU/hr (Figure 6). The large difference in heat recovery rates between systems is due to feedstock volume, heat exchanger size, and biodegradability of the feedstocks in the compost mixes (Appendix 2).

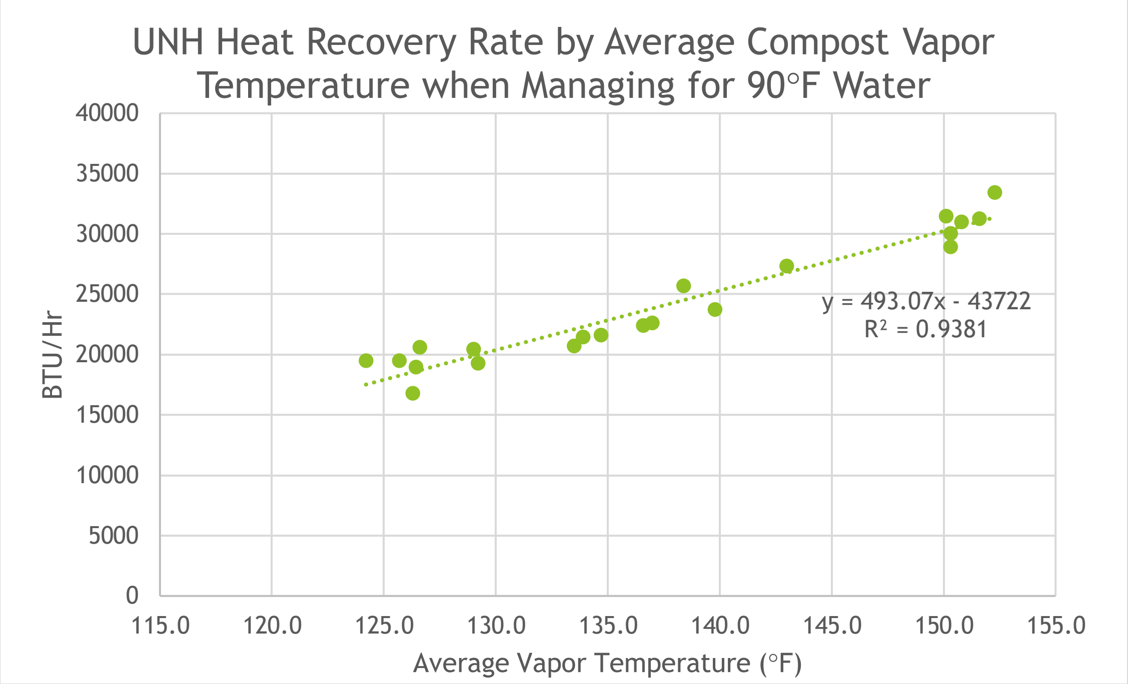

Figure 6: Heat Recovery Rate by Average Compost Vapor Temperature

As illustrated in Figure 6, a linear relationship exists between compost vapor temperatures and the heat recovery rate (BTU/hr). This is important to know from a management perspective, as there is a decreasing return per unit of biomass as the material ages and cools down. As stated previously, more frequent loadings allow the operator to manage the system in the highest heat producing phase of the composting process, increasing the heat recovery rate.

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CHAPTER 2 ORIGINS OF THE UNH PROJECT

The idea for the heat recovery composting facility at the UNH Organic Dairy Research Farm originated from a USDA Sustainable Agriculture Research and Education (SARE) grant. One of the goals of the grant was to develop a more-closed agricultural ecosystem (agroecosystem), where there is more internal cycling of nutrients, water, and energy. Importantly, the methods used to create the more-closed agroecosystem had to be profitable and replicable for farmers in the region. A large component of making the farm a more-closed agroecosystem involved reducing energy imports to the farm. A second major component was improving the farm's manure management system, which involved storing manure in a back field until it was applied to fields after spring and fall hay cuttings. While this type of management is common for many dairies, storing manure for extended periods of time does pose several concerns:

1. Standing manure piles serve as a breeding ground for biting flies that pose health issues and discomfort for cows (Campbell et al. 1993).
2. Anaerobic manure piles produce strong and unpleasant odors and emit CH_4, which is a powerful greenhouse gas.
3. Standing manure piles can leach NO_3^- into groundwater, contributing to nutrient runoff and potential eutrophication of nearby waterways.

The initial solution to the manure management problem was to develop a passive aeration windrow system to process the manure and spent bedding on the farm. This type of system is inexpensive and has proven to be successful in composting animal manures (Rynk et al. 1992). Three windrows were created with the dimensions of 30'L * 8'W * 4'H. Cost savings in fuel and labor were immediately recognized from a reduction in material to be spread on the fields. The final compost product was also more dry and stabilized, reducing runoff that was occurring when the feedstocks were not being managed aerobically. However, after a year of composting, UNH researchers and a private donor began discussing the possibility of building a heat recovery composting facility using Agrilab's Isobar heat pipe technology. They determined that a more advanced composting system would help address both the manure management and energy goals of the farm in one step. At the time, only one other facility in the world (Diamond Hill Custom Heifers in Sheldon, Vermont) was using this technology on a commercial level. Their facility (built in 2005) had 2000 heifers and processed 150 tons of feedstock every month (Tucker 2006). However, the UNH Organic Dairy Research Farm was much smaller, producing a fraction of the waste. As with most composting projects, economies of scale have to be considered. While the technology was proven to work for a large-scale dairy operation (Tucker 2006), it was yet to be tested on a small dairy farm with under 100 head of cattle. However, the research team and private donor decided that it was worthwhile to construct the facility, as it could be used to refine compost heat production and extraction methods, and also determine the economics of the composting system on a smaller-scale. Designs for the UNH facility began in May 2012 and the facility was completed in June 2013.

CHAPTER 3 PLANNING AND SIZING THE FACILITY

FEEDSTOCK PARAMETERS

The first step in designing an ASP composting facility with Agrilab's heat recovery unit is to determine the quantity of waste material being produced daily, along with the corresponding feedstock chemical and physical properties. In assessing feedstock quantity, the smallest of the heat recovery systems from Agrilab Technologies, require 60 yd^3 of mixed feedstock per month (Agrilab Technologies 2013). It is important to note that the feedstock requirement is based on a mixture of waste materials that collectively result in conditions that are optimal for microbial growth. The three most important factors to consider are C:N ratio, moisture content, and bulk density. A compost recipe builder, similar to the one presented in Rynk et al. (1992), can be used to determine whether one has enough waste materials in the right proportion to generate the 60 yd^3 minimum. In situations where there is a deficit of material, feedstock can either be imported, or in some cases, stockpiled from other times of the year when that material is in excess. For instance, the primary carbon source for the UNH facility comes from the bedded pack barn, which is cleaned out twice a year (May and November). Because it is only cleaned twice a year, the spent bedding has to be stockpiled. Likewise, during the summer months, manure is in shortage because the cows are out at pasture for more than eight hours a day. Excess manure from the winter months is stored in small windrows to supplement the summer composting batches. However, stockpiling is not ideal, as microbes will consume the stockpiled material, reducing heat recovery potential. In assessing feedstocks, it is important to realize that a deficit in nitrogen will slow down the composting process, reducing heat recovery, while too much nitrogen will increase temperatures too quickly and result in increased NH_3 volatilization and lower quality compost (Chiumenti et al. 2005, Rynk et al. 1992).

ASSESS HOT WATER DEMAND AND LOCATION

After determining whether enough biomass is available in the optimal proportions, the next step is to assess hot water demand and whether the heat recovery unit is economical. From a practical standpoint, if one is already planning on building an ASP composting facility, the added cost of the heat exchange unit will likely have a favorable payback period (Refer to Appendix 2). Regardless, assessing the current energy demand is valuable as the heat-exchange unit can be sized accordingly, ensuring it is not overbuilt. For UNH, the primary hot water demand is for cleaning equipment in the farm's milk house, requiring 180°F water for sanitization purposes.

FEEDSTOCK RESIDENCE TIME WITHIN FACILITY

The next step in the planning phase is to determine the residence time the composting materials will remain in the facility. In making this decision, it is important to consider whether the compost will be cured in the facility, as that decision will require more space, due to a slower turnover rate. For UNH, we decided to cure the compost in the facility (60-day residence time). The advantages of curing compost within a facility are: faster time to maturation due to forced aeration, less chance of contamination from weed seed, will not be saturated by rain, and results in the elimination of an extra step in material handling. However, curing compost within the facility requires a larger building and higher initial capital cost. An alternative is to have a much shorter residence time within the facility, and cure the compost outside under a compost cover. Compost covers are breathable, shed rain, prevent seed from entering, and are a fraction of the cost. Managing the system under a shorter residence time (if one has enough biomass) is also strategic from a heat recovery and economic standpoint, as compost temperatures under this type of system peak during the first few weeks of composting, and gradually decrease afterward (Figure 2). A shorter residence time also allows heat extraction to continually occur during the highest heat producing period of the composting process.

SIZING THE FACILITY

The size of the composting facility can be estimated with information on feedstock quantity and the length of time it will spend in the facility. With UNH as an example, facility size was based on 200 yd^3 of feedstock (manure, waste feed hay, and spent animal bedding) per month, and a feedstock residence time of 60 days. Assuming a pile height of 8 feet, the length and width of the composting floor can be determined based on a combination of site conditions and building design to get the needed volume. In our scenario, each bay was 32'L * 20'W * 8'H (190 yd^3/month) (Appendix 3).

After calculating the dimensions of the composting floor, extra footage has to be added for the mechanical room and walkways. For UNH, the isobar unit going into the mechanical room had dimensions of 30'L * 34.5''W * 30''H. In addition to the Isobar unit, extra space has to be added for the aeration pipe and the leachate system. In our scenario, the mechanical room ended up being 10'W * 96'L. The composting floor also had an additional 8' concrete apron for an internal walkway to the exits. The walkways were intentionally built with extra width at these locations to better accommodate large groups visiting the facility. In sizing a non-research facility, both the width of the mechanical room and the width of the internal apron can be reduced by several feet to reduce costs.

With information on the size of the composting floor, mechanical room, walkways, and all other needed internal space, a total footage can be estimated. For UNH, the resulting facility was 96'L * 50'W * 22'H (Appendix 3). For reference, while the facility was built to process 200 yd^3/month with a 60-day residence time, a facility of the same size only housing the feedstocks during the active phase (≈ 3 - 4 weeks), could go from processing 200 yd^3/month (4,800 yd^3/yr) to 800 yd^3/month (9,600 yd^3/yr). As mentioned earlier, the residence time the compost stays in the facility greatly affects the amount of biomass that can be processed annually.

AERATION FLOOR DESIGN

When designing the aeration floor, the successes and failures of past ASP floor designs were considered, to ensure the piles would receive an optimal level of aeration across the entire pile. It is important to note that there is a decrease in oxygen provided to the pile as the length from the blower increases. For this reason, piles should not exceed 50-75' (Rynk et al. 1992). At the UNH facility, aeration lines were 30' in length and were made of 4'' PVC pipe, which fit within the general recommendation of aeration lines being 4-6'' in diameter (Epstein 2011, Rynk et al. 1992). Each line had ½'' diameter aeration holes drilled every 6'' down the apex of the pipe. The specific size of the aeration holes was based on the diameter of the pipe and the length of the run. From a graphical standpoint, this is represented in (Figure 7).

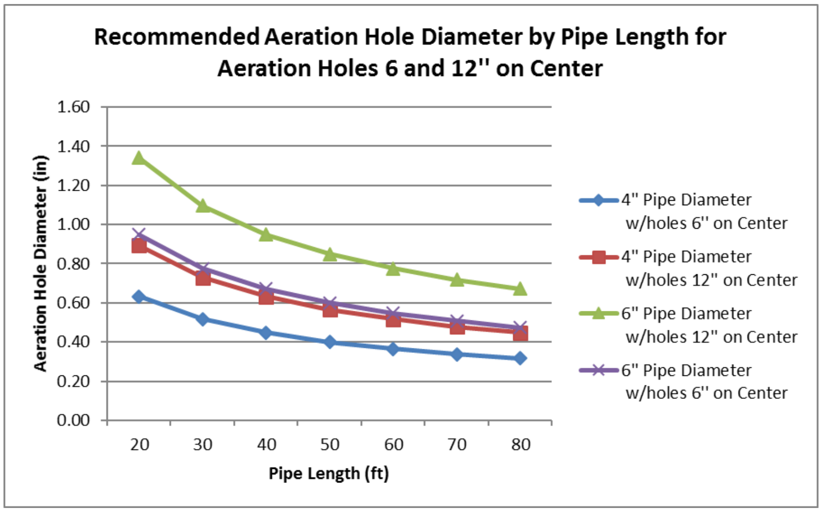

Figure 7: Recommended Aeration Hole Diameter by Pipe Length

__A Common Equation Used to Calculate Aeration Hole Size__

$$\text{Hole diameter} = \sqrt{[(D^2*S)/(L*12)]}$$

- *D = pipe diameter in inches*
- *L= pipe length in feet*
- *S= hole spacing (in)*

Although pipe with holes pre-drilled is available, it is best to purchase pipe and drill the holes on-site following the cement pour. The purpose of drilling the holes after the pour is to have the ability to fill the pipes with water to prevent them from moving or floating during the concrete pour, and prevent cement and other debris from getting into the aeration network during the construction process (both issues will be discussed in detail later).

After deciding on pipe diameter, length, hole spacing, and hole size, the next step is to determine the spacing between the aeration pipe. The general recommendation is to have aeration lines 3-4 feet apart (Epstein 2011). Closer spacing is recommended for materials with a higher bulk density (manures, sludge, etc.), where higher oxygenation is required. At the UNH facility, aeration lines were set up with research trials in mind, and were spaced to accommodate treatment walls (Appendix 3). In a non-research facility, a uniform spacing within the 3 - 4’ range would most likely be used for all the aeration lines, compared to our facility, which had varying spacing.

In addition to having 3 - 4’ between each pair of aeration lines, the two externally located lines on either side of the facility should be cast 3 - 4’ from the side walls (Figure 8). The reason to cast the first aeration line 3 - 4’ away from any wall is to prevent preferential air channels from the Coanda Effect, which is the tendency of moving air or liquid to attach itself to a nearby surface, and flow along it. In a composting pile, walls too close to an aeration channel can serve as this surface and result in preferential airflow on the edges, causing more oxygen/faster decomposition on the sides and less oxygen/slower decomposition in the middle (Chiumenti et al. 2005). As the pile continues to decompose under

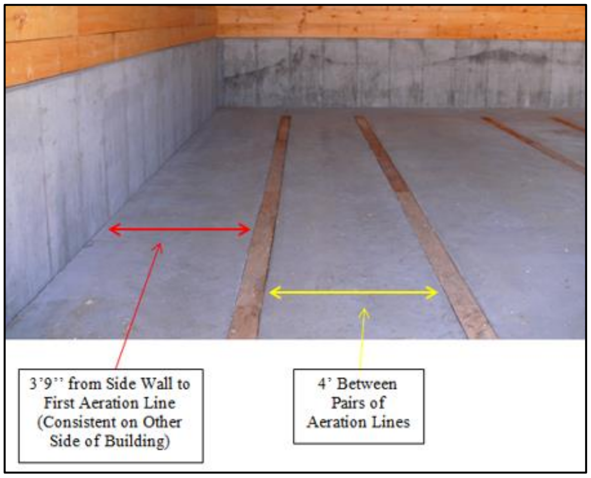

Figure 8: Aeration Floor Spacing at UNH Composting Facility

this condition, the problem can become worse, as pile slumping on the edges (from faster decomposition) will cause further preferential airflow in those locations, affecting the decomposition rate of the entire pile. Heat losses will not only occur from reduced decomposition in the middle of the pile, but will also occur from cold air being pulled into the aeration system from the edges of the pile.

In addition to preventing the Coanda Effect from the side walls, the section of aeration floor along the back push wall should also have a 3 - 4’ aeration dead zone to prevent preferential air channeling. At the UNH facility, the 3’ section of each aeration line closest to the back push wall did not have aeration holes and had a layer of concrete overtop instead of a cover plate (specifics will be discussed in detail later) (Figure 9).

Figure 9: Aeration Line Floor Spacing at the UNH Composting Facility

Cost Saving Tip # 1: *When considering cost-saving strategies, ensuring the facility is not overbuilt is a major one. This is especially true for the aeration network, which needs to be carefully planned and sized to meet the aeration demand of the various materials being composted. When deciding on pipe diameter for the aeration floor, it is important to consider the total airflow requirements in relation to the pile height and length. Increasing from a 4’’ to 6’’ diameter PVC aeration channel has thousands of dollars in cost ramifications. The general aeration setup within the mechanical room of these systems involves at least one size increase in PVC diameter beyond what was cast in the aeration floor. While the cost difference between 6’’ and 8’’ PVC pipe and fittings is not too significant, the cost difference between 8’’ and 10’’ PVC is enormous, costing several hundred dollars more per fitting and section of pipe. In most cases, 10’’ PVC pipe is not necessary, and careful planning should verify this point. The original aeration system at the UNH facility was constructed in a manner requiring 10’’ PVC pipe in the back mechanical room and was estimated to have cost an additional $12,000. The extra cost was attributed to:*

- *Extra cost in the PVC pipe and fittings*
- *Extra cost in shipping weight from the heavier components*
- *Extra labor in installing heavier and bulkier materials*
- *Extra sealant*
- *Extra support structures (clevis hangers, pipe riser clamps, threaded rods, etc.)*
- *Contractor markup (usually 25%)*

Cost Saving Tip # 2: *A second cost-saving strategy is to purchase all the PVC pipe, PVC fittings, sealant, aeration fan(s), flexible couplings, and support structures vs. having them purchased by a contractor. An important point to make is that this type of cost-saving strategy often comes with the trade-off that the contractor will not warranty the construction materials provided by the owner.*

FACILITY LOCATION

Specific information on the steps involved in siting a facility were omitted from this report, as each farm/compost operation will have tremendous variability with regard to proper location. For reference, detailed information on this topic can be found in Epstein (2011) and EPA (1994). However, some basic guidelines are provided below:

- Avoid close proximity to neighbors, unless a powerful air filtration system and biofilter are used. The single greatest cause of compost facility closures is due to nuisance claims from odor (Epstein 2011).
- Ensure the facility has adequate fire lanes on all sides and room for feedstock to be pulled out and piled should an internal smoldering fire occur and require breakup (code requirement for UNH facility).

- ***Cost Saving Tip # 3****: Site the facility as close to the feedstocks as possible and try to have straight-line transport of feedstocks to the composting bays. Minimizing feedstock handling time by siting and orienting the facility properly can save a tremendous amount of money (time, labor, fuel, etc.) with regard to material handling.*

In addition to the above recommendations, some specific location considerations for a heat-recovery facility using Agrilab's Isobar System are:

- Minimize distance from hot water production to hot water use. However, if using an underground insulated PEX pipe to transfer the hot water from source to sink, losses are only 2-3ºF per 100' length if buried properly (OWFB 2013). Siting to reduce material handling should take precedence.
- If attaching a high tunnel or greenhouse, proper facility orientation is needed to ensure shading from trees or other structures does not become a problem.

For reference, UNH sited the composting facility in a location that was closest to the feedstocks being composted. The reduction in time for material handling was determined to be the greatest factor in locating the facility (Figure 10).

Figure 10: Aerial View of UNH Organic Dairy Research Farm

CHAPTER 4 BUILDING A HEAT RECOVERY COMPOSTING FACILITY

The following sections outline the step-by-step process of building the UNH heat-recovery composting facility, with recommendations to operators on design and the various cost-saving strategies that can be used at their sites. The reader is encouraged to reference the appendices for additional diagrams/specifications and cost structure.

