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Connecting Composting and Greenhouses: An Energy Capture and Usage Model

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Title: Connecting Composting and Greenhouses: An Energy Capture and Usage Model

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Abstract: At the Organic Dairy Research Farm in Lee, New Hampshire, the practice of aerated static composting is researched for potential heat capture. In early 2019, an Excel model was created to illustrate the ability of greenhouses to retain heat during a cold month of January and the total energy balance for each day. This model shows that an average greenhouse, based on the dimensions of the greenhouse at Kingman Farm, requires an additional, external heat source to supplement its heating needs. By adding the heat generated by the aerated static composting pile to the greenhouse in the Excel model, the greenhouse is able to run without needing the additional heat.

Key Words: composting, greenhouse, crop, season extension, growing season, aerated, static, compost pile, high tunnel, heat, heat capture

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A. Introduction

There has been a large push in New England towards a future with significant growth in sustainable agriculture. A substantial part of this push can be credited to the New England Food Vision which has developed a goal (named 50 by 60) of producing 50% of the region's food requirements within the region by the year 2060. 50 by 60 promotes sustainable agriculture and fishing as well as healthy food for all of New England. In order to achieve this, the goals of 50 by 60 are bold. New England would need to triple the amount of land dedicated to farming and food production while assisting the growth and maintenance of health ecosystems. The New England food renaissance has led to more interest in agriculture education and growth in local food production (nefoodvision.org).

Short growing seasons are a major limitation and challenge to reaching the 50 by 60 goals. Winter makes it difficult for farmers to grow their crops and severely shortens season production in comparison to states in warmer climates. One response to this has been a growing interest in high tunnels throughout the world of agriculture, and UNH has been active in research on making effective use of high tunnel greenhouses.

High tunnels are generally low-cost greenhouses meant to extend the usual growing season. With additional heating, they can be maintained for year-round production, mainly of cool season crops not requiring high light levels. In the long winters in New England, meeting the energy requirement for heat can be expensive, making a 12-month season cost-prohibitive.

Recent research at UNH has demonstrated that aerated static pile (ASP) composting with heat capture (ASPHC), an innovative approach to processing agricultural wastes, can provide a significant source of heat (Smith). When located near greenhouse operations, this process could offset much of the cost of year-round production.

The goal of this research was to develop a model of the energy balance of a greenhouse and to combine that with estimates of the amount of compostable material produced on the UNH campus and results from research on heat generation and capture of an aerated static pile composting system to test the feasibility of using compost energy to heat greenhouses that can benefit the university and the community.

B. Background

1. High Tunnels and Other Greenhouses

The design of a high tunnel can range from having just a greenhouse frame, roll-up curtains, and a layer of polycarbonate to including heaters, an irrigation system, roof vents, and the ability to move to different locations. These greenhouses are cheaper to start and have a quick rate of return on the investment which makes them a popular choice for food production (rimol.com).

High tunnels are used to grow crops such as fruits and vegetables. In some other cases, high tunnels can be used to grow flowers but mainly tend to be used for food crops. High tunnels allow someone to begin their growing season earlier than usual or they can extend it afterward which is very useful to people in the northeastern U.S. where there is high seasonality. Not only can high tunnels extend the growing season, it is possible for them to be used year-round (rimol.com).

Currently, the University of New Hampshire uses high tunnels and other greenhouses for research as well as teaching. Research efforts have focused on cool season greens, fruits and berries, and even the extension of the growth of kiwis into New England. Production for use on campus includes brussel sprouts, tomatoes, eggplants, green peppers, okra, radishes, beets, and lettuce. Harvested crops are used in the UNH dining halls or at the on-campus restaurant the UNH Dairy Bar.

One innovative research project is housed in three permanent greenhouses at Kingman Farm and includes an aquaponic system with plant-treated wastewater. Tanks in which Tilapia are grown provide nutrient-rich water and waste that filters through the root systems of lettuce, acting as a fertilizer.

