Interactive Model for UBC Farm Compost Facility

Chen Zhao, Fahad Shabbir, Morgan Hibbert, Pranay Gupta

University of British Columbia

CHBE 573

April 09, 2015

Interactive Model for UBC Farm Compost Facility

CHBE 573 Environmental Engineering and Sustainability

Instructor: Dr. Naoko Ellis

Pranay Gupta

Morgan Hibbert

Fahad Shabbir

Chen Zhao

April 7th, 2015

Interactive Model for UBC Farm Compost Facility

Pranay Gupta
Morgan Hibbert
Fahad Shabbir
Chen Zhao

CHBE 573
April 07, 2015

Executive Summary

To address the future need of composting at UBC the UBC Farm and the SEEDS Sustainability Program have requested research on the feasibility for a compost facility at the UBC Farm. Previously work by other groups has been completed addressing the feasibility of this project from a variety of different perspectives.

The goal of this part of the project is two-fold: 1) to combine the existing knowledge from the previous reports into an interactive Excel model. The aim of this Excel model is to aid the decision process when determining how best to implement a compost facility at the UBC Farm. 2) To identify any holes / missing information in the current research and where possible, provide added knowledge.

The model is implemented in Excel and features six sheets:

1) Master
2) Compost Output
3) Decomposition Efficiency
4) Animal Bedding
5) Compost Facility
6) Compost Source

The areas of "Animal Bedding" and "Decomposition Efficiency" present new research in this report that adds to the greater project. Both of these sections present ways to increase funding, which is seen as a major stumbling block for the project. "Compost Source" is a combination of previously acquired knowledge with some new research added. The remaining sections feature previously acquired knowledge.

This interactive model is to serve as a base framework for a bigger more complete model that analyzes and relates all the different variables affecting the successful implementation of a compost facility at the UBC Farm. The purpose of the model is to provide the decision makers with a tool that should aid in helping select the correct plan of action for building a compost facility at the UBC Farm. In order for this to be an effective tool, it must first be a complete tool. The hope is that this base framework can identify gaps in knowledge that need to be further explored and answered before moving forward with implementing a compost facility.

In conclusion, there are many questions still left to be answered before a complete model and an informed decision can be made. The primary unanswered question is "where is the required source of funding coming from?" as financially this project does not appear viable.

Table of Contents

Introduction

Composting organic food waste has been identified as a priority in the Zero Waste Action Plan because of Metro regional's ban on composts going to the landfill making the need to increase our organic waste diversion a priority. In addition to the increase in organic waste produced at UBC, the current compost facility at UBC is also reaching its end of life. As a result the UBC Farm and the SEEDS Sustainability Program have requested research on the feasibility for a compost facility at the UBC Farm.

Previously work has been completed addressing the feasibility of this project. This includes a feasibility study on the methods of operating a compost facility completed by Eric Toren in 2014 (Toren, 2014) and a financial feasibility study completed by Claire Vivier, Kate Hyde, Teja Edara and Devin Durrant (Vivier et al. 2014).

The goal of this part of the project is two-fold: 1) to combine the existing knowledge from the previous reports into an interactive Excel model. The aim of this Excel model is to aid the decision process when determining how best to implement a compost facility at the UBC Farm. 2) To identify any holes / missing information in the current research and where possible, provide added knowledge.