SITE PREPARATION

Due to the high variability in soils and site conditions, site preparation should be assessed by the contractor hired for that particular job. One important consideration that may be slightly different from standard practices is that composting facilities require more attention with regard to drainage. Because there is potential for pollution of waterways from nutrients originating from the feedstocks, compost, and compost leachate (primarily nitrogen and phosphorus), all drainage from the site should pass through some form of filtration, whether a lagoon, engineered wetland, or a small portion of an agricultural field. At the UNH facility, drainage is directed into a portion of an agricultural field, which eventually travels into a swale, leading into the nearby farm woodlot. As with odor, careful planning of drainage needs to be assessed before a problem actually arises. Failure to do so could result in significant fees or facility closure.

UNDERGROUND SLAB AND CONCRETE WALL PREPARATION

Underground cold and hot water lines (1'' PEX Cresline HD-160) were installed prior to concrete forming. Both lines were set in a 5' trench between the milk house (location of hot water demand) and the future mechanical room (280 linear feet). The lines were 8'' apart, and had 6'' of sand surrounding them in all directions. Compacted backfill was put overtop. The 1'' PEX cold water line was connected to a ¾'' PEX line at the entrance of where the mechanical room would be located and led to a frost-proof post hydrant (Campbell CYH-5 Frost Proof Yard Hydrant) in the location of the main composting floor. A second ¾'' cold water line was also installed off the first line to a frost-proof post hydrant at the mid-point of the mechanical room. Both hydrant lines were buried below the frost line (5') and were marked and taped to prevent soil from entering the pipe until future hookup.

The 1'' hot water supply and return lines were contained within a heavily insulated pipe (Uponor Pre-Insulated Pipe Systems ASTM Ecoflex Thermal Twin), which are often used for outside wood boiler systems (Figure 11). As with the cold water lines, the pipe ends were taped until future hook-up to the heat exchange system in the mechanical room. The primary 1,500-gallon precast concrete leachate tank (Phoenix Precast Products) and small section of 4'' PVC connecting ductwork were also installed at this time (Figure 12).

Figure 11: Insulated PEX Pipe

Figure 12: Compost Leachate Tank at UNH Facility

Cost Saving Tip # 4: *If possible, install a leachate tank with a capacity > 4000 gallons. While smaller leachate tanks are less capital initially, they also reduce the ability to pump large volumes of leachate at a time for field application. Compost leachate is high in nutrients and serves as a great fertilizer/irrigation source, especially on farms. However, 1500 gallons is typically not enough volume to justify bringing out a tanker truck that usually has a capacity > 4000 gallons. As a consequence, the tank needs to be pumped more often, which may add cost to the operator.*

After installing the water lines and leachate tank, forms for the side walls and back push wall were constructed. The forms for the back push wall had 16 sleeves for the 4’’ PVC aeration lines (4 lines per bay). The forms for the back mechanical room also had a sleeve installed for the main electrical line.

Cost Saving Tip # 5: *During this stage of construction, it is important to identify and plan for all possible sleeve locations, as drilling holes after pouring concrete is much more expensive. Additionally, the larger sleeves for the aeration lines through the back push wall should be a tight fit and not oversized.*

POURING CONCRETE WALLS

The first pour at the UNH composting facility was the push wall, two side walls, and five concrete piers for the front supports of the building. The back push wall was the thickest and had the largest footings to accommodate a front end loader pushing material against it. The dimensions were 96’L * 12’’ W * 8’H. The footings were 96’L * 6’ 6’’ W * 1’ H (Figure 13).

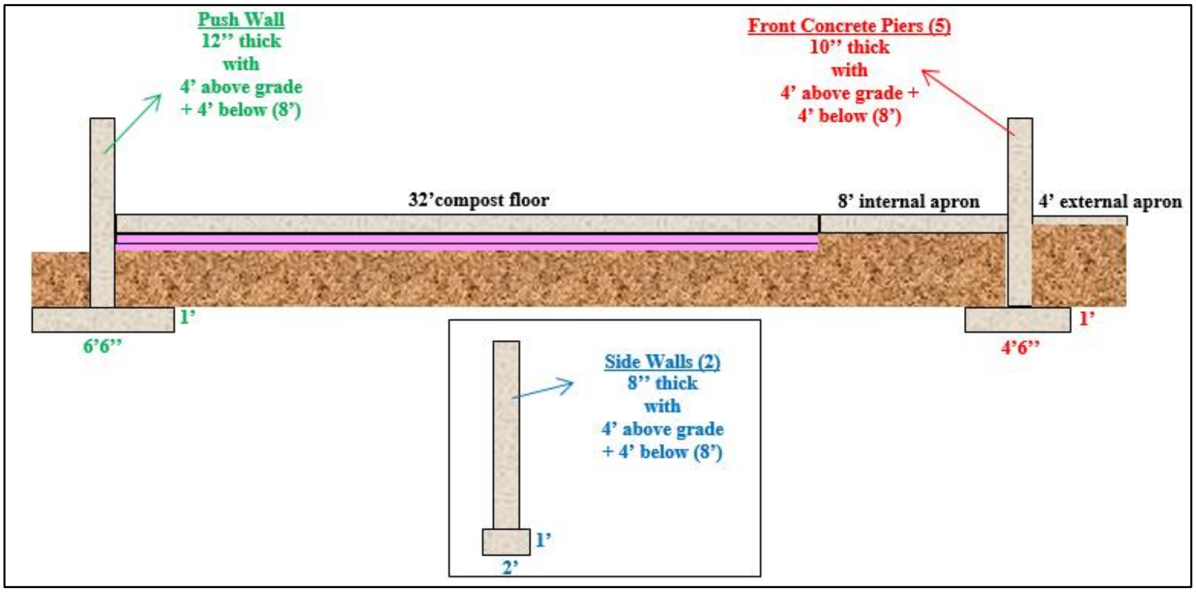

Figure 13: Concrete Dimensions at UNH Composting Facility

The dimensions of the two side walls were 40’ L * 8’’ W * 8’ H. The footings were 40’ L * 2’ W * 1’ H. The two side concrete piers in the front of the building were 2’6’’ L * 10’’W * 8’ H, with footings of 2’6’’ L * 4’6’’ W * 1’H (Figure 14). The three internal piers had dimension of 3’8’’ L * 10’’ W * 8’ H, with footings of 3’8’’ L *4’6’’ W * 1’ H. After the walls and piers cured, they were backfilled and brought to grade with compacted fill.

Figure 14: Concrete Piers at the UNH Composting Facility

The second pour at the UNH facility was the wall and piers for the back mechanical room. The dimensions were 32’3’’ L * 8’’ W * 6’ H, with footings of 32’3’’ L * 2’ W * 1’ H. In addition to this wall, eight concrete piers were cast to continue the structural support for the back of the building. The eight concrete piers were 12’’ L * 8’’ W * 4’ H, with footings of 2’ * 1’ (Figure 15 and Figure 16). After the wall and piers cured, they were backfilled and brought to grade with compacted fill.

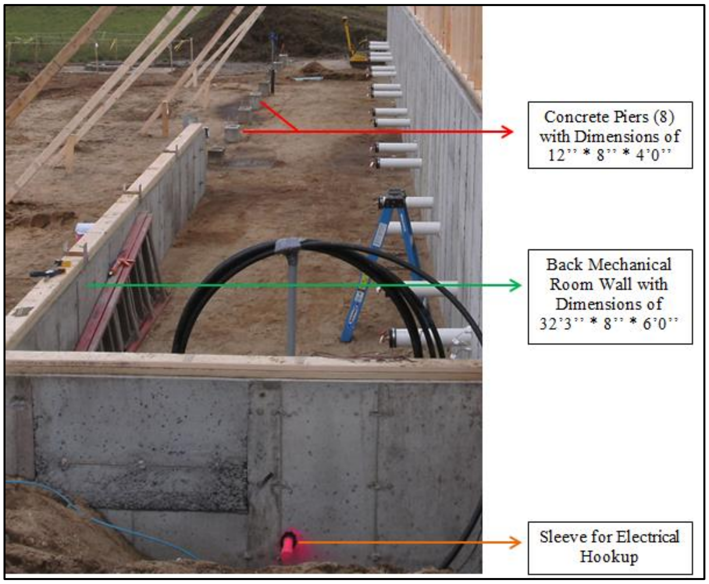

Figure 15: Back Mechanical Room After First Concrete Pour

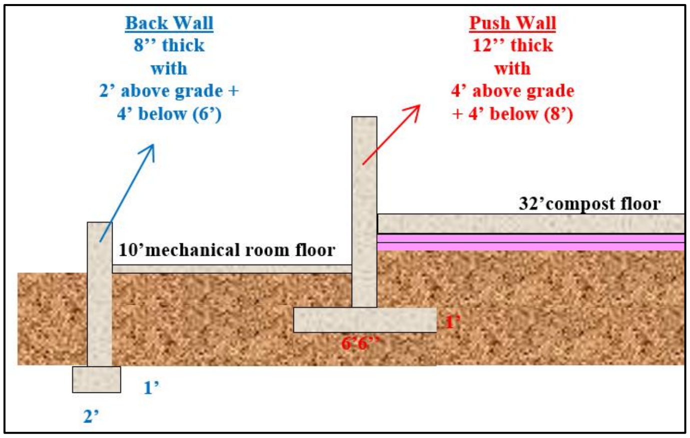

Figure 16: Back Mechanical Room Concrete Dimensions

***Cost Saving Tip # 6**: The amount of concrete used to construct the UNH facility was substantial (≈ 225 yd^3) and was one of the larger expenses in the project (Appendix 4). However, cost was reduced by using 5 ½’ of wood for the upper portion of the back push wall and side walls, reducing the concrete requirement by 30 yd^3 (Figure 17). When substituting wood for concrete, it is important to note the decreased longevity of the wall and the need to replace the wood at some point in the future.*

Figure 17: Back Push Wall at UNH Composting Facility

If using wood, it is important to note that the material may warp, due to the high heat and moisture from the composting process. Warpage is especially problematic if the mechanical room is on the other side of the wall and has a ventilation system. This is because the ventilation system will draw compost vapor and dust through the cracks between the boards and into the mechanical room. This poses a potential health concern, and needs to be addressed with some form of vapor barrier. To address this issue, UNH used 4’ * 8’ * 3/8’’ plywood and attached plastic sheeting (FrostKing 10’ * 25’ rolls) for the vapor barrier, and then used rough pine lumber (2’’ * 10’’* 16’) for the compost-to-wall interface (Figure 18).

Figure 18: Vapor Barrier on Back Push Wall at UNH Composting Facility

***Cost Saving Tip # 7**: Another major cost saving strategy, which could be utilized for those installing a high-tension fabric structure, would be to use interlocking concrete waste blocks for the side walls (Figure 19).*

Figure 19: High-Tension Fabric Structure with Waste Block Walls (ClearSpan 2013)

Waste blocks come in various sizes, with the most common for this purpose being 6’ L * 2’ W * 2’ H and weighing 3600 lbs per block. If buying a trailer load, cost per block is often under $65 per delivered block. Cost savings of using blocks are realized through a reduction in ground preparation associated with the walls and footings, along with a reduction in labor cost associated with forming and pouring the walls. This is especially true if the site has ledge. Had UNH built a similarly-sized fabric structure with waste block side walls, the material cost for the blocks would have been roughly $4,225 ($65/ block * 65 blocks).

If waste blocks are used, it is recommended to use them for only the side walls and not the back push wall that contains the aeration channels and heat exchange unit behind it. The back push wall should be poured with footings to create a structurally sound wall that has no chance of movement that could break seals in the aeration network and, in the worst-case scenario, damage the heat exchange unit. The seams in between the blocks would also create a pathway for vapor to enter into the back mechanical room. As with the wooden walls, negative aeration from the air filtration system would pull compost vapor into the mechanical room.

INSULATING THE CONCRETE SLAB AND SETTING UP THE AERATION DUCTWORK

One of the most important steps in building a heat recovery composting facility is ensuring enough insulation is put underneath the concrete slab, as this cannot be remedied afterward. The goal of insulating the concrete slab is to prevent cold soil temperatures from robbing heat from the slab and aeration ductwork. Insulating also reduces condensation from forming on the bottom of the slab, due to varying temperatures. While heat loss is impossible to avoid (1st law of thermodynamics), reducing losses pre-heat exchanger through proper insulation will increase heat recovery. Proper insulation of the pad will also ensure the base material is capable of reaching thermophilic temperatures. This is especially true during the winter months in cooler regions. A good way to think of the concrete slab is to consider it as a thermal battery for the compost – it has to be insulated to reduce heat from escaping. To prevent heat loss from occurring, two layers of 2’’ rigid extruded polystyrene foam (Foamular 250) were used at the UNH facility (Figure 20). This 4’’ layer of foam had a total R-value of 20. When installing these boards, it is important to overlap the top boards with the bottom to prevent continuous vertical seams that would enhance thermal loss.

Figure 20: Insulation Below Main Composting Floor at UNH Composting Facility

Cost Saving Tip # 8*: An alternative, and possibly cost-saving strategy if labor costs are high, is to use Insul-Tarp®. This product has an R-value of 5.9 and can be rolled out like a tarp, saving labor costs. At the UNH facility, it would have required 15 rolls of the 12'*50' tarp at a cost of roughly $9,000 to match the same R-vale of the rigid foam insulation, which cost $5,500 for the material (Appendix 1). R-values, local distributer prices, shipping, and labor costs should all be taken into consideration to determine which insulation is the most economical.*

The degree to which the slab is insulated depends on ambient ground temperatures during the winter season. Because the UNH facility is in New Hampshire, and experiences cold winters, two layers of insulation were required to separate the system from the ground. This recommendation originated from lessons-learned from the first heat recovery facility built in the neighboring state of Vermont at Diamond Hill. The first composting bay they built only had 2'' of foam insulation, which was found to be inadequate during the winter months. Insulation of the concrete slab is the last place money should be cut if one is planning to recover heat from this type of system. A minimum R-value of 10 should be used in all regions.

After installing the rigid foam insulation, the side walls also have to have a thermal break/expansion joint where the concrete pad meets the concrete walls. The function of this break is to allow for expansion and contraction of the pad, but to also prevent the back and side walls from robbing heat from the much warmer composting floor. To create this joint, two layers of ½'' polyethylene foam were used (A.H. Harris ½'' Polyethylene Expansion Joint Filler). The double layer provided a 1'' joint and an insulation value of R-6 (Figure 21).

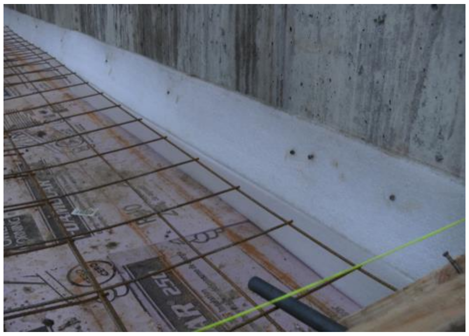

Figure 21: Thermal Break Installation Against Internal Walls

STRUCTURAL SUPPORT (JOINTS AND PAD REINFORCEMENT)

Figure 22: Concrete Slab-Connecting Dowels at UNH Composting Facility

The next step in the process was to install the forms to connect the main composting pad to the external concrete apron. This connection was made with 7/8'' D * 16'' L greased dowels, 12'' on center from one another (Figure 22). The dowels were greased to prevent cement from bonding to them. If cement were to bond to the dowels, it would reduce their functionality and prevent the two slabs from flexing, resulting in cracking.

As with the side wall expansion joint/thermal break, the expansion joint between the two slabs is crucial for both structural reasons and to prevent heat loss. Without this joint, the cooler concrete apron without active compost over it, would start robbing heat from the warmer composting floor. This would reduce heat recovery and effect the composting material nearest the joint. Ideally, this expansion joint should be two feet beyond the end of the aeration ductwork, with the idea of having the compost extend at least two feet beyond the joint. The four feet of composting material beyond the end of the aeration channels, with the expansion joint in the middle, is to prevent the aeration ductwork from pulling cold air into the system from the tapered portion of the pile, and to insulate the aeration ductwork and composting pad at the end of the aeration line (Figure 23).

Figure 23: Expansion Joint Between Compost Floor and External Apron

With insulation and forms in place, the next step was to install the welded wire mesh. Galvanized steel continuous high chair upper supports (4’’ high) were placed on top of the rigid foam insulation to hold the wire mesh at a pre-set level. Wire mesh was then placed on top of the supports to a height of 4’’ with sheets being overlapped a minimum of 12’’ and connected to maintain a continuous structure (Figure 24). The mesh used at the UNH facility was 6*6 W2.1*W2.1, meaning smooth (W) wire with 6’’ longitudinal and transverse spacing and a cross sectional area of 2.1 hundredths of a square inch. This material serves to reinforce the concrete pad by increasing the tensile strength. By increasing the tensile strength (up to 30%), the tensile force caused by expansion/contraction and/or shifts in the sub-base is reduced. It is important to note that cracks can still form, but will be less severe, as the mesh spreads the force across a much larger area.

Ensuring the above step is done correctly is very important, as the temperature profile across the concrete pad can be quite variable depending on how the various composting batches are loaded into the facility. Cracks in the concrete floor are of particular concern because of the amount of leachate that drains from the feedstocks.

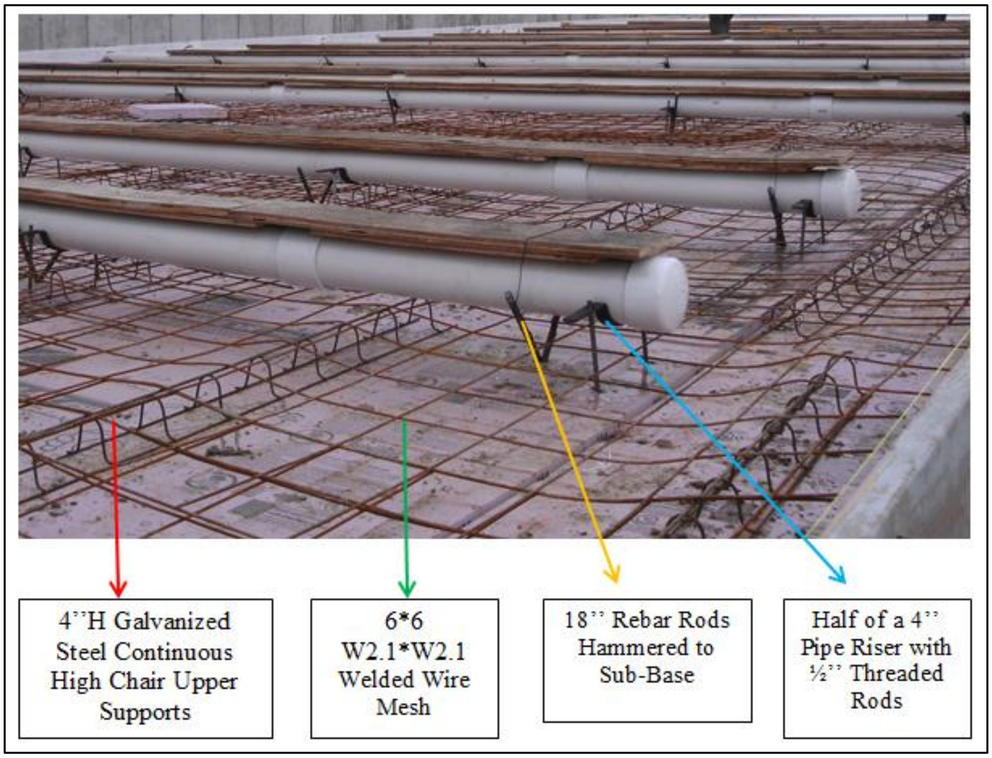

Figure 24: Aeration Line Form Setup Prior to Concrete Pour

INSTALLING THE AERATION CHANNELS

When installing the 4’’ PVC (Sch. 40) aeration channels, two feet of pipe was extended beyond the back push wall through the sleeves and into the mechanical room for future hook up to the aeration network. Expanding joint filler foam was used to fill the gaps between the PVC and sleeves (Figure 25). All PVC was connected using solvent cemented joints, as the temperature within the aeration channels exceeds the 110ºF maximum recommended temperature for threaded joint connections in Sch. 40 pipe (GF Harvel 2013). In sum, each aeration line had 33’ of PVC (2’ extending into the mechanical room, 1’ through the push wall sleeve, 3’ unperforated, and 27’ perforated to the expansion joint), with two 4’’ couplings, and one 4’’ end cap.