While high tunnels and other enclosed greenhouses can extend the growing season, the additional goal of maintaining year-round production in these structures requires a substantial amount of heat energy. By pairing aerated static composting with greenhouses, can farmers in the northeast extend their season of production and use less nonrenewable energy?

2. Composting Systems

Composting is an important source in sustainable agriculture and gardening. Disposing of food scraps in this manner leads to the creation of fertilizer that can be used in gardens, greenhouses, and on farms. Food scraps aren’t the only material that is sufficient for creating compost; animal waste, human waste, and compostable items such as wood shavings are also valid ingredients for a composting pile. From an environmentalist point of view, composting is an important practice that can be performed at home or on larger scales like a whole farm. Practicing composting takes away materials that would go into landfills and decompose at a much slower rate than if put directly into compost.

A variety of components can go into composting but the main needs for composting are an oxygen source, a carbon source, microorganisms, and a material that can decompose. Oxygen sources include turning the piles manually to get oxygen into them or by blowing oxygen into the static piles with vents underneath. Some examples of carbon sources are sawdust and wood shavings. Nitrogen comes from the animal waste. The microorganisms will grow rapidly in the compost once they sense materials such as food waste, animal or human waste, or compostable products such as paper plates and napkins. Carbon is the energy source and nitrogen is necessary to produce proteins and build cell walls. The microorganisms need oxygen because the process of aerobic decomposition is oxygen-demanding. During the process, the microorganisms in the pile excrete enzymes that break down the compostable materials into smaller molecules which they can then take up directly. Heat is generated by the microorganisms' metabolism and can get as high as 150 degrees Fahrenheit when using the aerated static composting system described below. The final product of composting is a nutrient-rich soil amendment which increases nutrient availability and water retention for plants.

Compost is used as a fertilizer for gardens, greenhouses, and farms, mainly for growing food crops. This green fertilizer adds nutrients the soil needs to grow healthy crops with an abundance of important nutrients in them. At UNH, the different farms practice a couple styles of composting whether it is the traditional turning method or the aerated static pile. In research at the university, composting plays an important role in studying sustainability.

Conventional methods for composting include the use of turn-able windrow piles in which materials are held for up to 1-2 years and turned frequently to assure mixing and complete aeration. This method is slow and labor intensive and is most frequently used by backyard gardeners and other small-scale operations. While materials managed in this way may reach elevated temperatures, there is no way to capture this heat.

An intermediate and older technology for capturing heat is the Jean-Pain method of composting. A French innovator who lived from 1930 to 1981, Jean-Pain created a composting style that was able to supply all of his energy needs. His design is relatively simple. A compost pile is created and on the inside is a large coiling of tubing. Water flows through the tubing and becomes extremely hot as the compost pile heats the water up. The piles were massive but gave him the energy he needed. Jean-Pain was also able to extract methane from the piles which he could use for heating or for cooking (Sjöberg, 2013). His style is another possible solution for generating heat but is more geared towards creating hot water.

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ASPHC composting is the preferred method for commercial composting operations, and for heat capture. The main difference between a traditional turned pile composting system and the ASPHC method is that the aerated static composting pile does not get turned. The pile remains in the same place, but rather than getting oxygen through turning the pile, it receives oxygen through a system of vents below the pile connected by pipes to a fan (Figure 1, see also a video prepared by UNH Communications at:
https://www.youtube.com/watch?v=YNTX5vqN2Fs&feature=youtu.be).

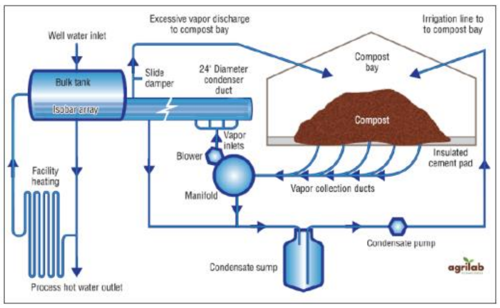

Figure 1. Diagram of the ASPHC system at the UNH Organic Dairy Research Farm. The heat is generated by the compost and travels as water vapor through the vapor collection ducts and into the condenser ducts. Here, the water vapor condenses, transfers heat to the exchanger, and into the hot water tank. It then runs through the facility heating system.