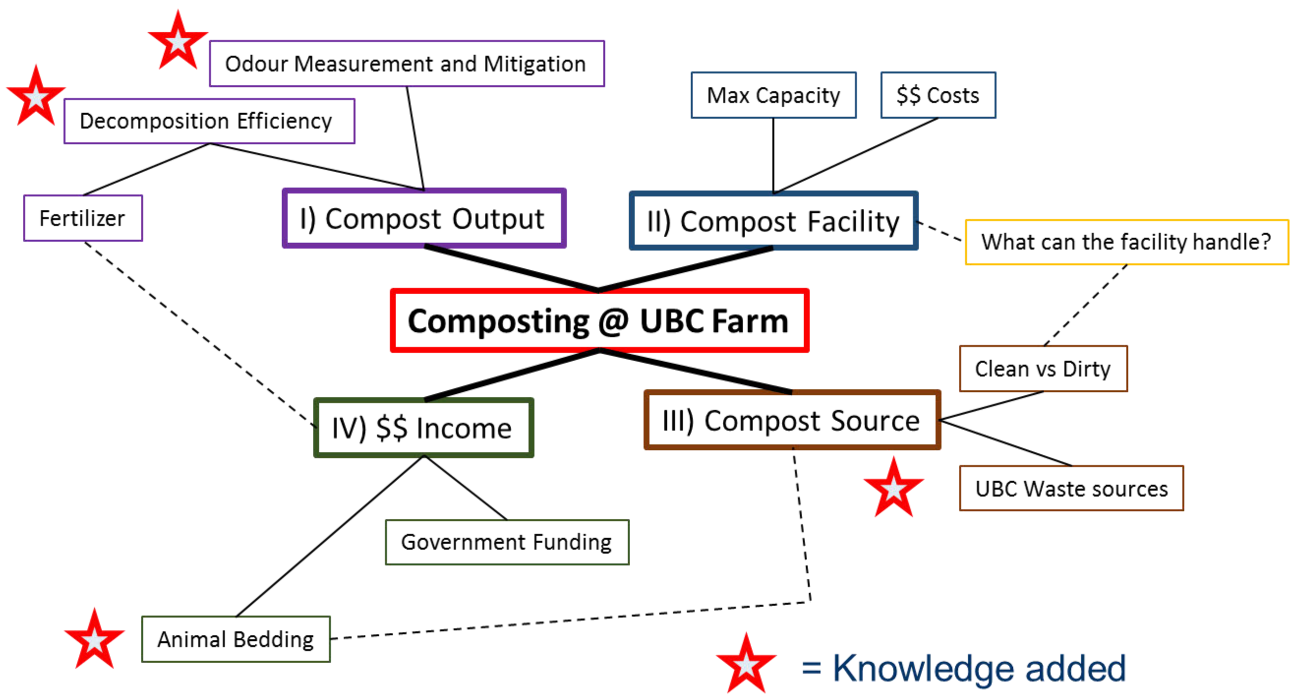
The result is a partially built interactive model using the combined knowledge of the previous research with newly added knowledge. The interactions and relationships between the various variables have been mapped out and connected. This model is intended to serve as a base level framework for future work and research into the feasibility of a compost facility at the UBC Farm.

This report serves as an instruction manual describing how to use the currently implemented parts of the model. These parts are:

- Animal Bedding
- Decomposition Efficiency
- Compost Source

Model Outline

The Excel model is developed based on the connected framework shown below. The connections developed in the framework are a combination of the previously completed research along with new knowledge. This is the framework from which the interactive model is constructed. Items with a red star are ones that have been implemented with high detail in the current working model. The rest of the report provides instructions on how to use the model and presents some supporting knowledge for why the model was constructed the way it was.



The model is implemented in Excel and features six sheets:

1) Master
2) Compost Output
3) Decomposition Efficiency
4) Animal Bedding
5) Compost Facility
6) Compost Source

Master – This sheet represents the central item “Composting @ UBC Farm” from the figure above and displays the final annual financial balance resulting from implementing a compost facility at the UBC Farm.

Compost Output – This is a blank sheet, left as a place holder for a later implementation.

Decomposition Efficiency – Mass loss in the compost facility is a potential source of lost income. This sheet provides a model for adjusting input parameters in the compost to reduce mass loss.

Animal Bedding – The greatest potential source of income is from the use of animal bedding. This model handles the variables related to animal bedding usage.

Compost Facility – Financial ramifications of the chosen compost facility.

Compost Source – The state of the current organic and yard waste availability at UBC for compost.

Animal Bedding

Animal Bedding is material (usually organic) used by animals to support their bodies when resting or otherwise stationary. The current status and features of animal bedding at UBC is summarized in the following points:

1. Animal bedding is mostly in the form of wood shavings (Toren, 2014).

2. UBC produces animal bedding totalling ~110 tonnes / year (Toren, 2014).

3. Animal bedding is suitable for creating Class A compost under schedule 12 of the Organic Material Recycling Regulations (OMRR) (Toren, 2014).

As per the report used as input information for this interactive model 11 tonnes of Animal bedding is used in a 50 tonnes pile for composting (Toren, 2014). Over the course of one year, it is expected that 10 compost piles will be processed at the facility. Hence, this would make use of approximately all of the ~110 tonnes of animal bedding currently being produced. The compost pile composition is considered as:

A. Food Waste (30 tonnes)

B. Yard Waste (9 tonnes)

C. Animal Bedding (11 tonnes)

Above data is taken as basis for the excel model considering animal bedding. In the excel values (highlighted in blue) which can be modified are:-

1. Whether animal bedding will be used or not (Enter Y / N)

2. Percentage of animal bedding sent to farm (Enter percentage) - This provides flexibility to the user to enter the amount of animal bedding sent to farm, in case it is decided in the future that only a part of totalling bedding will be used as compost material.