Figure 25: Aeration Lines Through Back Push Wall with Hose Bibbs

Each aeration line was held up by six 4’’ pipe risers (only half of the riser used) and six pairs of ½’’ threaded rods (18’’ long), hammered through the rigid insulation and down into the sub-base (Figure 24). The pipe risers were five feet apart and were used to easily establish a 1% grade over the 30’ compost floor, from the end of the pipe down to the back push wall. This allows leachate to drain from the pile and into the aeration ductwork, which is connected to the primary leachate system in the mechanical room. Each pair of pipe risers was accompanied by a pair of 18’’ rebar rods, hammered through the insulation and down into the sub-base in the shape of an X (Figure 24). The six pairs of rebar rods were used to prevent the pipe from moving during the concrete pour.

After setting up the pipe risers and supports, the next step was to fill the pipe with water to check for leaks in the joints and to increase the weight of the pipe to prevent it from floating during the concrete pour. The aeration lines were filled with water by connecting a 4" flexible end cap with a hose bibb to the 2' section of pipe on the other side of the back push wall (Figure 25). This temporary part can either be made by purchasing a flexible endcap and inserting a hose bibb with washers (method used at UNH), or by purchasing it premade like those from Fernco (HBC-4), and Band-Seal® (0704510). The latter option may end up being less expensive.

After filling the pipes with water and ensuring no leaks were present, the forms for the aeration channel cover plates were installed. When creating these forms, the goal is to create a lip for a cover plate to sit, and have the plate recessed ¼ - ½’’ below grade. It is important to have a lip for the cover plate to rest, otherwise the PVC pipe can be crushed if a loader drives over one of the cover plates. It is also important to have the cover plates recessed at least ¼’’ as it reduces the possibility of a loader catching one when loading/unloading the compost. The recession also allows for some warpage of the wood without worrying about catching the plate with a loader. The plywood cover plate forms used at UNH were ½’’ and ¾’’ thick * 6’’ wide and were stacked on top of each other for a total thickness of 1¼’’ (Figure 26).

Figure 26: Aeration Line Forms for Cover Plates

After concrete pouring, these forms were removed, allowing a ¾'' cover plate to be recessed ½'' below grade. As described previously, the first three feet of each aeration line did not have aeration holes, and did not require a cover plate, as solid concrete was poured over that section of pipe (reducing cold air intrusion).

Cost Saving Tip # 9*: An alternative to cut plywood cover plate forms is to use dimensional lumber (2'' * 6'' * 10' or 1'' * 6'' * 10'). This will save labor cost in cutting individual cover plates. Below are pictures from another ASP heat recovery composting facility (Sunset View Farm in Schaghticoke, NY) illustrating how to set up the cover plates with dimensional lumber (Figure 27, Figure 28 and Figure 29) (Jerose, Personal Communication, 2013).*

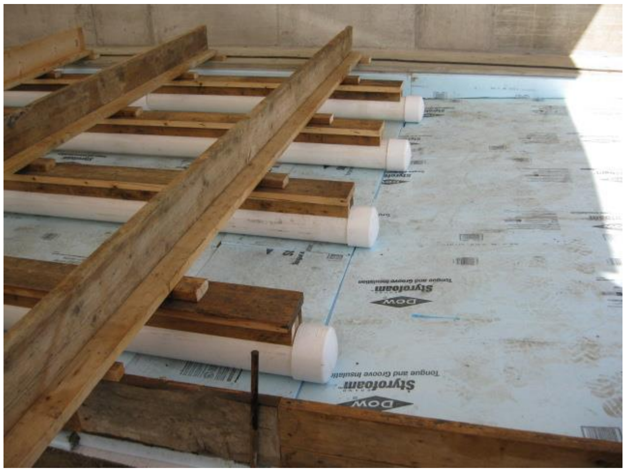

Figure 27: Alternate Cover Plate Form Setup

Figure 29: Alternate Cover Plate Form Setup

Figure 28: Alternate Cover Plate Form Setup

When looking at the three previous figures from Sunset View Farm, it is important to note that they placed the pipe directly on the foam insulation, and did not have it raised with pipe risers and rebar. They also omitted the welded wire mesh. While this reduces cost initially, both of these omissions are not recommended, as both reduce the structural integrity of the concrete floor. Placing the aeration pipe directly on the insulation could also pose a significant leachate problem, should one of the aeration pipes (also the floor drain), crack. However, the three previous figures illustrate cover plate design and how to use dimensional lumber to achieve the desired cover plate floor recession.

POURING THE SLAB AND FINISHING THE COMPOSTING FLOOR

Figure 30: Concrete Pour for Main Composting Floor

The main composting floor (94’ L *32’ W) received 88 yd^3 of concrete (nine truckloads) to a thickness of 9.5’’. When the concrete was being poured, it was first placed on either side of the aeration pipe, to ensure they were held in place during the rest of the pour (Figure 30).

After all 16 aeration lines had concrete on either side, the rest of the concrete was poured. When pouring the concrete, the welded wire mesh was held up with a metal rake in the few areas that were slumping, ensuring an even level of mesh across the whole surface of the slab. Additionally, the 3’ portion of concrete closest to the push wall that did not receive a cover plate, was given a 1% slope over 3’ from the back push wall. This allows leachate from that portion of the pile to drain into the aeration/drainage pipe, preventing leachate accumulation against the wall, which could potentially enter into the mechanical room should a crack form along the wall. The removal of leachate also reduces the possibility of saturating the composting feedstocks at the base of the pile. If this were to occur, an anaerobic spot would develop, producing methane, and reducing the heat value from that portion of biomass. Figure 31 illustrates the profile of the main composting floor.

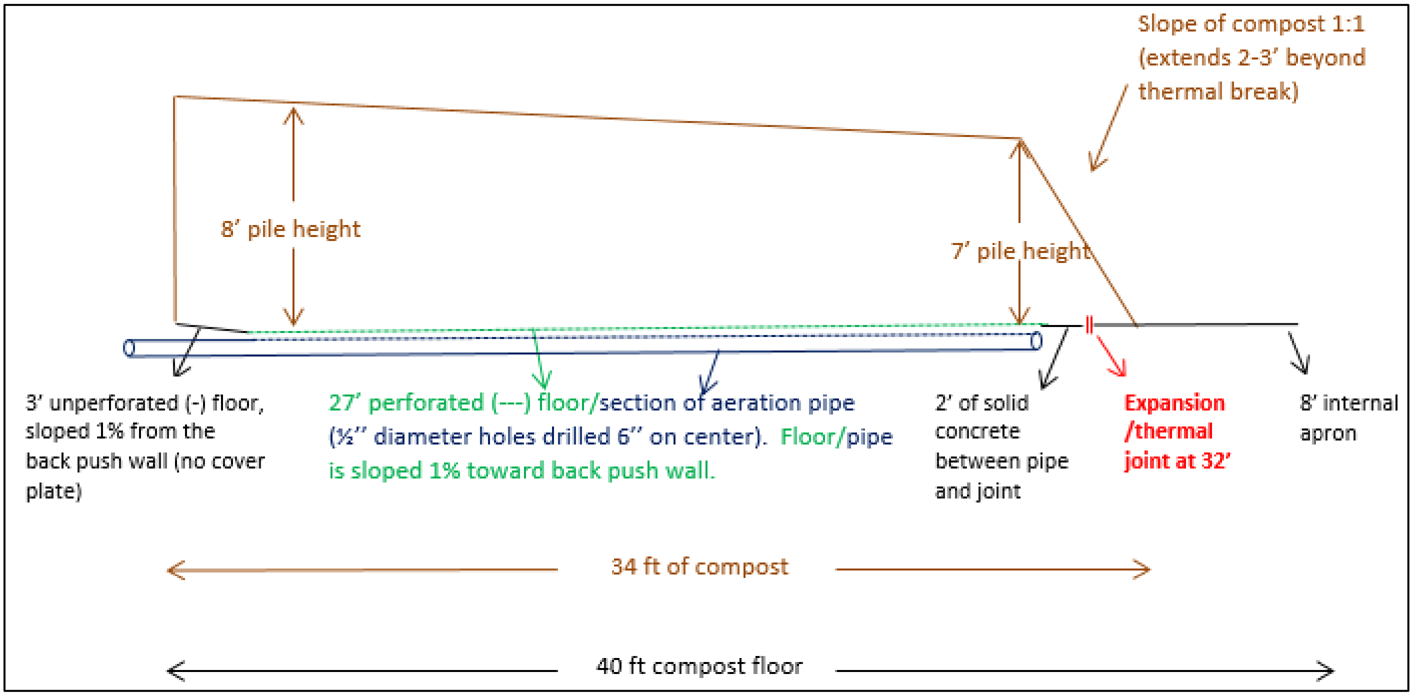

Figure 31: Profile of Compost Pile and Floor

After the concrete cured, the water was released from the aeration lines. The wooden cover plate forms were also removed at this time. Each aeration line had ½’’ diameter holes drilled every 6’’ down the apex of the pipe (Figure 32). On some of the aeration lines, concrete had to be gently chipped away to be able to access the pipe to drill a hole. After drilling, the holes were taped to prevent construction material from entering during the rest of the building process.

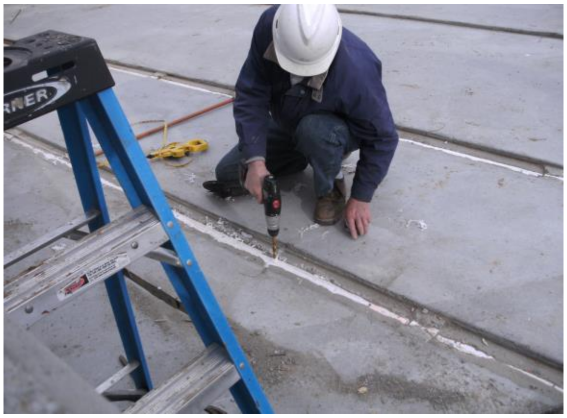

Figure 32: Drilling of Aeration Holes

***Cost Saving Tip # 10**: Drill holes in the aeration lines at the end of the construction process, as this will reduce the labor involved in taping and uncovering the holes. It also prevents debris from entering the aeration network.*

In addition to aeration holes, smaller leachate holes may be necessary toward the section of pipe nearest the back push wall. Because aeration holes are usually drilled at the apex of the pipe, leachate can accumulate and pool before draining into the lowest aeration hole by the back push wall (Figure 33). This can be resolved by drilling 1/8’’ diameter holes in each aeration line at the lowest point of the pipe closest to the back push wall. Additional 1/8’’ diameter holes may also be necessary at other low spots along each aeration line to allow for drainage. It is important to prevent this pooling, as it will reduce the longevity of the cover plates. A simple method to assess the floor drainage, and determine where additional leachate holes are needed, is to fill each aeration channel with water and drill where pooling occurs.

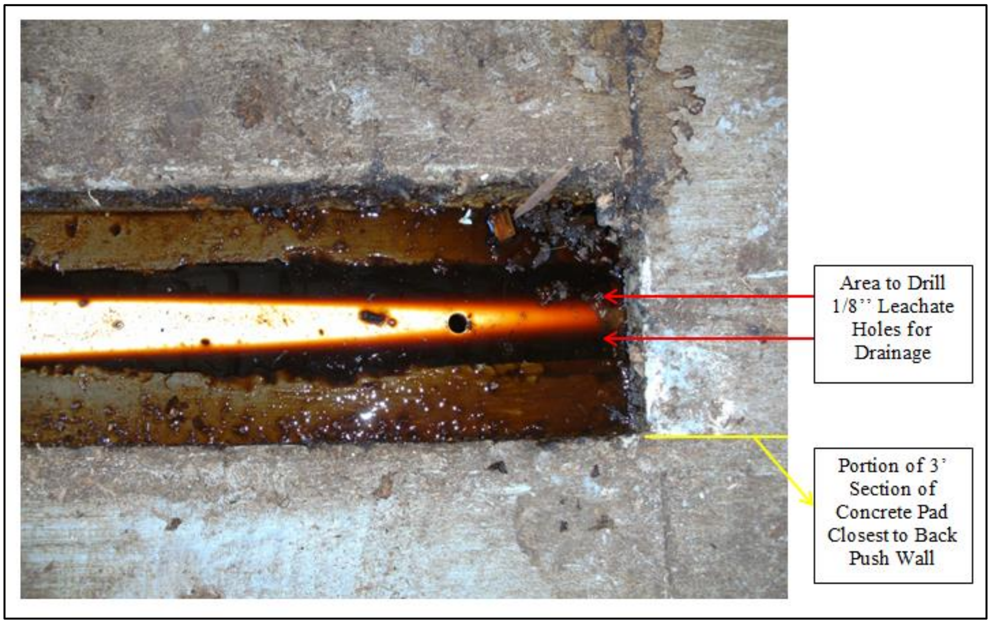

Figure 33: Drilling Location for Leachate Holes

After drilling the aeration holes, wooden cover plates made of marine-grade plywood (10’L * 6’’W * ¾’’H) were fabricated on site. An arch was sawn lengthwise across each cover plate to ensure that pressure from the wheels of a loader would not press down on the PVC aeration lines (Figure 34). Each cover plate had ½’’ holes drilled 6’’ from one another. Unlike the aeration holes in the PVC lines, the aeration holes in the cover plates were drilled slightly off center from one another, to reduce the possibility of the boards splitting down the middle. Additionally, the holes in the cover plates were not directly over the holes in the pipe, reducing a direct path for particles to be sucked into the aeration system.

Figure 34: Profile of a Cover Plate over an Aeration Line

Marine-grade plywood was used instead of pressure treated, as the farm is organic and there were concerns about the chemicals in the pressure treated wood leaching into the compost. Ideally, black locust would have been used, as it is naturally rot resistant and is accepted under organic practices. This wood will likely be used when the cover plates need replacing in the future. Figure 35 illustrates the profile and dimensions of the aeration floor at the UNH facility.

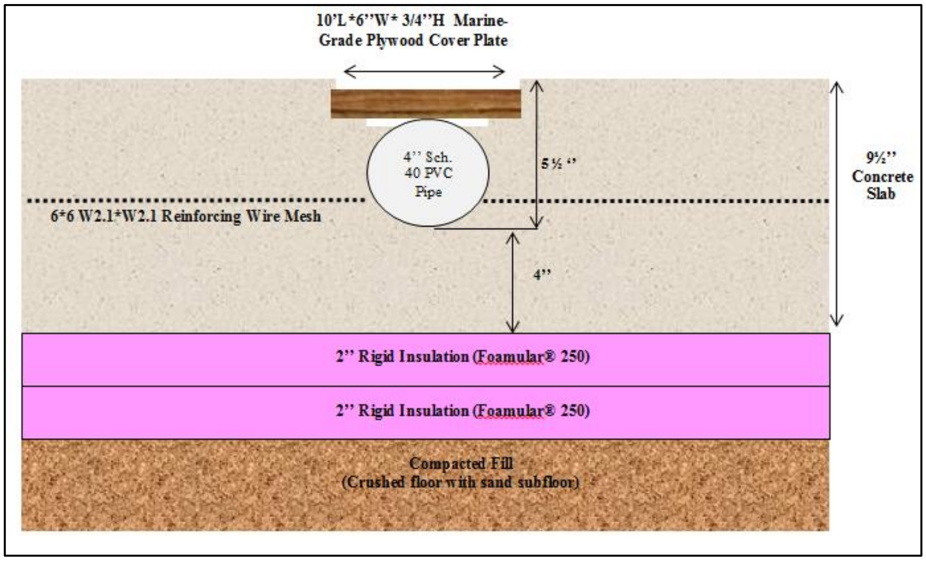

Figure 35: Profile of the UNH Aeration Floor and Subfloor

An important point to mention is that the aeration holes in the pipe and cover plates need to be drilled cleanly, without pieces of the material inhibiting the orifice (Figure 37). Prior to loading the composting facility for the first time, all holes should be checked and smoothed with a rasp. The aeration channels should also be checked for any welded wire mesh that may impede the ability of the cover plates to rest at the appropriate height (Figure 36).

Figure 37: Aeration Hole with Chipping

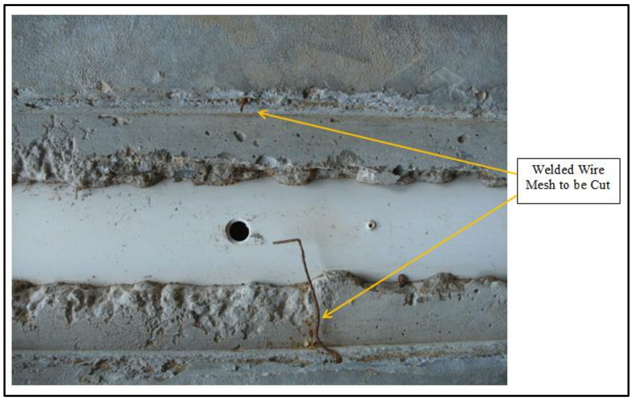

Figure 36: Mesh Impeding Cover Plate

PREPPING AND POURING THE INTERNAL CONCRETE APRON

The first step in prepping the internal apron (96’ L * 8’ W * 9.5’’ H) was to remove the wooden forms encasing the dowels. After removal, two layers of ½’’ polyethylene foam (A.H. Harris Polyethylene Expansion Joint Filler) were used for the expansion joint, providing a 1’’ joint and an R-6 insulation value. Plain 4’’ concrete dobies were then placed on the compacted fill to hold up the 6*6 W2.1*W2.1 welded wire mesh (Figure 38).