On a pre-scheduled basis, air is drawn down through the pile by the fan, through the vents and pipes, so that it is aerated for the oxygen source that it needs. ASPHC piles achieve a much higher temperature which completes the composting process more quickly. Temperatures are high enough to become useful in heating structures like buildings.

Composting can also be a valuable source of heat generation. By being able to capture the heat from a compost pile, renewable energy can be directed towards something such as heating a greenhouse. The heat generated helps to close the system, isolating the materials involved so that there is no need for external materials, by connecting an energy source that is not a fossil fuel. My research considers how heat generated by composting piles can be captured for use in heating greenhouses.

Reducing the amount of energy that it takes to heat the greenhouses at UNH would be a positive action because it would mean a decrease in using non-renewable energy and a movement towards a more sustainable source of heat. This also means a reduction in total cost, since it removes having to buy heat from an outside company and using your own compost pile for heat. A reduction that helps the environment and your wallet is a win-win situation.

C. Approach, Data Sources, and Results

The research presented here consists of five parts: 1) Estimating the quantity of compostable material produced on the main UNH campus and an assessment of current management practices, 2) Using results from recent UNH research on heat energy generation and capture to determine the amount of heat energy that could be produced, on an annual basis, by an ASPHC composting system using the amount of material generated at UNH, 3) Accessing data from the UNH Energy Office to estimate the amount of heat energy required by high tunnel and research greenhouses on campus, 4) Comparing annual totals for greenhouse heat requirement and potential heat generation to estimate how much of this requirement could be met, on an annual basis, with the ASPHC system described in step 2, and 5) Developing a generalizable energy balance model for greenhouses and using that model to assess the viability of heating UNH greenhouses with heat captured from an ASPHC composting system at hourly to daily timesteps, and running that model for a prototype greenhouse at UNH.

1**. Data on Sources of Compostable Material and Current Management Practices**

Data on compostable materials are available from the UNH equine facility, the Organic Dairy Research Farm, and UNH Dining operations, as well as a potential source of organic materials from the Town of Durham (Table 1).

Table 1. Compostable material available (Tons)

Source	per month	# of months	Total	
Food waste	30	9	270	
Equine 2	60	12	720	
On campus total				990
ODRF	68	12	816	
UNH Total				1806
Durham	30	12	360	
Community Total				2166

The equine facility at UNH cares for a substantial number of horses, housed in stalls with bedding materials such as hay and wood shavings, and generates a substantial amount of manure/bedding material. According to Brenda Hess-McAskill from the equine facility, the average amount of manure and shavings mixture produced is 60 tons per month. For one semester, this means that around 240 tons of the manure and shavings mixture is created, with an annual total of 720 tons.

UNH dining operates three dining halls that produce copious amounts of food waste per day. At Holloway Commons, Philbrook Dining Hall, and Stillings Dining Hall, food waste is collected in the dining halls in the course of one week for a total of eight hours at each hall in a study led by dietetics interns. During the week of February 25th in 2016, the interns collected 1,226 pounds of food waste across the dining hall facilities on one select day. Holloway Commons alone produced 540 pounds, with Philbrook coming in second at 350 pounds and Stillings at 336 pounds. An annual estimate for food wastes created at the three facilities is 270 tons per year, with maximum amounts produced during spring and fall semesters, and lesser amounts during January term and summer.

Dining hall food wastes and manure/bedding from the equine facility are currently composted using a conventional turned-pile process located at Kingman Farm. It takes a considerable amount of effort to turn the composting piles. Kingman Farm workers use a machine called a Turner that is about 10 feet wide and 5 feet tall. The Turner is pulled by a 108-horsepower tractor of a good stature and moves at 0.2 miles/hour. Each windrow of compost is about 200 to 300 feet long and is turned every 2 to 3 weeks. One to two years are required for material in this type of windrow composting to be ready for use, sitting and curing. Finished compost is spread on UNH fields which is a further means to closing the system.