3. Disposal Fee per T - Here, the amount to be charged by UBC farm for disposal of animal bedding needs to be entered. The value is in $ per tonne of animal bedding.

The sheet will calculate the total revenue that can be earned by UBC farm for animal bedding disposal. The sheet will also give an approximate idea about pile composition. The relevant notes based on assumptions made and other basis considered are mentioned in the sheet.

Decomposition Efficiency

The UBC Farm should have a profitable model which can generate much revenues and allow it to be financially self-sustainable for better fertilizer supply at UBC. In the previous financial model study, calculations of different income streams were conducted, and the capital and operating costs were properly estimated. This model also gives the approximation of the best and worst scenario annual revenue for UBC Farm facility, and the data indicates that the total annual revenue can barely cover the operating costs. The net present value remains negative because of the large capital expense, so this prevents UBC Farm from being a successful business model and has to be changed by investigating many influence factors in the composting process.

The annual revenue can be improved by increasing decomposition efficiency which are affected by two major factors - mass loss rate and pile density. The compost facility operators are in charge of creating a favourable environment for aerobic microorganisms in order to maintain the highest decomposition efficiency. In order to understand the influence of mass loss rate and pile density, five important factors affecting decomposition efficiency were analyzed based on the Erik's report. The five factors are pile size, moisture level, carbon to nitrogen (C:N) ratio, PH value and temperature, and the effects of these five factors are summarized in Table 1 (Toren, 2014):

Among these five factors, moisture level (ML) and carbon to nitrogen ratio (CN) affect the mass loss rate (MLR) the most. In order to model the effect of these two factors toward mass loss rate, a linear model is proposed to give a proper approximation of mass loss rate. This is because of the fact that the higher the moisture level or the C:N ratio, the more mass loss rate can be observed. According to Erik's report, the range of mass loss rate is from the bottom boundary (MLR_b) of 30% to the top boundary (MLR_t) of 50%. As a result, the linear models can be written as the following (Ryckeboer , et al., 2003):

For Moisture Level: $$MLR_{ML} = MLR_b + (ML - ML_b) * \frac{MLR_t - MLR_b}{ML_t - ML_b} \quad (1)$$

where ML is the current moisture level between top moisture level (ML_t) of 65% and bottom moisture level (ML_b) of 30%

For Carbon to Nitrogen Ratio: $$MLR_{CN} = MLR_b + (CN - CN_b) * \frac{MLR_t - MLR_b}{CN_t - CN_b} \quad (2)$$

Table 1 Operational Range of Five Influence Factors Affecting Decomposition Efficiency (Toren, 2014)

Influence Factors	**Value Boundaries**	**Effect**	**Ideal Conditions**
Pile Size (m^3)	Pile too large (>125m^3)	• Fresh air pore crush • Dense, anaerobic section • Odor problem	Around 76m^3
	Pile too small (<27m^3)	• N/A	
Moisture Level	Moisture too high (>65%)	• Water fills majority of pore of gas exchange • Oxygen transport slows dramatically • Anaerobic conditions within pile • Low temperatures within the pile	50%-60% by weight
	Moisture too low (<30%)	• Microbe become dormant • Composting process stops	
Carbon to Nitrogen (C:N) Ratio	C:N ratio too high (>35)	• Nitrogen becomes a limiting elements • Incomplete compost process	25-35
	C:N ratio too low (<25)	• Microbe transform excess nitrogen into ammonia • Ammonium lost from system by leaching or ammonia • Odor problem	
PH Value	PH too high (>8)	• More ammonia gas is generated and lost to atmosphere	7-8
	PH too low (<5.5)	• Inactive aerobic bacteria • Release methane and greenhouse gases • Odor problem	
Temperature	Temperature too high (>70°)	• Denature beneficial microbes	10°C-70°C
	Temperature too low (<10°)	• Microbe inactive • Composting process stops	