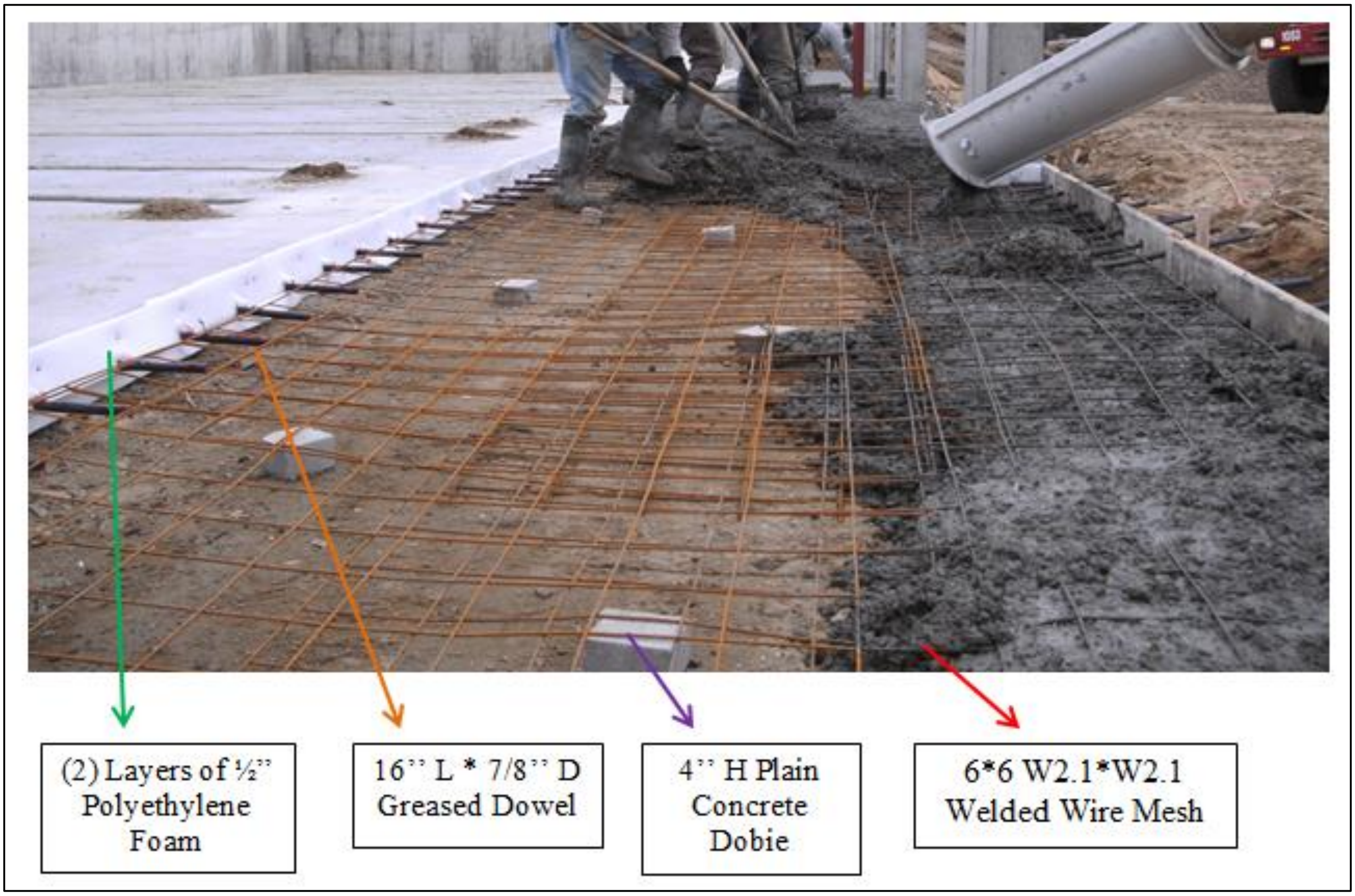

Figure 38: Specifications when Pouring the Internal Concrete Pad

Because this section of concrete pad was for a walkway, and a thermal break was installed between the pads, ground-level insulation was not required. A second line of 7/8’’ diameter * 16’’ long greased dowels, 12’’ on center from one another were also installed in the wooden forms to connect the internal apron to the external concrete apron for a future pour.

PREPPING AND POURING THE EXTERNAL CONCRETE APRON

The external concrete apron (96’L * 4’W * 4’’H) was prepared in a similar fashion to the internal apron - two layers of ½’’ polyethylene foam around the slab-connecting dowels, with welded wire mesh being held up by plain concrete dobies, with no ground-level insulation (Figure 39). However, the thickness of the slab was reduced by 5 ½’’, reducing the concrete requirement by 6.5 yd^3.

Figure 39: Specifications when Pouring the External Concrete Pad

***Cost Saving Tip # 11:** The concrete slabs for the walkway and external apron can be thinner than that of the main composting floor, due to a lack of aeration lines. This decision has to be made early on in the process, as the placement of the dowels connecting the slabs will have to be adjusted. Alternatively, depending on facility design, the walkway and external apron could also be stone dust, forgoing concrete completely.*

INSTALLING THE LEACHATE NETWORK AND POURING THE MECHANICAL ROOM FLOOR

The mechanical room floor (96’L * 9’ 3 ½’’W * 4’’H) was poured the same day as the external apron and was prepared with the same welded wire mesh and plain concrete dobies for risers. However, before the floor was poured, the primary 80’ long * 4’’ PVC leachate line was installed against the back push wall with 4’’ riser clamps 4’ on center (21 riser clamps in total), and connected to the 1500-gallon leachate tank. Along the 80’ leachate line was eight 4’’ – 2’’ PVC wye reducers, located directly under every aeration header. At a later step, these wye reducers were used to connect the primary leachate line to the 2’’ leachate lines coming from each pair of aeration lines forming a single header (Figure 40). Before the pour, the mechanical room also had forms for a 2’ L * 2’ W * 1’’ H sump pit. This pit was later covered with a welded grate cover (McNICHOLS GW-100A). The floor on either side of the sump pit was also sloped toward the pit to allow for drainage.

Figure 40: Specifications when Pouring Back Mechanical Floor

RAISING THE BUILDING

Following the concrete pours, the final carpentry for the pole barn began. Specific step-by-step details about raising a pole barn are not included in this portion of the report, as a detailed document on the topic already exists (Carson and Dougherty 1997). However, the engineering/architectural diagrams used to construct the pole barn are included in Appendix 5.

Cost Saving Tip # 12*: When considering what type of structure to build, one should understand that the primary purpose of the structure is to enclose the mechanical room and keep the elements off the compost, as wind, rain, and snow negatively affect the composting process and heat recovery. That being said, any structure capable of protecting the compost and mechanical room would be suitable for achieving the end goal of compost stabilization and heat recovery. For this reason, tension fabric structures like those from ClearSpan will often be the least expensive option, unless the farmer/compost operator plans to build the structure themselves and can do so more cheaply. A fabric structure of similar size to the pole barn described in this report would have cost $62,400 (total cost for material, delivery, installation, etc.). Fabric structures have also been shown to maintain interior air temperatures 15-20°F warmer in the winter than wood or metal buildings (ClearSpan 2016). This is an important advantage, as less compost-derived energy is lost to balance the cooler replacement air as it travels through the feedstocks. This increases heat recovery and also decreases compost processing time.*

What is important to note is that the steps prior to raising the facility in this report, and those that follow, will likely be the same regardless of building type. For reference, a pole barn was constructed at UNH due to the research nature of the project, and the requirement for the building to last for decades. Though the facility was designed for research, the aeration floor and mechanical room setup would have been the same had a fabric structure been used.

Although step-by-step details on raising a pole barn are not provided, there are several operational recommendations worth mentioning. Regardless of structure type, the operator should consider what equipment will be used in the facility and scale the height of the building accordingly. At the UNH facility, the height was based on a silage truck dumping material onto the composting floor, requiring a building height of 22’. A second important consideration is ventilation, and the need to allow these types of compost buildings to breathe. If the building is too airtight, it will result in the accumulation of bioaerosols, which are unhealthy to breathe. Buildings without adequate ventilation will also cause an over accumulation of moisture, which will corrode the building. If building a pole barn, an exaggerated ridge vent will allow for ample ventilation, preventing the accumulation of compost bioaerosols and moisture. When constructing the ridge vent, ensure a mesh is installed to prevent birds and wind-driven snow from entering the facility (UNH had to install Cobra mesh following construction for these purposes). If using a fabric structure, a mesh upper end wall can be used to allow the building to breathe. More expensive mechanical ventilation systems can also be added, but are not likely necessary for most operations.

SETTING UP THE MECHANICAL ROOM

The setup for the mechanical room will vary based on whether aeration lines have individual blowers with timers and fan speed controllers, or the whole system has one large blower with damper controls. The UNH facility was originally designed with individual blowers and fan speed controllers. This decision was made to have greater manipulation of each bay for research purposes. However, having individual blowers and timers significantly increased labor when adjusting the aeration schedules. More importantly, the company selling the blowers switched materials and blowers that lasted more than 3 years at other facilities, lasted no more than three months at the UNH facility, due to corrosion from the compost vapor stream. After 1.5 years of operation, the mechanical room at the UNH facility was completely overhauled and converted to a single fan system with pneumatic damper controls. The following sections describe the updated mechanical room setup.

All PVC components installed in the mechanical room were Schedule 40 and were connected using solvent cemented joints and flexible couplings. Threaded components were not used as they are not capable of maintaining a seal in high heat conditions like those found in a compost aeration system. To reduce costs, the mechanical room was built within the facility. The ceiling was made of clear corrugated polycarbonate sheets (SUNTUF ®) that were arched away from the back wall to allow compost material to slide off, should it make it that high during compost loadings (Figure 41).

Figure 41: Specifications for Mechanical Room Ceiling

AERATION LINES

Aeration lines were set up in pairs, forming a single aeration header (2 headers per bay). Each 4'' diameter PVC aeration line was extended 6'' into the mechanical room (originally 2' but cut to 6'') and was connected to a 4'' manual butterfly valve (Hayward 4'') (Figure 42). If using butterfly valves, it is important that the interior disc is corrosion resistant.

From each butterfly valve, an 8'' 90° elbow and 12'' section of PVC pipe was connected into an 8'' PVC tee, forming a single aeration header (Figure 43). Following the 8'' PVC tee, each aeration header was reduced to 4'' diameter pipe.

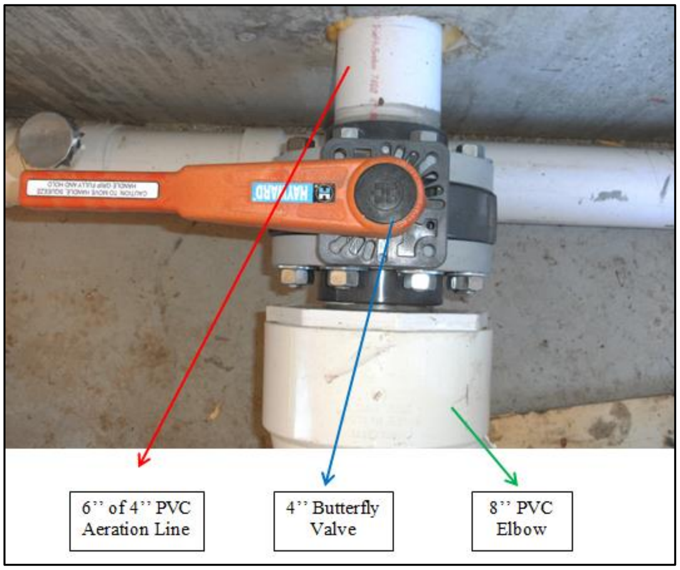

Figure 42: Butterfly Valve Connecting Aeration Line to Aeration Header

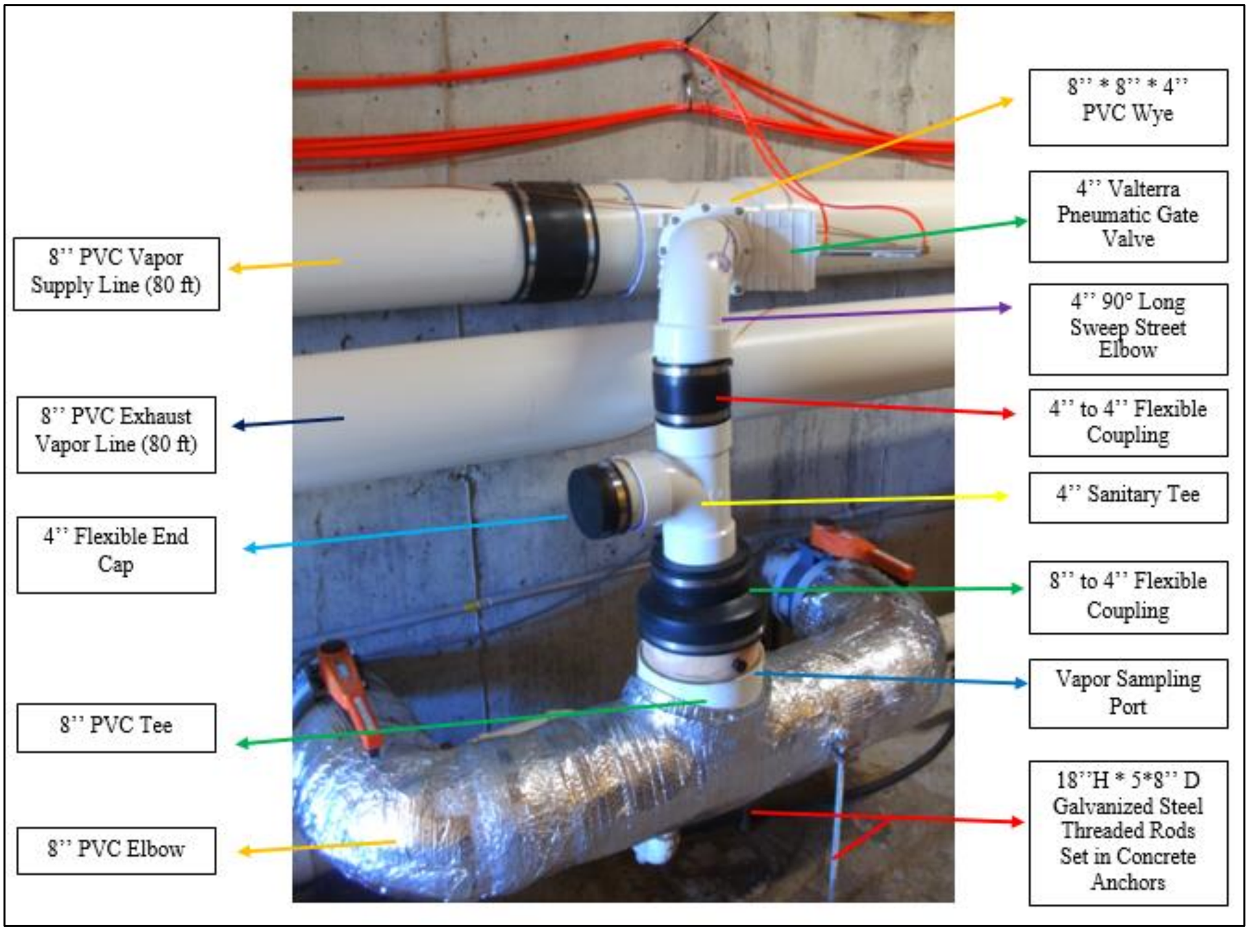

Figure 43: Setup for Aeration Headers

Cost Saving Tip # 13: *Reducing the pipe diameter at the header was to reduce costs in the pneumatic gate valves, which increase in cost exponentially as pipe diameter increases (4''diameter valves ≈ $80/ valve vs. 8''diameter valves ≈ $900/valve). While the reduction in pipe does cause more resistance in the aeration system, Agrilab engineers confirmed that the fan could handle the extra resistance. The valves used at the UNH facility were 4'' Valterra pneumatic gate valves (6201P) and were selected due to low cost and the fact that all the internal components were corrosion-resistant.*

Cost Saving Tip # 14: *Each aeration header was equipped with a 4'' diameter PVC sanitary tee with a flexible end cap (Figure 44). Tees were installed at each header to be able to recirculate exhaust vapor into newly loaded bays during the winter. This procedure can reduce composting time by several weeks, by bringing partially frozen feedstocks up to temperature in hours vs. days. This not only increases the volume of material that can be composted, but also reduces the amount of cold vapor being sent into the heat exchanger as piles warm up. The recirculation process is accomplished by connecting a 4'' flexible drainpipe into the 4'' tee at the header and into an 8'' * 8'' * 4'' PVC wye located in the exhaust line. Vapor is then forced into a bay by closing a valve in the primary exhaust line and at the bay header. Since the heated vapor is from the exhaust line, one bay can be heated without a loss of heat recovery from Agrilab's system.*

Figure 44: Exhaust Vapor Recirculation Connection Points

Connected to the bottom of each aeration header was a 2'' S-trap with waste, which connected into the primary 4'' leachate system through a 4'' – 2'' wye reducer (Figure 45).

A P-trap with waste can also be used, but would not fit in our situation. The function of the S-tap (or P-trap) is to capture any condensate, and to prevent the aeration system from pulling vapor from the leachate line or tank. Having a waste valve is essential, especially for facilities built in cooler regions where freezing may occur. Winter freezing can occur if: 1) a compost batch is too old and not heating up enough, 2) a bay is empty, 3) a bay is unloaded during the winter and not loaded fast enough to prevent a freeze and 4) if a power outage occurs during the winter and the system is not hooked up to a generator. Having a waste valve on the trap will allow drainage of the water until that bay is up to temperature.

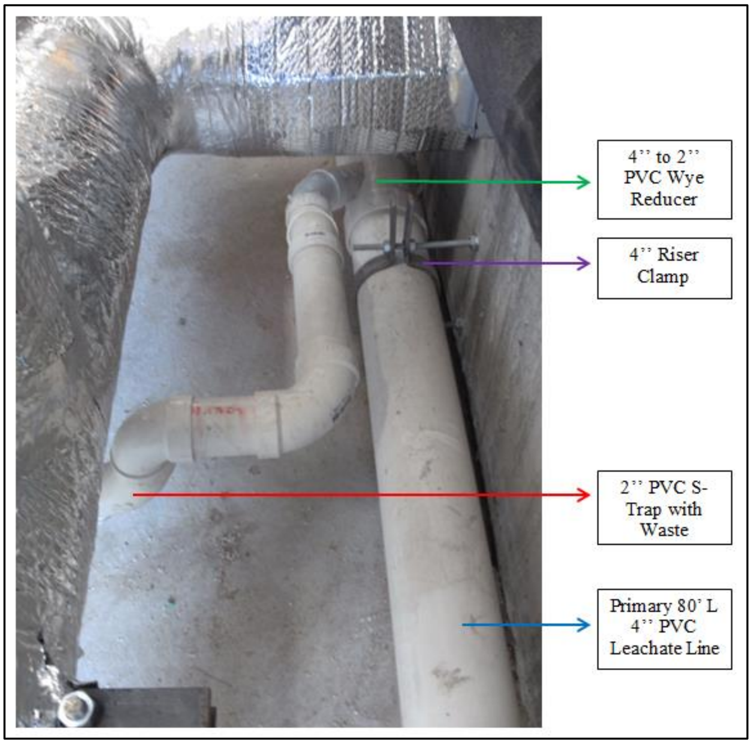

Figure 45: Leachate Hookup Specifications for Each Pair of Aeration Lines

PRIMARY AERATION SUPPLY AND EXHAUST LINES

Each aeration header was connected to the primary 8’’ diameter aeration supply line through an 8’’ * 8’’ * 4’’ PVC wye (Figure 43). Flexible couplings (8’’ to 8’’) were used to connect lengths of pipe in between bays. Few solvent cement seals were made in the aeration network, due to the research nature of the facility and the need to modify components for continual experimentation. While this design is suited for research, there are advantages to using flexible couplings over standard PVC solvent cemented couplings when connecting joints in this type of system. Flexible couplings are leak proof and allow the aeration network to flex. Additionally, if any upgrades or alterations are required, the flexible couplings allow entire sections pipe to be easily removed and reused without having to saw pieces off.