The ASPHC system is located at the Organic Dairy Research Farm (ODRF), part of the Burley-Demeritt Farm in Lee, NH. The ODRF houses an average of 40-50 milking cows at any one time, and a total of about 100 animals, including calves, heifers and dry cows. The bedded pack barn at this facility generates about 68 tons of waste per month, or a total of 816 tons per calendar year.

The aerated static composting piles consist of animal manure from the cows and wood shavings used in the barn. These piles can be ready for curing in as little as three weeks, but the material can also be held for longer periods to maximize heat generation. Finished compost is spread over the fields at the ODRF. The main difference between a traditional turned pile composting system and the aerated static composting pile is that the aerated static composting pile does not get turned. The pile remains in the same place and remains aerated by having air drawn down through the piles by the pipe/fan system

One possible additional source of material for composting on campus could be the town of Durham, which is considering the separation of compostable organic materials from the general refuse collection system. According to town sources, as much as 25% of the town's current waste stream could be compostable, for an estimate of 360 tons in one calendar year.

2. Data on Energy Generation of the UNH ASPHC and Other Composting Systems

ASPHC systems are a relatively new technology and there are very few studies that report heat generation capacity for commercial scale systems (Smith et al review). Research at the ASPHC system at UNH, using a realistic mix and variation in quality and initial moisture content of materials, produced a range of results for rate of heat generation over time. As a result, there is only a limited amount of information available on the rate at which heat energy can be captured from these systems, and much of what is available is reported in different units. Table 2 compiles a range of values from different sources.

In a thorough review of available literature, Smith et al. (2016) report an average rate of heat capture of 4.8 million BTUs per day from commercial-scale operations, and an average of 7,000 BTU per ton of material per hour. For the ASPHC system at UNH, Smith and Aber report an average of about 700 BTU per ton per hour under on-farm operating conditions. The Agrilab estimates are also for optimal conditions over short periods of time. We conclude that the best estimates for our purposes are the most conservative. The Cornell and Smith and Aber references are for farm-scale operations over long time periods and are reported in terms of total energy capture per ton of material.

Table 2 – Rates of heat production reported in the literature (BTU)

Total per ton	Per hour per ton	Reference
	1,000	Cornell
1,400,000		Diamond Hill
	5,000	Agrilab
	7,000	Smith et al.
1,000,000	700	Smith and Aber

3. Estimating Energy Requirements for Greenhouse Heating on an Annual Basis

Data are available from the UNH Energy Office on the quantity of heat required for year-round operation of three different high tunnel/greenhouse systems, one at Kingman and two at Fairchild (Table 3). Data are recorded as "therms" of propane, with a therm being equivalent to 100,000 BTUs. Kingman #5 is actually a set of 3 greenhouses. The average annual total for energy demand is about 3125 therms (312.5 million BTU) per greenhouse per year.

Table 3. Annual Energy Requirement for high tunnel greenhouses
(Propane Therms : 1 Therm = ~100,000 BTUs)

Fiscal Year	Fairchild #1	Kingman #5	Fairchild #3
2015	4,378.30		
2016	2,754.70		
2017	3,112.90		
2018	3,442.00	9,657.00	
2019	3,654.30	6,412.40	4,084.40

4. Comparison of Potential Energy Production and Greenhouse Energy Demands

Data from tables 2 and 3 were used to determine the potential for heating UNH greenhouses with available compostable materials and an ASPHC composting system (Table 4). Using all of the possible sources, UNH Dining, UNH equine facilities, the ODRF, and the town of Durham which totals 2,166 tons per year, the compost could generate a total of 3,032 million BTUs (MBTU) per year. If you divide this number by the required 312.5 MBTU needed in one year, you get the number 9.6. This means we could heat 9 high tunnel greenhouses and a little more for a full year. If we only used the UNH Dining food waste and the waste from the equine facilities which is a total of 990 tons per year, we could heat 4 greenhouses because the compost could generate 1,386 MBTUs in one year. All numbers would be reduced by about 30% if the lower rate of heat production from Table 2 (1.0 MBTU/ton) were used.