The primary exhaust line coming from the fan was also made of 8’’diameter PVC pipe. As with the primary supply line, 8’’ to 8’’ flexible couplings were used to connect sections of pipe. In the original set up of the facility, the exhaust line left the Isobar unit and went directly outside to vent the compost vapor to the ambient air. While this method reduced material cost and labor, it did not scrub the contaminants out of the exhaust stream, which contributed to odors around the farm. Removing the vapor immediately also reduced the ability for further heat extraction and usage. During the renovation of the mechanical room in 2015, the primary exhaust line was upgraded and extended along the entire length of the facility and out to a biofilter (Figure 46). PVC wyes (8’’ * 8’’ * 4’’) were also installed two feet to the left of every aeration header to connect into the 4’’ PVC tees located at every header for reutilization of exhaust vapor (Figure 44). Two sections of 8’’ diameter * 6’ long aluminum pipe were also installed in the exhaust line to serve as a space heater for the back room (Figure 44).

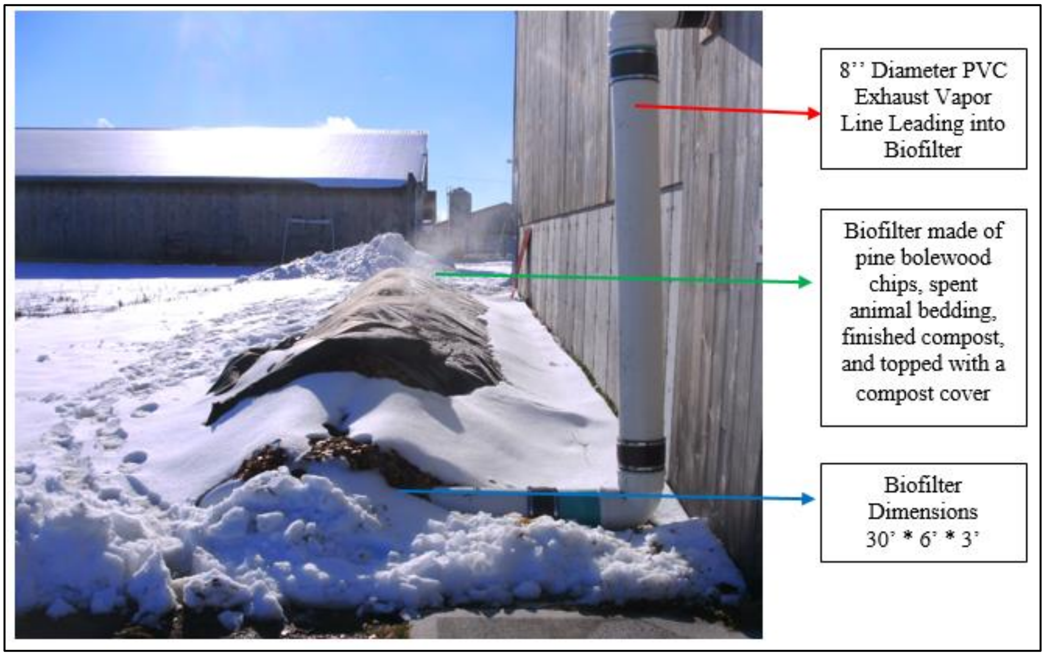

Figure 46: Biofilter Processing Exhaust from UNH Composting System

The central 80’L * 8’’ diameter PVC exhaust and supply lines were held up with custom-made pipe stands (Figure 47). The pipe stands were made of 4’’*4’’ beams, ½’’ threaded rod couplings, 7’’ threaded rods, and half of an 8’’ clevis pipe hanger. The stands were designed in this manner to allow for 6’’ of adjustment, making it very easy to adjust the slope of the aeration system for proper drainage. Free-floating stands were also used instead of fixed supports, due to the research nature of the facility and the requirement to test various pipe and aeration layouts. While the decision between fixed and free-floating pipe supports is up to the operator, the flexibility of free-floating supports has been incredibly useful at the UNH facility, especially when making alterations to increase system performance. Fewer holes and anchors in the concrete also reduce the risk of cracking. However, regardless of support structure, all metal components touching the aeration network should have a layer of insulation between the metal and PVC. This will reduce conductive heat losses or points of condensation within the aeration network.

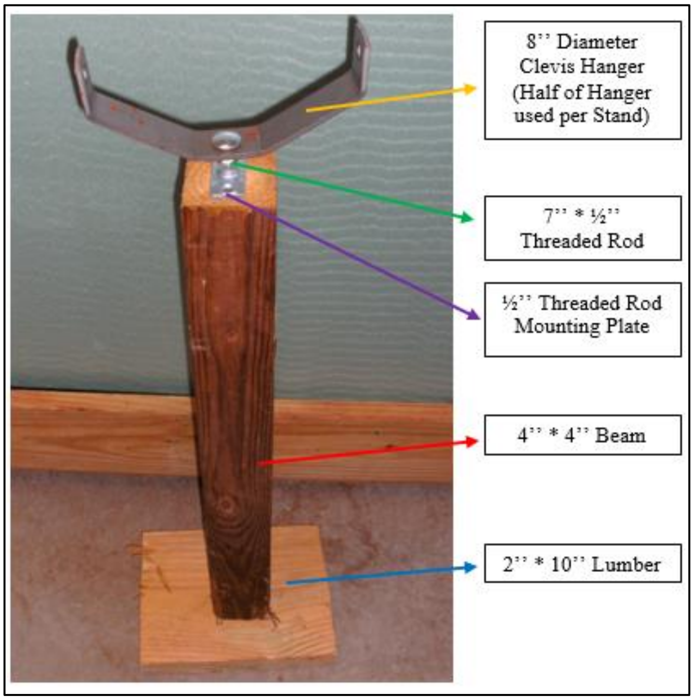

Figure 47: Pipe Stands for Aeration System at UNH Facility

INSTALLING AGRILAB TECHNOLOGIES ISOBAR UNIT

Figure 48: Delivery of Agrilab Technologies Heat Exchange Unit

Agrilab's heat recovery system was delivered to UNH on a flatbed truck halfway through the mechanical room setup. The unit was 30'L * 34.5''W * 30''H with six isobars. Because of its narrow size, it could be brought through one of the side doors of the mechanical room with a telehandler (Figure 48). It should be noted that Agrilab's new heat recovery units are much more compact (can fit on a shipping pallet) and have similar heat recovery rates. When delivered, the heat-exchange unit was 1300 lbs, (total weight of 3800 lbs after filling the bulk tank with water and loading the Isobars with refrigerant). The system also came with supports for the vapor portion of the unit. Supports included two adjustable steel cradle floor stands and three 24'' C-shaped steel brackets with a top loop for a ½'' threaded rod to be connected to the ceiling studs. Due to differences in facility layout, supports for the much heavier bulk water tank were not included with the isobar unit. Instead, a support structure was built ahead of time and was made of 6’’L * 6’’W * 25’’H wooden beams, 2’’ * 10’’ lumber, and a layer of ½’’ cement board (Figure 49). The layer of cement board was placed in between the water tank and wooden frame of the stand due to a requirement from the state fire inspector, who was concerned about having water temperatures in excess of 120°F being in contact with wood. Across the 30’ span of the heat recovery system was a 4’’ drop, allowing for drainage of condensate and more efficient circulation of the heat exchange refrigerant.

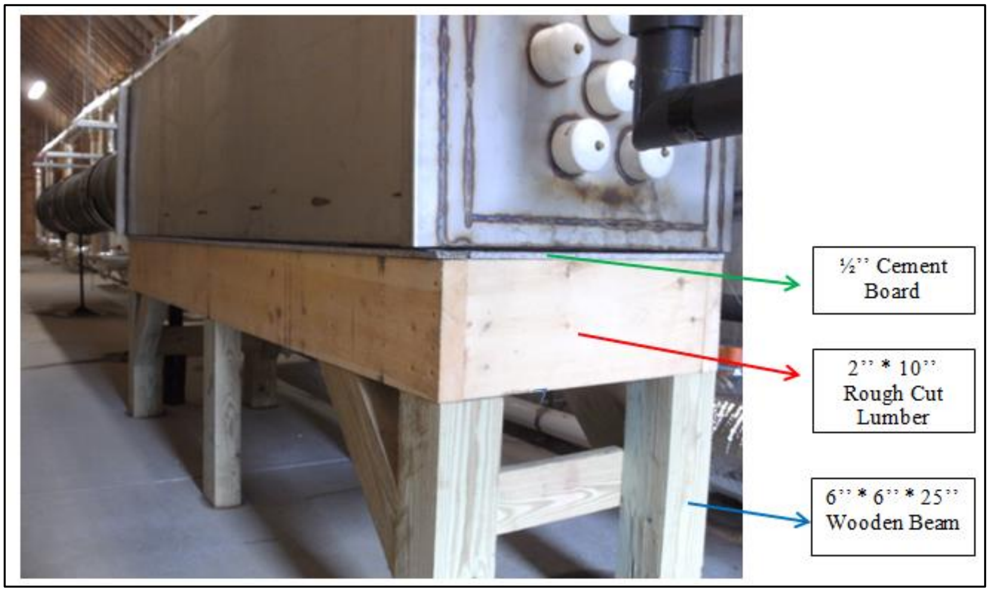

Figure 49: Support Structure for Bulk Storage Tank of Water

The isobar unit was connected to the primary 8’’ PVC aeration network with a 12’’ to 8’’ flexible Fernco coupling, and a section of SDR-35 8’’ pipe and elbow (Figure 50). SDR-35 was used for this section, as it was leftover material from another project. While the setup between the Isobar unit and primary aeration network will vary between facilities, it is important that all systems have at least one flexible coupling in this connection. The flexible coupling(s) at this joint will allow the system to expand and contract, as it heats up and cools down between composting batches.

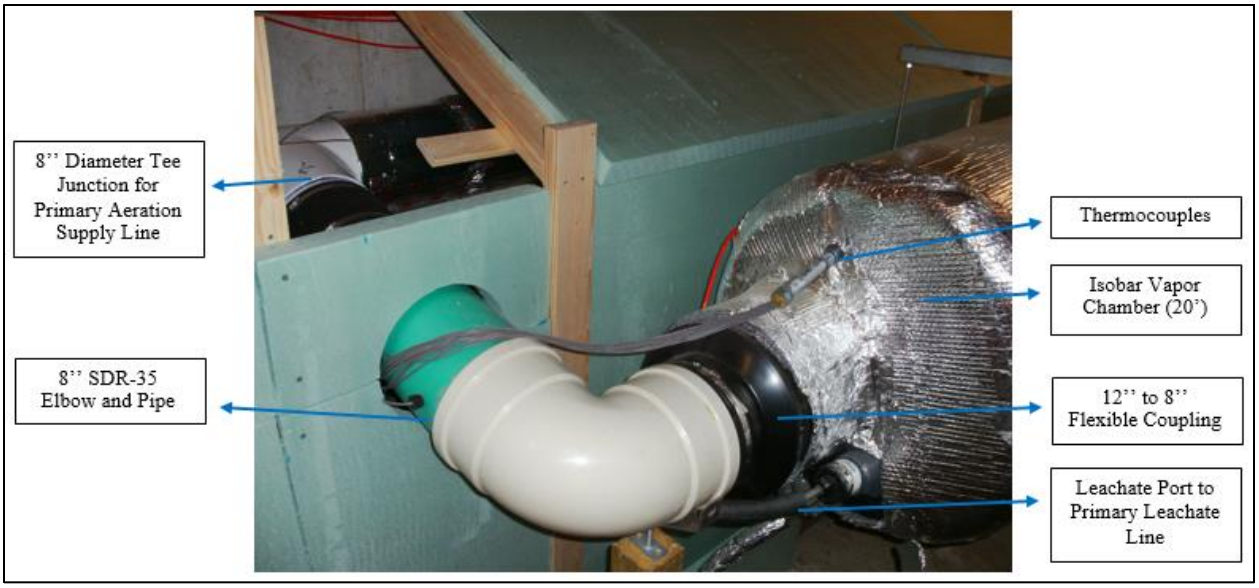

Figure 50: Aeration Line Hookup with Heat Exchange Unit

The Isobar unit was also connected to the primary 4’’ leachate drain through ¾’’ nylon tubing (Figure 50). The heat exchange system was then attached to the aeration blower (NY Blower 126 CGI). The blower was deliberately placed after the heat exchanger, as vapor temperatures and moisture content are considerably lower following heat exchange, putting less stress on the blower. The blower was attached to the isobar unit with a 6’’ to 8’’ flexible coupling and a few sections of 6’’ PVC pipe (Figure 51). From the blower, an 8’’ to 8’’ flexible coupling was used to connect into the exhaust line.

The final hook up to Agrilab’s heat recovery system was connecting the 1’’ copper pipe (Type L) to the water lines in the bulk tank. From the heat exchange unit, copper pipe was connected to a network of hose bibbs, which were added for various research needs (Figure 52). From the network of hose bibbs, the hot water supply and return lines were attached to the underground PEX pipe leading to the milk house (Figure 53).

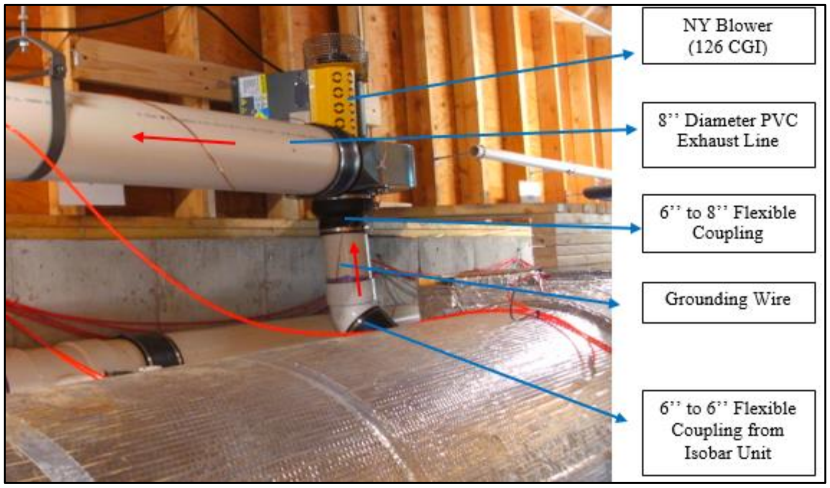

Figure 51: Connections to and from Primary Blower

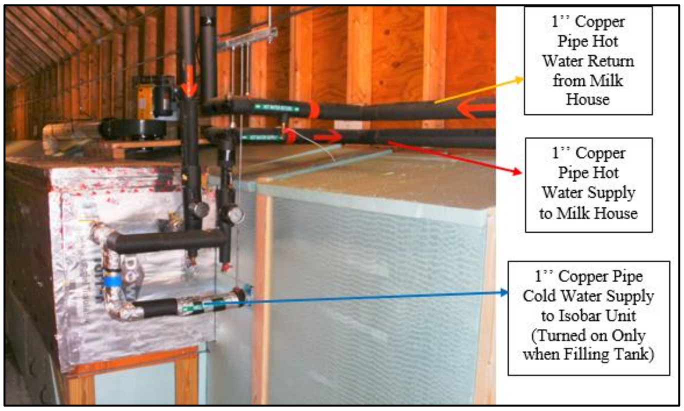

Figure 52: Hot Water Supply and Return Lines from Isobar Unit

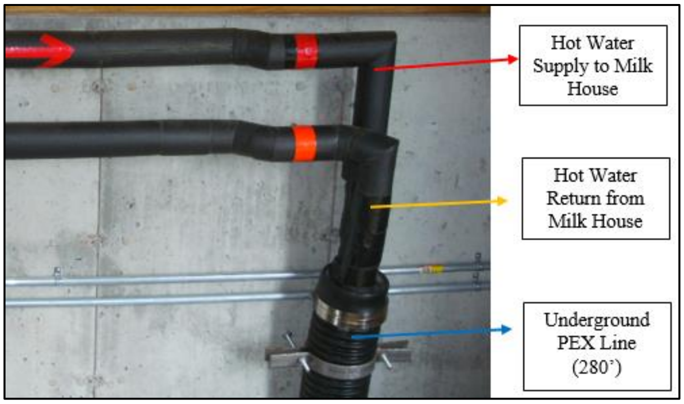

Figure 53: Underground PEX Hot Water Supply and Return Lines

Once in the milk house, the underground PEX lines were connected to 1’’ copper pipe (Type L) leading to another batch of copper hose bibbs to allow for direct hot water removal from the closed-loop system (Figure 54).

The copper pipe was then connected to a plate heater (GEA #FG10X20-20 with 1 ½’’ threads), where heat is transferred from the hot water line to a separate cold water line coming from the farm’s well (Figure 55). During this transfer, the 50ºF well water is warmed to 90ºF, before entering the farm’s water heater where it is heated up another 50-70ºF to serve all the farm’s hot water demands (Figure 56). The range in expected temperature is dependent on how many compost bays are loaded and their age.

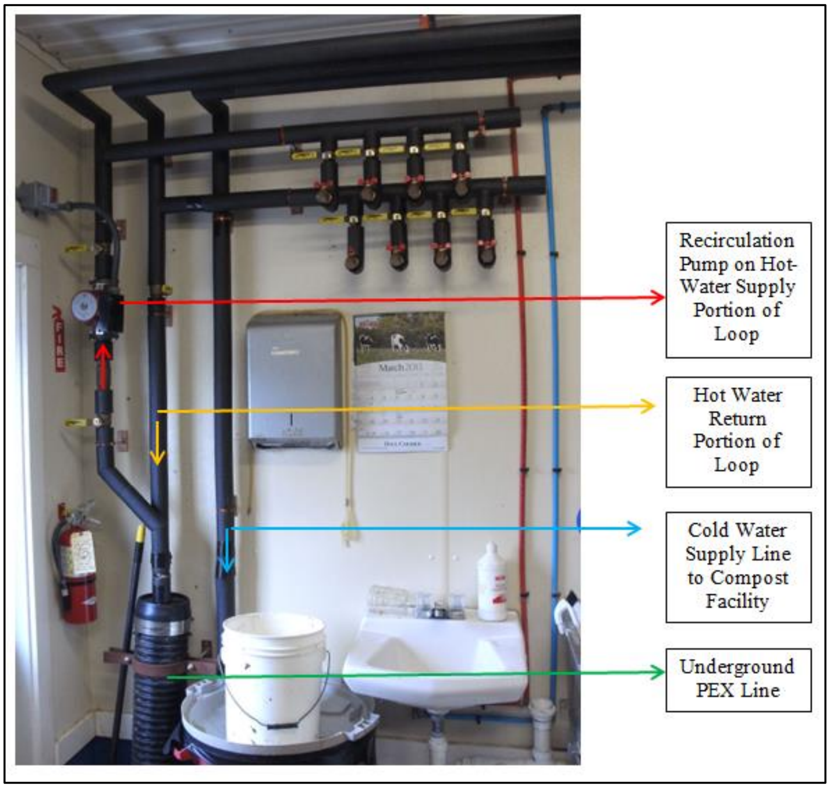

Figure 54: Water Lines Between Composting Facility and Milk Room

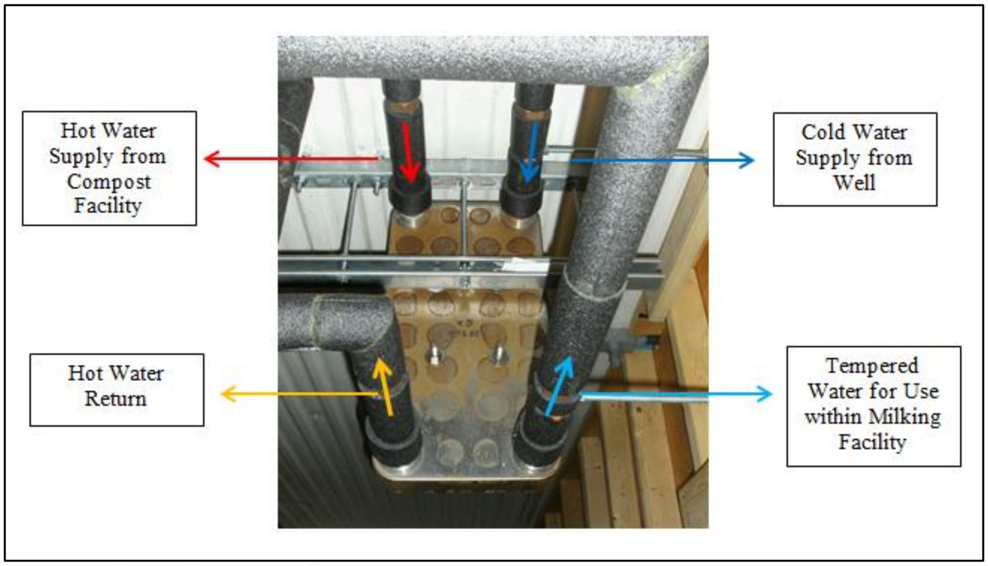

Figure 55: Plate Exchanger in Milk House

Figure 56: Hot Water Heater Receiving Compost-Heated Water

After heat transfer, the cooler water from the closed loop is sent back to the heat exchange water tank, which is connected to the isobar unit by a circulation pump (GRUNDFOS UPS26) (Figure 54 and Figure 57).

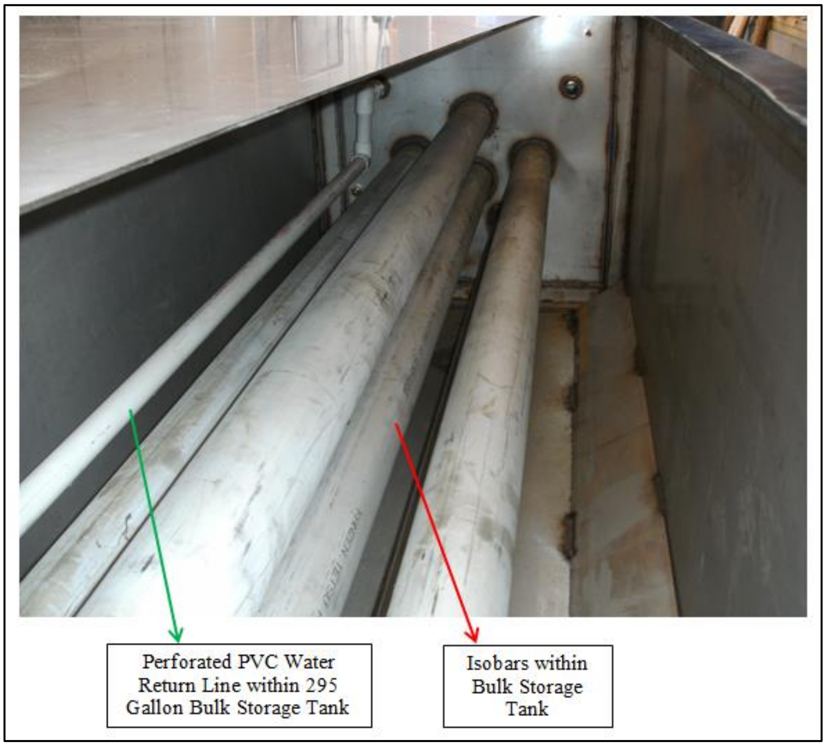

Figure 57: Isobars within the Bulk Storage Tank (Empty)

Cost Saving Tip # 15: *If possible, use PEX pipe to transfer the heated water vs. copper pipe. PEX is much less expensive in both material and installation cost. Additionally, the thermal conductivity of PEX is 0.51 w/mK vs. copper, which is 401 w/mK (Patterson and Miers 2015). The lower thermal conductivity of PEX means less heat will be lost from the pipe transferring the heated water.*

Cost Saving Tip # 16*: If underground insulated PEX pipe is used to transfer the heated water between buildings, leftover material should be used within the building to connect to the heat exchange unit. This not only saves material cost, but also reduces labor costs associated with insulating the piping.*

INSTALLING THE AERATION CONTROL SYSTEM

The aeration control system at the UNH facility was designed and installed by Agrilab Technologies. The system is run by a Do-More Programmable Logic Computer (PLC), which is housed in one of two control boxes (Figure 58).

Cost Saving Tip # 17*: If using a cascading effect for the aeration schedule, the actual aeration demand and horse power of the fan does not have to be as large compared to aerating several bays at once. This is advantageous in reducing the initial capital expense of the fan (can purchase a smaller fan), and also from an operational standpoint (lower HP saves electricity). Additionally, some of the larger fans require three-phase electric power, which is costly to install if not already on the site.*

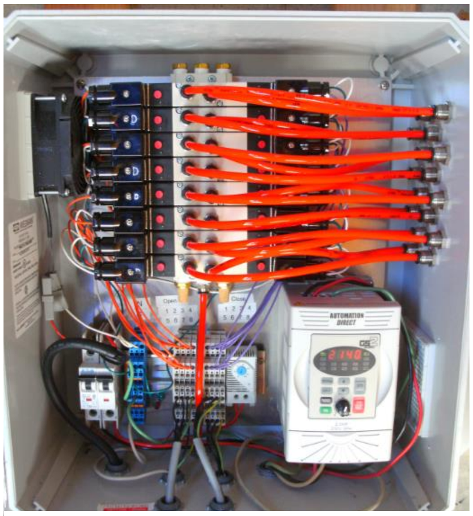

Figure 58: Agrilab's Aeration Control System

This PLC controls an air compressor and Valterra pneumatic gate valves that open and close the various composting bays (Figure 43 and Figure 59). The system operates by running the fan continuously, with the PLC controlling when bays open and close. The bays open and close in a cascading effect, ensuring the heat exchange system is always receiving hot compost vapor.

Figure 59: Compressor Running Pneumatic Lines in the Aeration System

TESTING AND INSULATING THE SYSTEM

After all the connections were made between the heat exchange unit and the rest of the mechanical room, two smoke tests were conducted to ensure all the aeration joints were sealed. The first test involved smoke bombs, where smoke was forced out of unsealed joints by turning on the fan system and capping the exhaust pipe with a smoke bomb within. The second smoke test involved incense and was conducted by turning on the aeration system with all the bay valves closed and searching for joints where smoke from the incense was sucked into the aeration system. Each test found one bad joint, which was sealed with marine-grade silicone seal. Ensuring that all joints are sealed properly is crucial, as leaks will reduce heat recovery and also pose a health concern to workers from the bioaerosols in the compost vapor. In addition to testing the aeration system, the water lines were also tested for leaks. This test was conducted by filling the water tank and loading the isobars with refrigerant through their Schrader valves. If performing this test during the winter and the room with the heat exchange unit is not heated, it is imperative that the aeration system works and compost batches have been loaded and are up to temperature. This will reduce the risk of freezing and bursting pipes.

After all the leaks were sealed, the entire aeration network was double-wrapped with a radiant heat barrier (Reflectix® Insulation). This material reflects 97% of radiant heat, has a combined R-vale of 8.4, and is antimicrobial (Reflectix 2013). Joints were also sealed with foil tape (Reflectix® foil tape) (Figure 60). The copper pipes were also insulated with a double layer of standard closed-cell polyethylene foam pipe insulation (R-12). Following the insulation of individual components (aeration and leachate pipe), the entire aeration system was enclosed in an insulated box made of dimensional lumber and 4’ * 8’ sheets of foam board insulation (Lowes 2.5’’ R-10 Insulation). Because of the research and sampling demands of the system, the insulated box was constructed in a way to allow entire 4’ * 8’ panels to be removed easily. Small ports for data sampling were also installed.

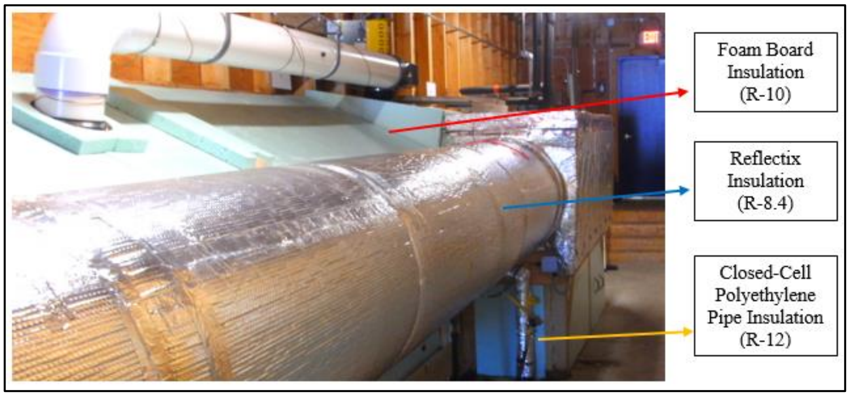

Figure 60: UNH Aeration System Following Insulation

CHAPTER 5 COST OF THE UNH HEAT RECOVERY COMPOSTING FACILITY

Before providing the cost of the UNH heat recovery composting facility, several important points need to be made to make sense of the amount paid.

1. This was a university building and was engineered to follow the University's stringent codes and long-term building requirements.
2. Because the compost heat recovery technology was relatively new at the time, a tremendous amount of time and money ($21,500) was spent designing the system. Future facilities pulling designs and ideas from this report will not likely have to go through such a lengthy design process.
3. An additional concrete pad at a cost of $54,668 was added to the budget to serve as a staging area for mixing the feedstocks. A pad of this size may not be required or necessary at other facilities.
4. Typical cost saving strategies utilized at previous sites (owner helping with construction to reduce labor cost, owner purchasing materials, etc.) were not allowed in our situation.

With the above statements in mind, the total cost for the UNH project was $538,000. A specific breakdown of the cost is provided in Appendix 6. If a facility of similar-size were built outside of a university/research setting, with a fabric structure, waste blocks for the side walls, owners doing some of the labor, and purchasing the aeration components themselves, the total cost could be well under $300,000. A specific breakdown of this estimated cost, along with a summary of all the previously recommended cost-saving strategies throughout the report, can be found in Appendix 1 and Appendix 7.

CONCLUDING THOUGHTS

When looking at the economics of building a heat recovery composing facility, it is important to realize that managing for optimal composting also results in optimal heat recovery. As stated at the beginning of this report, a specific combination of feedstocks is required to generate the kind of heat needed for recovery. Compost operators that are not capable of acquiring the right combination of feedstocks in a large enough quantity throughout the entire year, should probably consider something other than the advanced CHRS described in this report. Alternative CHRSs are described in detail in Smith and Aber (2016).

A second important consideration when looking at the economics of this type of system is that heat capture is just one of several value-added products that will make this type of operation profitable. Other important economic factors to consider for both farmers and compost operators include:

Potential Revenue Streams

- Sale of compost
- Sale of compost leachate
- Tipping fees for accepting other forms of waste (food, agricultural, municipal, etc.)
- Carbon credits (very possible if utilizing a greenhouse to scrub CO_2 from waste vapor)
- Sale of winter crops produced in a greenhouse or high tunnel that is heated with the composting system.

Potential Cost Reductions

- Reduction in fossil fuels previously used to heat water
- Reduction in time, fuel, and labor spent spreading more bulky manure on fields (farmer benefit). Also reduces the problem of smothering grass with wet manure, which can cause temporary dead spots reducing hay or pasture yields.
- Reduction in fly control costs, as the composting process destroys larva and removes the material the flies can breed in (farmer benefit). Biting flies are known to impact herd health on dairy farms and reduce milk yields (Dyck et al. 2009).

Potential Non-Market Benefits

- Reduction in compost bioaerosols and overall farm odor through biofilter usage. Colon et al. (2009) described a biofilter at commercial composting facility, capable of reducing NH_3 emissions by 90% and VOCs by 70%.
- Reduction in nutrient leaching associated with producing a more stabilized product (compost).
- Increased awareness and management of the farm's waste streams through the composting operation (have to know the quantities of the various waste feedstocks for compost recipe building).

The above only represent a few of the economic factors relating to a heat recovery composting facility. As previously stated, a payback of 4-8 years (not including grants or cost sharing) has been recognized for this type of system (Agrilab Technologies 2013). For those already composting using the ASP method, the payback period is even shorter, as the heat exchange system can simply be attached to the current aeration system. An important point to note regarding the payback is that it is dependent on a number of factors. What greatly influences the time at which these systems pay for themselves is whether new infrastructure (compost building, compost storage facility, etc.) and machinery (loaders, screeners, mixers, conveyors, etc.) are required. The quantity of available compost for sale, combined with proximity to markets is also a major factor that will determine the payback period. In assessing economic feasibility, all of these considerations need to be made.

It is important to note that the primary goal of this report is to provide food for thought and to save those interested in the technology capital in engineering and consulting costs, which are often high for new technologies. The case study in this report represents one possible design for a heat recovery composting facility. The three other facilities utilizing this technology have slight variations within the mechanical room and the type of building used to cover the aeration floor. A summary table outlining the differences (and commonalities) between the four facilities, along with references related to their construction/building procedures, can be found in Appendix 2 of this document.

In deciding whether to go forward with a heat recovery composting facility, the authors encourage the reader to reference portions or even the entire report to policy makers and/or investors, as it should answer many questions/concerns individuals have regarding this type of technology. We also encourage all users of this technology to share their ideas with one another and join the network of composters extracting heat from waste biomass.

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APPENDICES

APPENDIX 1: MATERIALS LIST & ESTIMATED COST OF A SIMILARLY-SIZED FACILITY

Item Description	**Quantity**	**Cost/Unit**	**Store**	**Total Cost**
Main Composting Floor				
4" PVC Pipe (10' Sections)	52	$ 23.77	US Plastics Corp	$ 1,236.04
4" PVC Couplings	48	$ 3.35	US Plastics Corp	$ 160.80
4" PVC End Caps	16	$ 4.76	US Plastics Corp	$ 76.16
Band-Seal End Cap w/Hose Bibb	16	$ 9.48	Amazon	$ 151.68
4" Galvanized Steel Pipe Risers	48	$ 15.90	Grainger	$ 763.20
1/2" Diameter Black Threaded Rod (10' Sections)	15	$ 8.55	Platinum Fire Supply	$ 128.25
1/2" Diameter Rebar Rod (20' Sections)	29	$ 7.47	Home Depot	$ 216.63
4" Foamular 250 Foam (2"*4'*8' Sheet)	196	$ 33.92	Home Depot	$ 6,512.64
Cover Plate Plywood Forms (4' * 8' * 1/2" Sheet)	7	$ 25.98	Lowes	$ 181.86
Cover Plate Plywood Forms (4' * 8' * 3/4" Sheet)	7	$ 32.20	Lowes	$ 225.40
Marine Plywood Cover Plates (4' * 8' * 3/4" Sheet)	7	$ 95.00	GooseBay	$ 665.00
Mechanical Room & Aeration System				
Bay Headers (Eight Total)				
8" x 4" Flexible Rubber Coupling	8	$ 43.06	Zoro	$ 344.48
4" Sanitary Tee	8	$ 17.35	SupplyHouse.com	$ 138.80
4" Flexible Rubber End Cap	8	$ 2.72	SupplyHouse.com	$ 21.76
4" x 4" Flexible Rubber Coupling	16	$ 4.35	SupplyHouse.com	$ 69.60
4" Long Sweep Street 90° Elbow	8	$ 13.45	SupplyHouse.com	$ 107.60
4" Valterra Pneumatic Gate Valve (Model 6401P)	8	$ 153.26	Amazon	$ 1,226.08
8" x 8" x 4" PVC Wye	8	$ 61.75	SupplyHouse.com	$ 494.00
Aeration Supply and Exhaust Lines				
8" x 8" Flexible Rubber Coupling	20	$ 15.35	SupplyHouse.com	$ 307.00
8" Flexible Cap	3	$ 18.86	Drainage Solutions	$ 56.58

4" PVC Sch. 40 Pipe (10’ Sections)	2	$ 23.77	Lowes	$ 47.54
8" PVC Sch. 40 Pipe (20’ Sections)	10	$ 174.00	Eliminator Systems	$ 1,740.00
Oatey 32 oz PVC Primer	3	$ 16.51	Home Depot	$ 49.53
Oatey 32 oz Heavy Duty PVC Cement	3	$ 16.20	Home Depot	$ 48.60
8" 90° PVC Sch. 40 Elbow	2	$ 78.95	SupplyHouse.com	$ 157.90
8" Clevis Hanger	2	$ 25.80	Grainger	$ 51.60
7/8" Diameter Galvanized Steel Threaded Rod (6’ Sections)	2	$ 82.00	Grainger	$ 164.00
Custom Made Pipe Stands for Aeration Supply & Exhaust Line	18	$ 12.00	Home Depot	$ 216.00
8 Gauge Solid Bare Copper Grounding Wire (200 ft roll)	1	$ 160.00	Home Depot	$ 160.00
Aeration Control System				
Laptop	1	$ 500.00	Staples	$ 500.00
Aeration Control System (Labor + Materials)	1	$ 7,200.00	Agrilab Technologies	$ 7,200.00
California Air Tools 4610A Ultra Quiet Air Compressor	1	$ 259.00	Home Depot	$ 259.00
1/4" NITRA Pneumatic Tubing (1000 ft Roll)	1	$ 182.00	Automation Direct	$ 182.00
Connection to Isobar				
8" PVC Sch. 40 Vent Tee	1	$ 84.95	SupplyHouse.com	$ 84.95
8" x 8" Flexible Rubber Coupling	1	$ 15.35	SupplyHouse.com	$ 15.35
10" x 8" Flexible Rubber Coupling	1	$ 29.14	Zoro	$ 29.14
Isobar to Exhaust Line				
6" x 6" Flexible Rubber Coupling	3	$ 10.15	SupplyHouse.com	$ 30.45
6" PVC 45° Elbow	2	$ 21.95	SupplyHouse.com	$ 43.90
6" PVC Sch. 40 Pipe (10 ft Sections)	1	$ 38.49	Lowes	$ 38.49
8" to 6" Flexible Rubber Coupling	1	$ 16.77	Zoro	$ 16.77
1 HP Blower with Speed Control	1	$ 1,775.00	NY Blower (126 CGI)	$ 1,775.00
8" Flexible Coupling	1	$ 15.35	SupplyHouse.com	$ 15.35
Drain Line for Exhaust				
4" to 2" Flexible Rubber Coupling	1	$ 5.99	SupplyHouse.com	$ 5.99
2" x 2" Flexible Rubber Coupling	2	$ 5.02	Zoro	$ 10.04
2" PVC P-trap with Cleanout	1	$ 9.27	Home Depot	$ 9.27
2" PVC Sch. 40 Pipe (10 ft Sections)	1	$ 8.96	Lowes	$ 8.96