Table 4. Potential energy generation in relationship to annual heat energy demand for high tunnel greenhouses on the UNH campus. All values are in millions of BTUs (MBTUs).

Source	Material Tons	Energy Potential MBTU per ton	Total MBTU per year	Greenhouse Heat Demand MBTU/year	Number of Greenhouses Heated
On-Campus	990	1.4	1,386	312.5	4.4
All UNH	1806	1.4	2,528	312.5	8.1
Plus Durham	2166	1.4	3,032	312.5	9.6

5. A Generalized Greenhouse Energy Balance Model Including Compost Energy

Data at the annual time step as presented above provide a rough assessment of the potential for compost energy to heat greenhouses at UNH. However, for this combination of technologies to be successful, the timing of energy supply and energy demand must coincide. To allow this more detailed analysis, a model of energy demand based on high-resolution weather data was developed and linked to measured rates of energy generation by the UNH ASPHC system.

The model was constructed in Microsoft ® Excel to increase accessibility to practitioners and general audiences. The model includes 1) an hourly time step calculation of solar energy gain and heat losses through the greenhouse surfaces and by air turnover, 2) a summation of hourly data to daily totals, and 3) the addition of heat energy from a separate model of potential heat gain based on estimates from the UNH ASPHC composting system.

1. Greenhouse Energy Balance

a. Hourly Balances

	Variable	Label	Description
Greenhouse Constants	Length		Length of the greenhouse. Involved in the surface area, floor area, and volume calculations.
	Width		Width of the greenhouse. Involved in the surface area, floor area, and volume calculations.
	Sidewall height		Height of the greenhouse sidewalls. Involved in the surface area, floor area, and volume calculations.
	Peak height		Peak height of the greenhouse.
	Surface area of the cover	Ac	Describes the surface area of the greenhouse cover in feet squared.
	Floor area	Af	Describes the floor area of the greenhouse in feet squared.
	Internal volume	V	Describes the internal volume of the greenhouse in feet cubed.
Cover Constants	Type		Type refers to the type of cover used for the greenhouse, our scenario uses polycarbonate.
	Rate of heat transfer	U	Rate of heat transfer is the rate at which heat moves through the cover. This is used in the cover loss equation.
	Light transmissivity	I	Light transmissivity explains the ability of light to pass through the cover. It is used in the energy in equation.
	Air exchange parameter	C	The air exchange parameter is the constant for how air is exchanged through the cover. This is used in the exchange loss equation.

	Sun angle effect	B	The sun angle effect is how the angle of the sun impacts the heating of the cover. It is assumed to be the same as the measured radiation and is used in the energy in equation.
Operational Goal	Internal temperature	Ti	The internal temperature is the temperature in degrees Fahrenheit inside the greenhouse. It is used to calculate temperature difference (Tdiff).
Meteorological Data	Outside temperature	To	The outside temperature is the temperature in degrees Fahrenheit outside of the greenhouse. It is used to calculate temperature difference (Tdiff).
	Temperature difference	Tdiff	The temperature difference is the internal temperature minus the outside temperature in degrees Fahrenheit. It is used in the cover loss and exchange loss equations.
	Solar radiation	SW	Solar radiation is a given weather data variable detailing how much solar radiation is present per hour.
	Wind speed		The wind speed is a given weather data variable and describes how fast the wind is moving in feet per second.