Biofilter				
8" 90° PVC Elbow	3	$ 55.00	Eliminator Systems	$ 165.00
8" PVC Tee	1	$ 75.00	Eliminator Systems	$ 75.00
8" x 6" Flexible Rubber Coupling	1	$ 20.00	Eliminator Systems	$ 20.00
6" SDR-35 Cross Tee	1	$ 45.00	Eliminator Systems	$ 45.00
6" SDR-35 6" Pipe (10 ft Sections)	6	$ 35.00	Lowes	$ 210.00
6" x 6" Flexible Rubber Coupling	6	$ 12.40	Eliminator Systems	$ 74.40
6" SDR-35 90° Elbow	2	$ 10.98	Lowes	$ 21.96
6" Flexible Rubber End Cap	2	$ 10.28	Zoro	$ 20.56
Water Lines in Compost Facility				
1" Type L Copper Pipe (10 ft Sections)	1	$ 64.15	Grainger	$ 64.15
1" Copper Tee	5	$ 4.45	Pex Supply	$ 22.25
1" 90° Copper Elbow	15	$ 2.93	Pex Supply	$ 43.95
8 oz Oatey Paste Flux for Soldering	2	$ 4.50	Home Depot	$ 9.00
Underground PEX Hot Water Supply and Return Line	300	$ 6.00	Outdoor Boilers	$ 1,800.00
Campbell 5' Frost-Proof Yard Hydrant	2	$ 83.10	Grainger	$ 166.20
Water Lines in Milk House				
1" Copper Pipe Type L (10 ft Sections)	12	$ 64.15	Grainger	$ 769.80
1" Copper Tee	6	$ 4.45	Pex Supply	$ 26.70
1" Copper 90° Elbow	27	$ 2.93	Pex Supply	$ 79.11
Grundfos UPS 26-150SF Circ Pump	1	$ 550	Plumber Surplus	$ 550.00
GEA 100 GPM Plate Exchanger	1	$ 1,436.95	Pex Supply	$ 1,436.95
Leachate Network				
4" PVC Pipe (10’ Sections)	8	$ 23.77	Lowes	$ 190.16
4" - 2" PVC Wye Reducer	8	$ 8.38	Home Depot	$ 67.04
2" PVC 90° Elbows	16	$ 1.20	US Plastic Corp	$ 19.20
2" PVC S-trap with Waste	8	$ 9.95	Home Depot	$ 79.60
2" PVC Pipe (10’ Sections)	1	$ 8.96	Lowes	$ 8.96
2" PVC 45° Elbows	24	$ 1.31	US Plastic Corp	$ 31.44
4" Galvanized Steel Pipe Riser Clamp	21	$ 15.90	Grainger	$ 333.90
5/8 " Threaded Rod (6’ Sections)	1	$ 28.25	Grainger	$ 28.25
Pre-cast 1500 Gallon Leachate Tank	1	$ 1,100.00	Phoenix Precast	$ 1,100.00
Leachate Tank Pump Alarm (Zoeller)	1	$ 74.33	Amazon	$ 74.33
4" PVC from Facility to Leachate Tank (10’ Sections)	2	$ 23.77	Lowes	$ 47.54

Portable Semi-Trash Water Pump	1	$ 259	Home Depot	$ 259.00
Major Capital Expenses				
Agrilab Isobar Heat Exchange Unit w/Insulation and Technical Support	1	$ 55,245	Agrilab Technologies	$ 55,245.00
Fabric Structure + Installation (65'W * 70'L)	1	$ 62,400	ClearSpan	$ 62,400.00
Interlocking Waste Blocks (6' * 2' * 2') for Two 65' L Walls 2' W and 6' H	65	$ 65	Coleman Concrete	$ 4,225.00
Concrete Pad and Back Push Wall + Forming of Main Composting Floor	1	$ 40,000		$ 40,000.00
			Subtotal Materials Cost	$ 195,653
Additional Costs to be Included				
Land (Variable)				
Site Work (Variable)				
Installation of Aeration System in Mechanical Room				
Installation of Electrical				
Permits (Variable by State)				
Total Estimated Cost				

APPENDIX 2: SUMMARY SPECS FROM OTHER HEAT RECOVERY COMPOSTING SITES

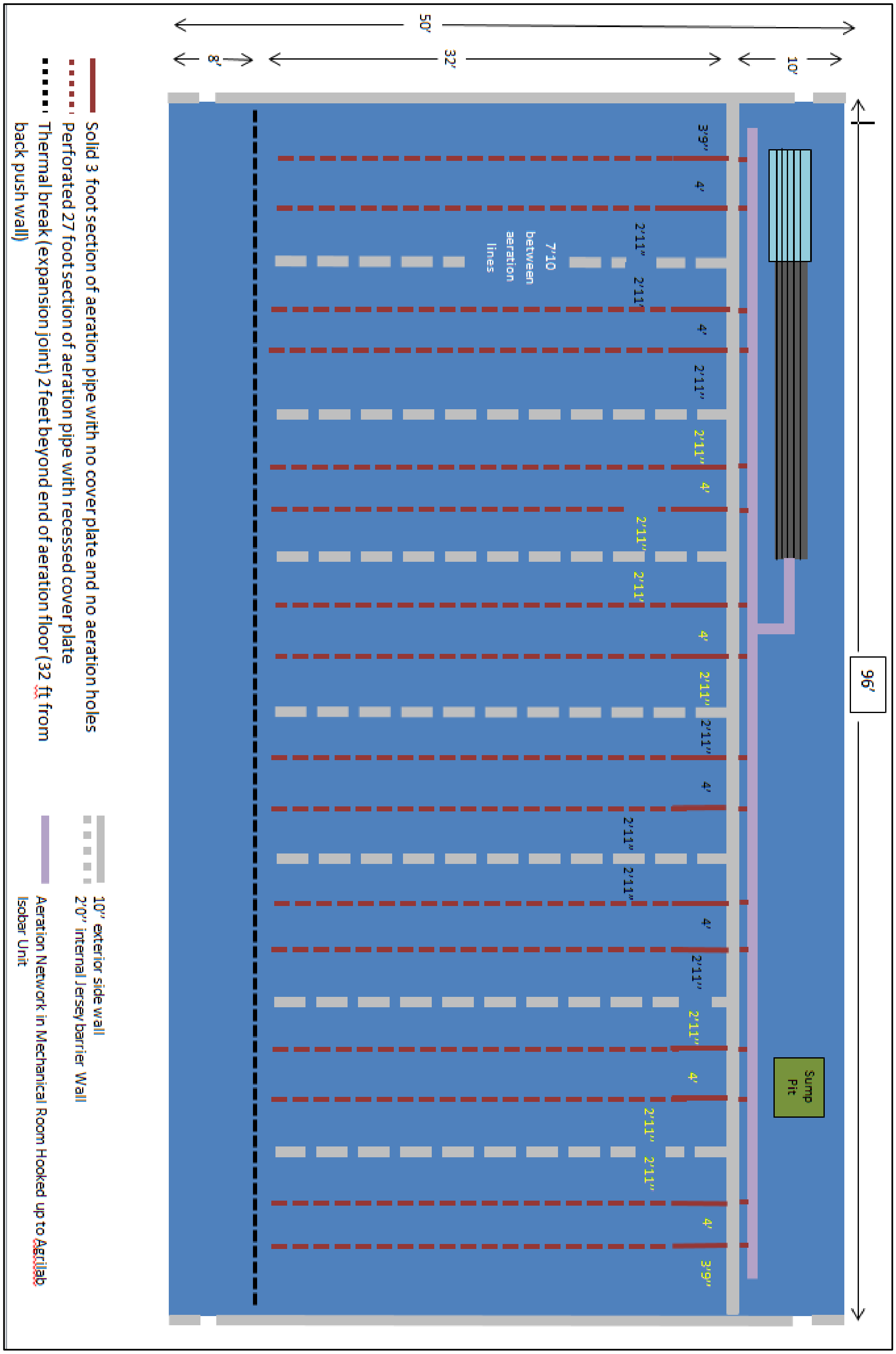
	Diamond Hill Custom Heifers Sheldon, VT	**Sunset View Farm (Schaghticoke, NY)**	**Jasper Hill Farm Greensboro, VT**	**UNH Organic Dairy Durham, NH**
Owners	Terry and Joanne Magnan	Sean and Sandy Quinn	Andy and Mateo Kehler	University of New Hampshire
Operation Type	Raise 1800-2100 calves and heifers	Raise 1300 to 2000 calves and heifers + 100 cows	On-farm cheese maker with 45 Ayrshire cows + replacements	Organic Dairy with 50 cows + 50 replacements
Isobar® System Installation	2006	2010	2012	2013
Building Size	Two 52’ * 60’ bays + mechanical room	130’ * 55’	120’ * 55’	96’ * 50’
Aeration Floor Size	52’ * 60’ + apron	53’ * 60’ + apron	80’ * 30’	96’ * 32’
Aeration Zones	4	4	8	8
Aeration Line Length and Diameter	60’ of 6’’ diameter pipe, 4 per zone, 16 total	60’ of 6’’ diameter pipe, 4 per zone, 16 total	30’ of 4’’ diameter pipe, 2 per 6 zones, 4 per 2 zones, 16 total	30’ of 4’’ diameter pipe, 2 per 8 zones, 16 total
Feedstock Tonnage/month (Wet Weight)	180-200 per windrow with 4 contiguous batches	200 - 250	60	65
Feedstocks for Composting	Cow manure and bedding from calves	Cow manure, separated solids, and bedding from calves	Cow manure, separated solids, and bedding	Manure, bedding, waste feed hay
Method of Mixing/Loading	Mix with vertical mixer into pile, followed by loading with telehandler	Mix with manure side slinger into pile, followed by loading with front loader	Mix by unloading directly into facility with a rear-discharge manure spreader,	Mix by unloading with a rear-discharge manure spreader,

			followed by piling higher with tractor	followed by piling higher with tractor
Compost Residence Time	8 - 26 weeks (12 Average)	8 - 20 (12 Average)	10 - 16 (12 Average)	8 weeks
Size of Isobar Unit	6 Isobars 60’ long with an 800-gallon bulk tank	12 Isobars 42’ long with 600-gallon bulk tank	6 Isobars 30’ long with 300-gallon bulk tank	6 Isobars 30’ long with 295-gallon bulk tank
Hot Water Uses	Radiant floor heat for calf barn and heat milk formula for calves	Sanitization of equipment, calf hutches and preparing feed	Used as a heater for three anaerobic digester tanks (maintains digester at 100°F)	Hot water heating and sanitization in milk room at farm
Average Bulk Storage Tank Temperature	120ºF	115ºF	101ºF	110ºF
Peak Temperature in Bulk Tank	146ºF	129ºF	109ºF	120ºF
Final Target Water Temp	155ºF	110 - 115ºF	101ºF	170ºF
Average BTU/hr Recovery	200,000	150,000	Not Reported	30,000
Peak BTU Recovery/hr	440,0000	195,000	Not Reported	34,500
Annual Farm Energy Savings/yr	$10,000	$9,200	Not Reported	Not Reported
Heat Exchanger Cost	$60,000	$80,000	$39,500	$38,415
Annual Farm Profit from Compost Sales	$35,000	Uses Compost as Bedding Instead	Not Reported	*$27,000

Annual Farm Savings in Manure Management	$19,000	$34,500	Not Reported	$0 (Wash from Previous Management)
Annual Farm Savings from compost bedding	NA	$101,700	NA	NA
Total Project Cost	$480,000 (Includes composting barn with concrete aeration floor, storage area, mechanical room, plumbing connections and compost curing shed. Costs include design, labor and materials.)	$819,000 (Includes composting barn with concrete aeration floor, storage area, mechanical room, plumbing connections and dewatering/separator equipment, pumps and building. Costs include design, labor and materials.)	Estimated $750,000 (Includes composting barn with concrete aeration floor, storage area, mechanical room, plumbing connections, greenhouse, digestion tanks, liquid biofiltration cells, vapor biofilter bed and manure dewatering/separator equipment, pumps and building. Costs include design, labor and materials.)	$538,000 (Includes composting barn with concrete aeration floor, compost and feedstock mixing area. Costs include design, labor and materials.)

*The estimation of compost sales from the university farm is theoretical, as the university does not sell compost. However, the value presented is the net return on compost sales if compost were to be sold. Calculation is based on 900 yd^3 of compost being sold at $35/yd^3 with a cost of production of $5/yd^3. While the facility produces 900 yd^3, the total finished volume of compost would be around 7,500 yd^3 if it were operating under commercial and non-research management. Compost sales would then be higher than those reported here.

APPENDIX 3: UNH FACILITY LAYOUT



APPENDIX 4: QUANTITY OF CONCRETE USED AT UNH FACILITY

- Concrete Pads
  - Main Composting Floor → 32’ * 94.33’ * 9.5’’ = 88 yd^3
  - Internal Apron → 8’ * 94.33’ * 9.5’’ = 22 yd^3
  - External Apron → 4’ * 96’ * 4’’ = 5 yd^3
  - Mechanical Room → 10’ * 94.33’ * 4’’ = 12 yd^3
    - Total Concrete for Pads = 127 yd^3

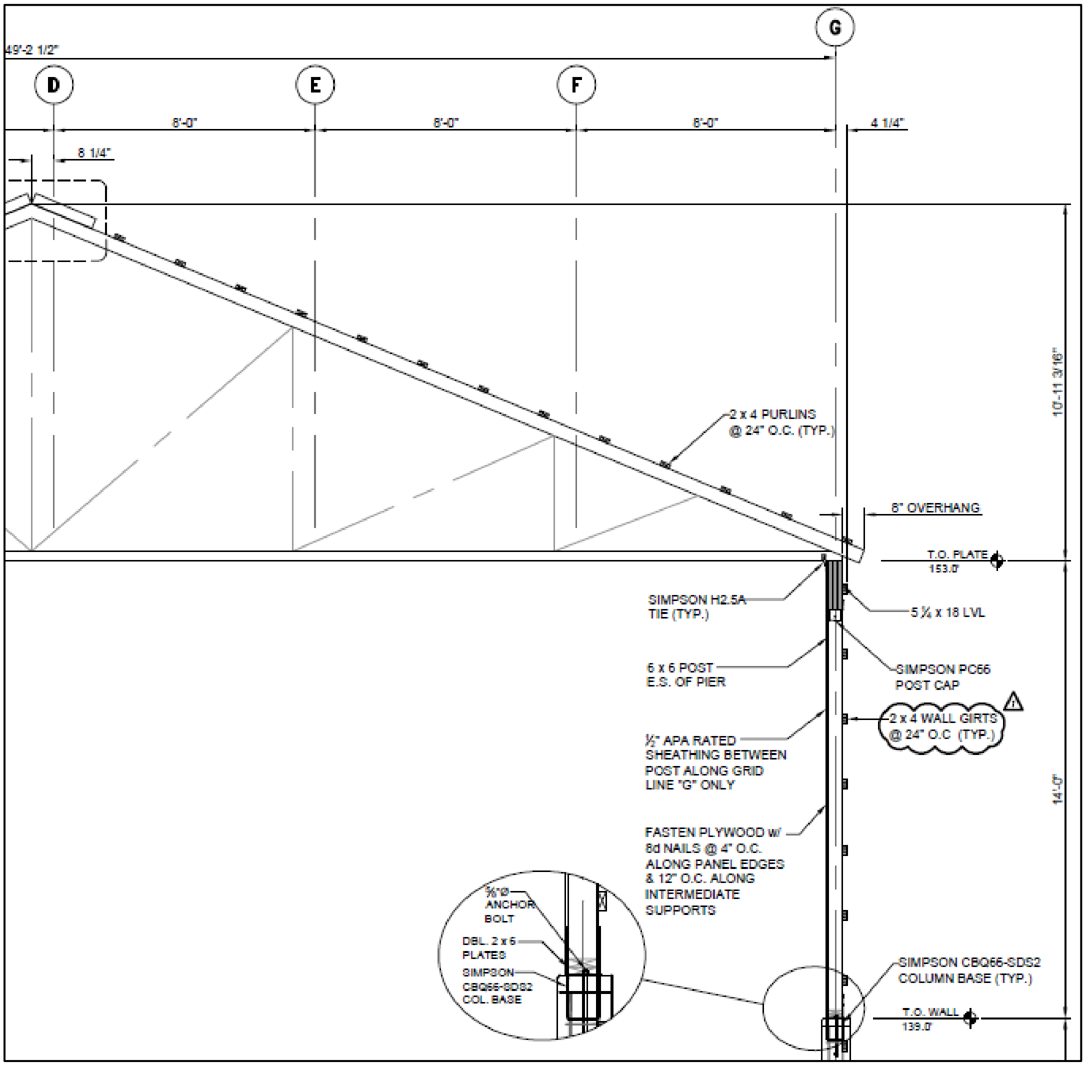
- Push Wall and Side Frost Walls
  - Back Push Wall Footing → 6.5’ * 96’ * 12’’ = 23 yd^3
  - Back push Wall → 8’ * 94.33’ * 12’’ = 28 yd^3
  - Side Frost Wall Footing → 2’ * 40’ * 12’’= 3 yd^3 * 2 = 6 yd^3
  - Side Frost Wall → 8’ * 40’ * 8’’ = 8 yd^3 = 16 yd^3
    - Total Concrete for Main Composting Room = 73 yd^3

- Mechanical Room Walls
  - Mechanical Room Wall Footing 1 → 2’ * 32.25’ * 12’’ = 2.4 yd^3
  - Mechanical Room Wall 1 → 6’ * 32.25 * 8’’= 4.8 yd^3
  - Mechanical Room Wall Footing 2 → 2’ * 10’ * 12’’ = 0.75 yd^3
  - Mechanical Room Wall 2 → 6’ * 10’ * 8’’ = 1.5 yd^3
    - Total Concrete for Mechanical Room = 9.5 yd^3

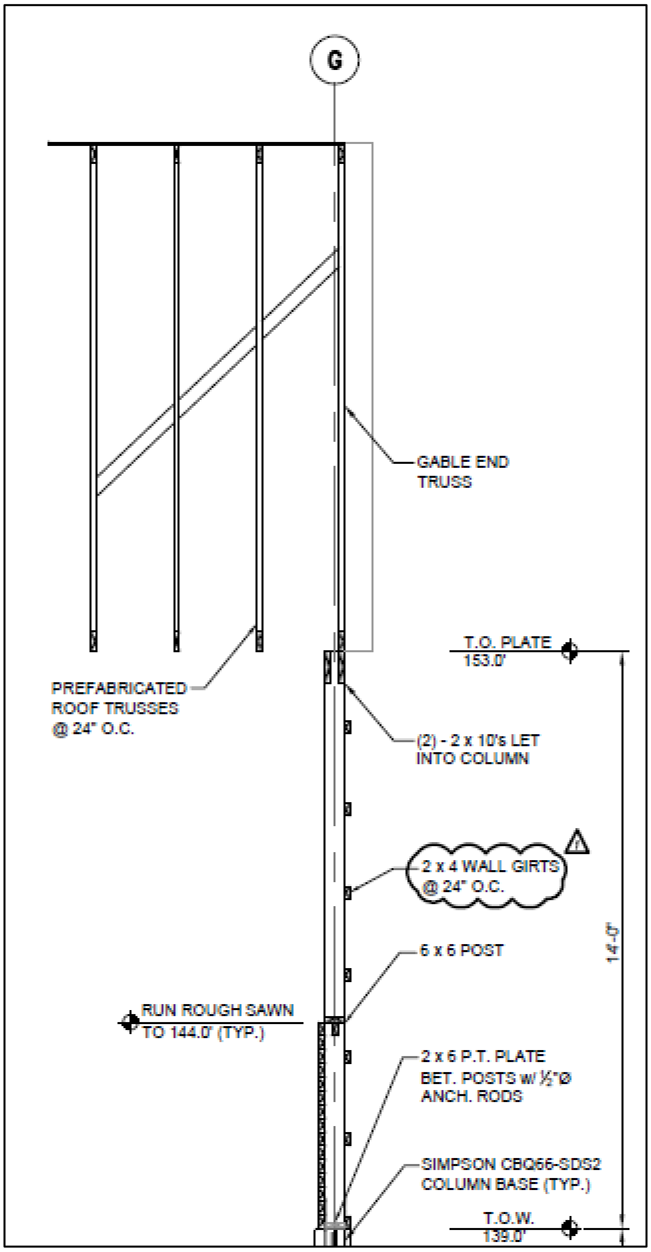
- Concrete Piers
  - Front Concrete Pier Footings (2) → 2.5’ * 4.5’ * 12’’ = 0.42 * 2 = 0.84 yd^3
  - Front Concrete Pier (2) → 8’ * 2.5’ * 10’’ = 0.62 * 2 = 1.24 yd^3
  - Front Concrete Pier Footings (3) → 3.67’ * 4.5’ * 12’’ = 0.62 * 3 = 1.86 yd^3
  - Front Concrete Pier (3) → 3.67’ * 8’ * 10’’ = 0.91 * 3 = 1.82 yd^3
  - Mechanical Room Pier Footing → 2’ * 1’ * 12’’ = 0.07 * 8 = 0.56 yd^3
  - Mechanical Room Piers (8) → 4’ * 1’ * 8’’ = 1.09 * 8 = 8.72 yd^3
    - Total for Piers = 15 yd^3

Total Concrete for Facility = 225 yd^3

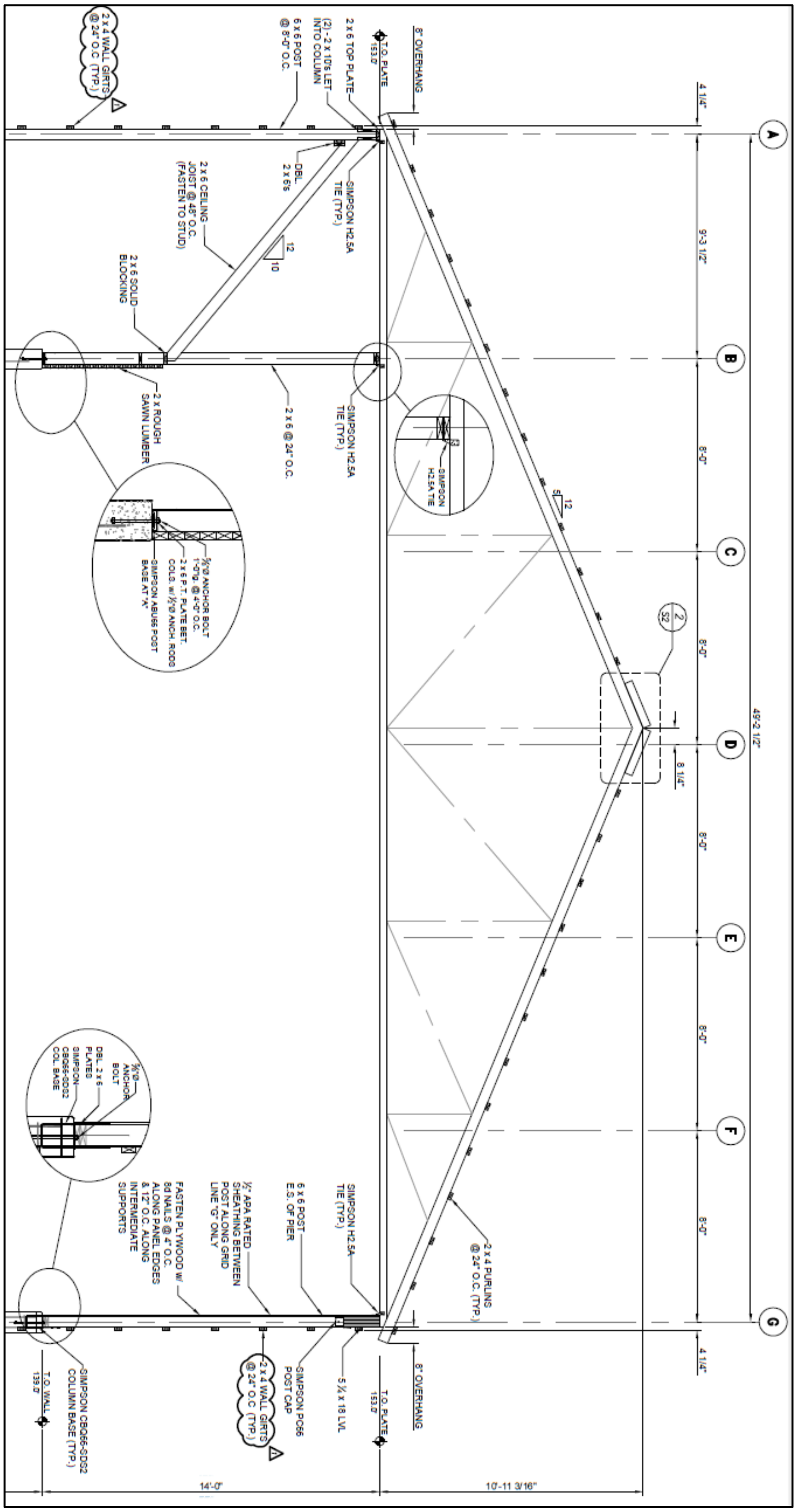
APPENDIX 5: DIAGRAMS FOR UNH POLE BARN



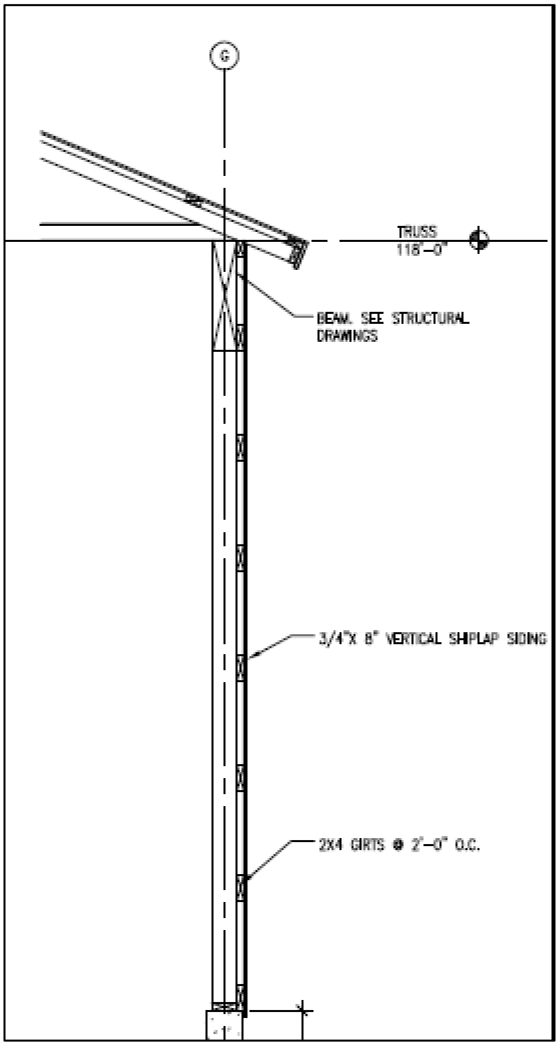
(H.L. Turner Group Inc. 2013)



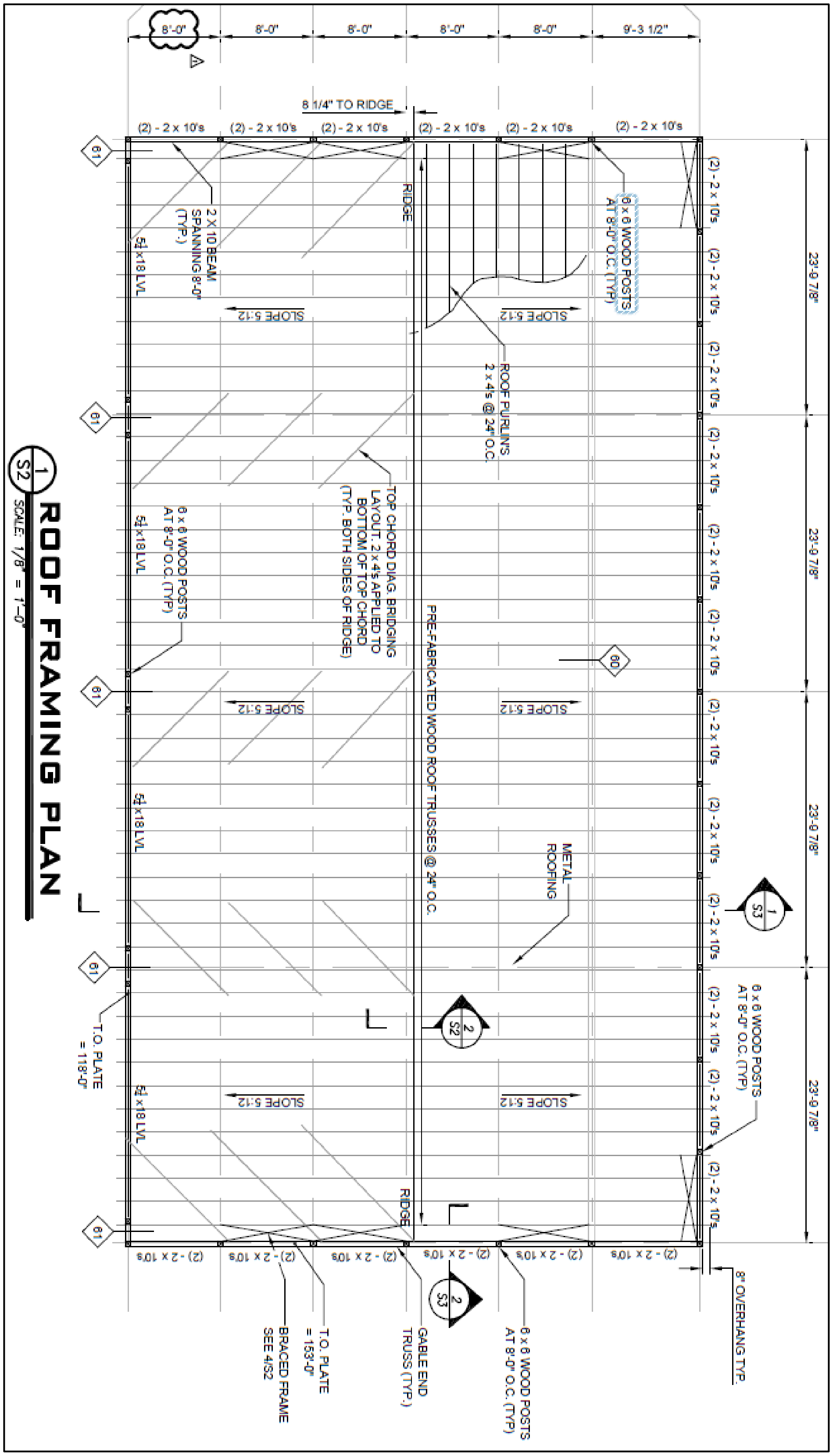
(H.L. Turner Group Inc. 2013)



(H.L. Turner Group Inc. 2013)



(Warrenstreet Architects 2013)



(H.L. Turner Group Inc. 2013)

APPENDIX 6: BREAKDOWN OF THE COST FOR THE UNH FACILITY

Item	**Cost**
Preliminary Design Services	$ 7,179
Detailed Design Submission	$ 14,358
General Requirements (site costs that include temp toilets and office trailer rental, temp telephone and fax connection/usage, temp electrical, temp water, travel, office supplies, cost of superintendent, etc.	$ 74,020
Sitework	$ 68,284
Demolition	$ 1,730
Concrete	$ 64,924
Metals	$ 150
Rough Carpentry	$ 66,421
Finish Carpentry	$ 15,316
Moisture Protection (roof, insulation of all water and aeration lines, water proofing foundations, etc.)	$ 35,580
Doors, Frames and Hardware (includes 4 standard doors and 4 20'*20' compost bay doors)	$ 21,685
Painting	$ 150
Specialties	$ 100
Agrilab Technologies Isobar Unit + Support	$ 52,400
Mechanical	$ 65,550
Electrical	$ 19,595
Overhead and Profit	$ 29,214
Other	$ 1,675
Total	**$ 538,131**

APPENDIX 7: RECOMMENDED COST-SAVING STRATEGIES FOUND THROUGHOUT REPORT

1. Carefully assess the aeration demands of the system, as the cost of PVC pipe increases substantially as pipe diameter increases. This is especially true for the difference between 8’’ and 10’’ diameter PVC pipe and fittings.
2. Purchase materials yourself [PVC pipe and fittings, fan(s), flexible couplings, insulation (rigid foam for concrete sub-base, thermal joints, pipe insulation, etc.), support structures (clevis hangers, piper riser clamps, threaded rod, etc.), plate exchanger, Isobar heat exchanger, etc.].
3. Ensure the facility is sited properly to reduce the travel distance between the feedstocks and the composting floor. This is one of the more important cost-saving strategies, as extra time maneuvering around objects will add substantial cost over the long run.
4. Consider installing a larger leachate tank (≥ 3500 gallons), capable of filling a tanker truck in one load. This will reduce the number of pumpings and allow for full loads when transporting and spreading leachate on fields for fertilizer/irrigation.
5. Ensure all possible holes through the concrete are planned ahead of time and receive sleeves during forming to prevent the need to drill through the concrete.
6. For the primary back push wall, wood can be used for the upper portion of the wall, reducing the cost of concrete. This cost-saving strategy needs to be looked at carefully though, as it will require a vapor barrier, and the need to replace the wood in the future.
7. Instead of pouring side walls, investigate the cost of concrete waste blocks. These blocks are commonly used for side walls for fabric structures. UNH received quotes in the $65 -$75 range per 2’ * 2’ * 6’ delivered interlocking block (when purchasing a trailer load). This cost-saving strategy will not only reduce concrete costs, but could significantly reduce the ground preparation costs as well.
8. If labor costs are high in the area, a cost comparison between rigid foam insulation and Insul-Tarp is warranted when deciding which insulation to place under the concrete slab.
9. Make the cover plates out of dimensional lumber to save labor cost and increase the recession of the aeration floor.
10. Do not drill the aeration holes in the PVC pipe until all construction is complete – this reduces the labor involved in cleaning, should the holes get plugged with construction material.
11. The concrete aprons (internal and external) and mechanical room slab do not have to have the same thickness as the primary aeration floor, saving concrete costs.
12. Use a high tension fabric structure if possible. This represents one of the greatest cost-saving strategies, especially if the operator was not planning on building the structure themselves.
13. If using pneumatic valves to control the aeration system, valves increase exponentially with an increase in pipe diameter size. Reducing the pipe diameter prior to the valve can save thousands of dollars in cost, provided the fan is capable of handling the increase in resistance.
14. Installing PVC tees or wyes at every header and in the adjacent exhaust line allows for compost vapor recirculation. This method can be used to start bays, especially in the winter, reducing the time to reach thermophilic conditions. This not only increases the volume that can move through the composting facility, but also reduces cooler air being sent into the heat exchange system as a pile warms up.

15. PEX pipe should be used instead of copper whenever possible. Copper pipe has a higher thermal conductivity, meaning more heat will be lost from the heated water as it travels from source to sink. PEX pipe is also less expensive to purchase and install.
16. If using an underground PEX pipe, use as much of it as possible and bring it as close to the isobar unit as possible, reducing the need for insulating additional PEX or copper pipe.
17. Setting up the aeration schedule in a cascading effect will allow for a smaller horse power fan. This saves capital initially and operating expenses perpetually from reduced electricity costs. Many of the higher-powered composting fans > 2 HP also require 3-phase electricity, which is expensive to install if it is not already on site.

APPENDIX 8: SUMMARY STEPS FOR UNH FACILITY CONSTRUCTION

1. Size Facility - Size according to feedstock quantity, residence time, and available funds. Remember to size facility with appropriate aeration dead zones, walkways/internal concrete apron, mechanical room, etc.
2. Ground Preparation – Ensure any potential runoff from the facility does not enter neighboring waterways, as high nitrogen and phosphorus levels could cause environmental problems/litigation from those downstream.
    a. Install underground water lines that go under the concrete footings.
    b. Install leachate line and tank.
3. Footing and Wall Forming – Install 4’’ sleeves for the aeration lines on the back push wall. Install all other sleeves (electrical, thermocouples, etc.).
4. Pouring Walls and Piers – Following pours, bring ground up to grade with fill.
5. Aeration Floor Forming and Insulation - Lay down pad insulation, supports, welded wire mesh, and pipe risers/rebar rods.
    a. Install slab-connecting dowels between aeration floor and internal concrete apron.
    b. Add in thermal break to all portions of the facility where the concrete pad touches the side walls.
    c. Lay down aeration lines with PVC going through back wall sleeves and extending 2’ into mechanical room. Cap PVC ends and fill aeration lines with water.
6. Pouring Aeration Floor - Pour around aeration lines first to hold them in place. Ensure there is a 1% slope across the 3 ft. section of concrete without a cover plate, and at least a 1% slope from the end of the aeration line to the back push wall.
    a. After concrete curing, remove flexible end caps from the aeration lines and release the water. Also remove all the forms (slab-connecting and cover plate).
    b. Fill any gaps around the aeration lines sleeves with Leakmaster LV-1 (or similar product).
    c. Install cover plates (do not drill yet, but saw arch across length).
    d. Install leachate line against the back push wall in the mechanical room.
7. Slab Forming and Insulation for Internal Apron – Lay down concrete dobies and welded wire mesh.
    a. Ensure insulation is placed around the dowels from the aeration floor to the internal apron for a thermal break/expansion joint between the two slabs.
    b. Install dowels to connect internal apron with external apron.
8. Pouring Internal Apron – Ensure internal apron has 1% slope toward aeration floor for drainage.
9. External Apron Forming and Insulation – Lay down concrete dobies and welded wire mesh. Ensure insulation is installed around dowels between internal and external concrete aprons.
10. Pouring External Apron – Pour concrete with a 1% slope away from the building
11. Forming Mechanical Room Floor – Install forms for the sump pit
12. Pouring Mechanical Room Floor – Ensure floor is sloped to back floor drain/sump pit.
13. Raising the Building - (pole barn, ClearSpan, etc.)
14. Aeration Line Holes - Drill ½’’ holes in aeration lines and cover plates once the building is raised. Ensure all orifices are properly drilled and are clean.

15. Leachate holes – Fill aeration lines with water and assess where pooling occurs. If aeration holes were drilled at the apex of the pipe, small diameter (1/8'') will likely be required by the back push wall. Additional leachate holes may also be warranted if low spots exist along the aeration lines.
16. Mechanical Room Aeration Setup - Install aeration ductwork to where the Isobar unit will be installed.
    a. Ensure appropriate insulation is placed around all metal components (stands, riser clamps, clevis hangers, etc.) that come into contact with the aeration network. Do not insulate the pipe itself yet.
    b. Connect all aeration channels to primary leachate network.
17. Install aboveground waterlines (cold and hot) to where the Isobar unit will be housed (do not insulate the copper pipe yet).
18. Install isobar unit
    a. Hook Isobar unit to aeration, exhaust, leachate and water (cold and hot water supply/return) networks
    b. Install aeration control system
    c. Smoke test aeration system for leaks
    d. Insulate aeration ductwork
    e. Fill bulk storage water tank
    f. Test water lines for leaks
    g. Insulate copper pipe
    h. Insulate Isobar unit after system has run/tested for leaks