Equation Name	Equation
Internal volume	length * width * sidewall height = V
Surface area	length * width = Ac
Temperature difference	Ti - To = Tdiff
Energy in	B * I * Af = energy in
Cover loss	U * Ac * Tdiff = cover loss
Exchange loss	0.018 * V * C * Tdiff = exchange loss
Hourly balance	Energy in - cover loss - exchange loss = hourly balance
Energy from compost	trial 1 + trial 2 = energy from compost
System balance	daily balance + energy from compost = system balance

Model of Greenhouse Energy Demand and Potential Heat from the ODRF Composting Facility

Greenhouse Constants

Dimensions (feet)				Cover			
Length	40	Sidewall Ht	6	Type		Polycarbonate	
Width	40	Peak Ht	6	Rate of Heat Transfer	U	0.634	BTU/ft2.hr
				Light Transmisivity	I	0.82	no units
Surface Area of the Cover (Ac)	2990	ft2		Air Exchange parameter	C	0.50	per hour*ft3*F
Floor Area (Af)	1600	ft2		Sun Angle Effect	B	1.00	
Internal Volume (V)	14400	ft3					

Operational Goal

Internal Temperature (Ti)	60	F

Meteorological Data							Energy In	Cover Loss	Exchange Loss	Hourly Balance
Date Time	Day	Run Hour	(To) Temperature (F)	Ti-To Tdiff (F)	(ε*I) SW Radiation BTU/ft2.h	Wind Speed ft/sec	(ε*I*Af) BTU/hr	U*Ac*Tdiff BTU/hr	0.018*V*C*Tdiff BTU/hr	Energy in - Cover Loss - Exchange Loss BTU/hr
1/1/2014 1:00	1	1	10.3	49.7	0.0	0.18	0	94,209	6,440	-100,649
1/1/2014 2:00	1	2	9.9	50.1	0.0	0.23	0	94,926	6,489	-101,415
1/1/2014 3:00	1	3	14.1	45.9	0.0	0.28	0	87,009	5,948	-92,956
1/1/2014 4:00	1	4	13.8	46.2	0.0	0.35	0	87,623	5,990	-93,613
1/1/2014 5:00	1	5	13.6	46.4	0.0	0.51	0	87,964	6,013	-93,977
1/1/2014 6:00	1	6	14.1	45.9	0.0	0.37	0	87,009	5,948	-92,956

Figure 2. Sample inputs and outputs from a simple greenhouse energy balance model. See text for explanations.

b. Daily Balances

Hourly balances for each day were summed over the 24-hour period to calculate total energy gain and loss. These values were paired with estimated energy capture from two sets of measured data drawn from 2 different trials at the UNH ASPHC facility (see c. below), and a total daily estimated energy net gain or loss calculated for each day.

Daily Balance (BTU/day)							Energy From Compost Potential (BTU/day)			System Balance BTU/Day
Day	Avg Tdiff	Solar Gain	Cover Loss	Exch Loss	Total Loss	Total Balance	Trial 1	Trial 2	Total	
1	44	853,500	-1,995,042	-136,374	-2,131,416	-1,277,916	699,212	1,874,581	2,573,792	1,295,876
2	56	184,930	-2,537,525	-173,456	-2,710,981	-2,526,051	647,028	1,338,628	1,985,657	-540,394
3	58	618,130	-2,620,488	-179,127	-2,799,615	-2,181,485	591,535	1,343,032	1,934,568	-246,917
4	54	873,351	-2,439,137	-166,731	-2,605,867	-1,732,517	626,942	1,383,288	2,010,230	277,713
5	40	943,562	-1,805,432	-123,413	-1,928,845	-985,283	652,135	1,350,546	2,002,681	1,017,397
6	21	126,935	-938,641	-64,162	-1,002,803	-875,868	667,116	1,395,430	2,062,545	1,186,678

Figure 3. Daily total energy balances estimated for the first 6 days in January 2014 including estimated energy availability from an ASPHC facility of the size at UNH (see text for explanation).

c. Estimated Heat Capture from an ASPHC Composting System

Smith and Aber (2016) report rates of energy capture for the ASPHC system at the UNH ODRF (Table 2). Those rates are for a system with a heat exchanger and warm water storage tank. This exchanger does not capture all of the heat energy generated by the compost piles, as exhaust gases from this exchanger can still be 90F or higher. While other exchange/storage systems can be devised, their characteristics are uncertain. For the calculations here, a simplifying assumption has been made.

Vapor from the composter is assumed to be piped directly to the greenhouse through standard baseboard heat types of piping, and that enough length of pipe is installed in the greenhouse to reduce the temperature of the vapor to that of the target temperature in the structure. The vast majority of heat transfer from vapor to structure or storage is through the energy released in the condensation of water (Smith et al., 2016). The calculations that follow assume that all of that condensation occurs within the heating pipes within the greenhouse.

This assumption allows a simple calculation of heat transfer to the greenhouse (Figure 4). Vapor leaves the composter at the measured temperature and 100% relative humidity (saturation). As the temperature drops to the target temperature in the greenhouse, the vapor remains at saturation. Using a standard relationship between air temperature and the amount of water vapor that can be held (engineeringtoolbox.com), the total amount of condensation in the pipes can be calculated as the difference between saturated moisture content at the vapor and greenhouse temperatures. Then the amount of energy released can be calculated using a standard value for the energy released through condensation.

Estimating the total heat generation from condensation of water vapor in Compost Exhuast Stream

Assumptions

1. **Vapor is at 100% relative humidity**
2. **Potential heat capture is from energy released by condensation**
3. **Vapor will reach greenhouse air temperature and exchange released heat into greenhouse air before venting**

Saturated water vapor content as a function of temperature is:

$y = a*T^3 + b*T^2 + c*T + d$

Where y = total water vapor in lbs/ft^3

And T is Temperature (F)

a= 0.0000055
b= -0.0006
c= 0.0364
d= -0.4771

Target Greenhouse Temperature = 60 F **Heat of Condensation** 1060 BTU/lb

Saturation Absolute Humidity 0.00601 lbs/ft3

Trial 1 Bay 1 and 2						Volume	input		outlet		Condensation	
Running day	Pitot	Trial day	Volume ft3/min	Average F	open hrs/day	total volume ft3	Vapor Absolute Humidity lb/ft3)*100	Total Water vapor lb/day	Vapor Absolute Humidity lb/ft3)*100	Total Water vapor lb/day	Total Water lb/day	Heat Released BTU/day
150.0	0.9	1	88.3	148.5	4.0	21196.9	0.03713	787.0	0.00601	127.4	659.6	699,212
151.0	0.9	2	80.9	149.1	4.0	19413.4	0.03745	727.1	0.00601	116.7	610.4	647,028
152.0	0.8	3	74.9	148.4	4.0	17965.8	0.03707	666.0	0.00601	108.0	558.1	591,535
153.0	0.8	4	80.4	147.7	4.0	19300.1	0.03665	707.4	0.00601	116.0	591.5	626,942
154.0	0.8	5	82.8	148.2	4.0	19880.3	0.03696	734.7	0.00601	119.5	615.2	652,135
155.0	0.8	6	84.8	148.2	4.0	20351.6	0.03693	751.6	0.00601	122.3	629.4	667,116

Figure 4. Daily estimates of heat release by condensation of vapor drawn from compost piles by the ASPHC composting system at UNH (see text for explanation).

Data from two different compost trials at the UNH ASPHC system were used to generate estimates of heat energy that could be captured using these assumptions (Figure 5). The two were chosen as they varied widely in terms of initial temperature, change in temperature over time, change in amount of air drawn through the piles and amount of energy released. It is important to note that these data are for just one of 4 sets of bays in the facility. At full operation, potential heat capture could be up to 4 times those presented here.

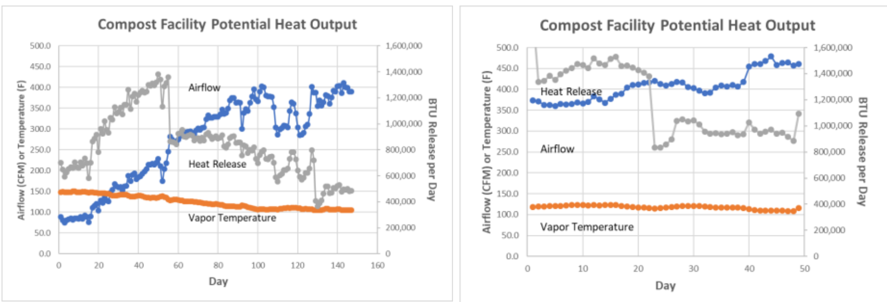

Figure 5. Data from two different composting trials at the UNH ASPHC facility. Blue line – air flow (CFM), Orange line - pile and vapor temperature (F), Grey line – heat released using assumptions described in the text (BTU/day).

d. Total Daily Energy Balances

Data on daily energy capture (Figure 5) are combined with daily energy balances for the greenhouse (Figure 3) to determine whether or not the target temperature for the greenhouse could be maintained (Figure 6). Figure 6a shows the energy balance for the greenhouse described in Figure 2 for the month of January 2014, a particularly cold month. The balance is negative on all days (green line), as solar gain is insufficient to offset losses through the cover and by air exchange.

Figure 6b shows how the balance is altered by the assumed connection described above. The green line is the greenhouse balance from Figure 6a. The orange line in this case shows energy capture for both bays described in Figure 5. As mentioned before, this includes only 2 of 4 sets of bays, such that potential energy capture from this type and size of ASPHC system could be higher still. With these assumptions and these data, the energy balance for this greenhouse is positive for all but one day. On that day, the greenhouse temperature would drop below the target temperature of 60F. Lowering that target temperature to 50F would create a positive balance for all days.

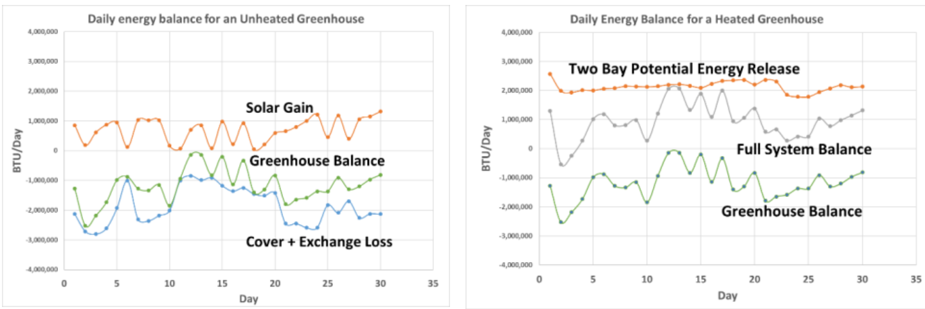

Figure 6. a) Daily heat energy balance for an unheated greenhouse as described in Figure 2 for the month of January 2014 b) the same balance with estimated heat gain potential from two sets of bays using data from two trials of the UNH ASPHC system (from Figure 5).

E. Conclusions

Composting is a reliable means of sustainably getting rid of food waste, animal waste, and other compostable materials like paper napkins. The compost can then be repurposed into fertilizer for growing more crops which can be composted again and again. With the New England food renaissance underway, it is more important now than ever for people to practice composting as a means of supplying their own fertilizer. I believe that if UNH took on the project of using aerated static composting piles to heat their greenhouses, this could further promote the excellence of our sustainability as a campus. UNH could take a large lead in sustainable agriculture and be the first to create a system such as this one.

Doing a project of this magnitude taught me a lot about dedication, problem-solving, and how much potential we have to practice composting as a society. I learned how to better manage my time and gain information from outside sources such as literature and people around the UNH community. Culminating this information taught me that sustainability is an imperative forward step for the future of people and making choices that better our environment is something we all need to work towards. I believe that we can all contribute in our own little ways. For me, that means helping to show others that it's possible to heat greenhouses using the heat from aerated static composting piles or that it's possible for everyday people to pursue other methods of sustainable energy and practices.

I would like to thank Dr. Aber for being a wonderful thesis and capstone advisor. He was a great mentor throughout the past year and a half, and I owe so much of the success of this project to him. I've learned many valuable life lessons from him and I couldn't be more grateful to have had someone as wise and positive as he is. Thank you, Dr. Aber, for guiding me through the most impressive project that I have ever taken part in and for a wonderful two and a half years of knowing you.

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