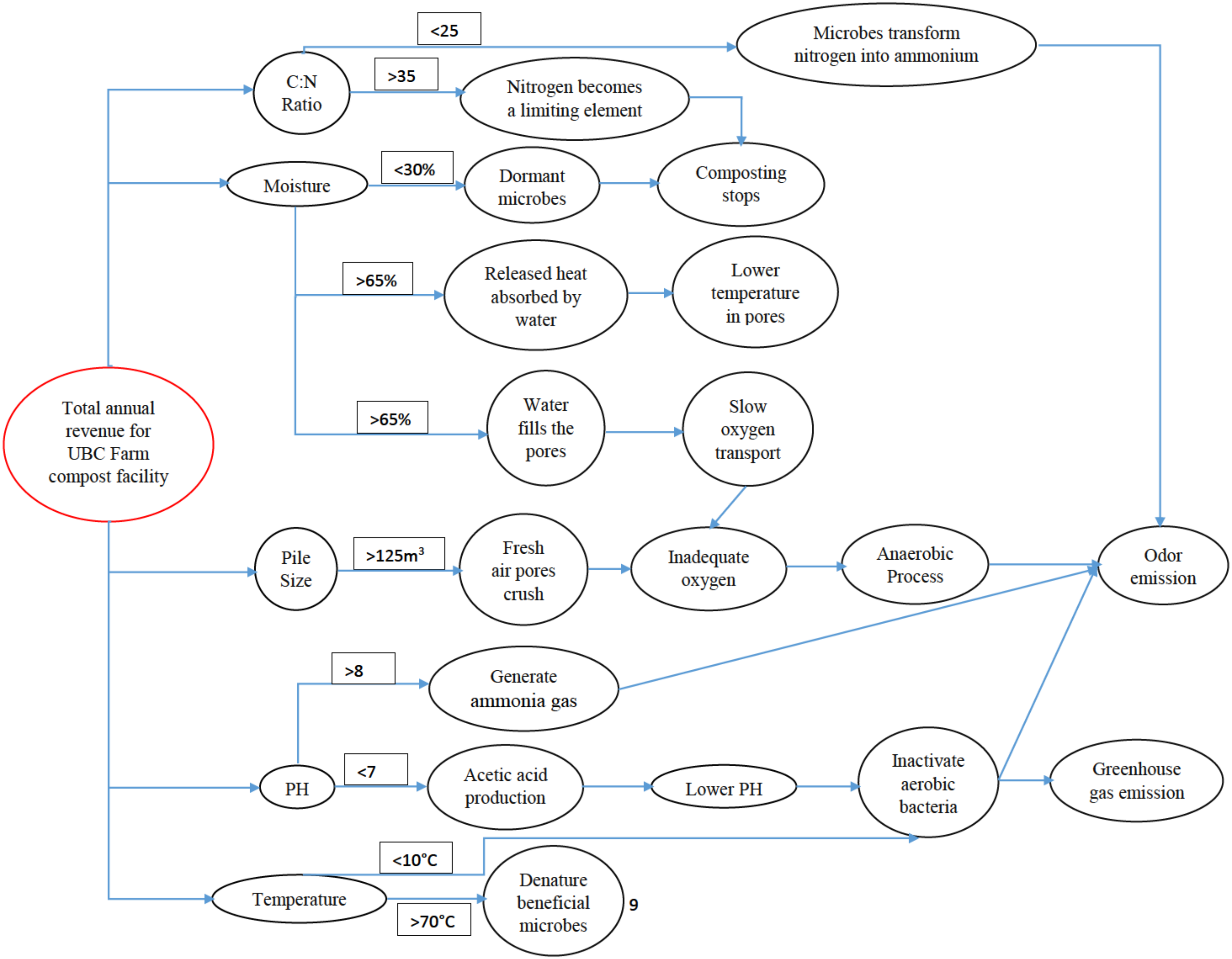
where CN is the current moisture level between top C:N ratio (CN_t) of 35 and bottom C:N ratio (CN_b) of 25 (Jones, Koenig, Ellsworth, Brown, & Jackson, 2007).

Pile density (PD) is also an important factor affecting the annual revenue from compost sale, and it directly relates to pile size (PS). A linear relationship between pile density and pile size can also be assumed because the bigger the pile size, the lower the pile density for the same pile mass. According to the previous financial studies, the range of compost density is from the top density boundary (PD_t) of 0.726ton/yard^3 to the bottom density boundary (PD_b) of 0.454ton/yard^3. As a result, the estimation formula for pile density can be written as the following (Richard , Trautmann, Krasny, Fredenburg, & Stuart, 1996):

For Pile Density: $$PD = PD_t + (PS - PS_b) * \frac{PD_b - PD_t}{PS_t - PS_b} \quad (3)$$

The resulting pile density and the highest mass loss rate obtained from MLR_{ML} and MLR_{CN} can be used to substitute into the "Revenue" sheet of the financial Excel sheet for calculation of total annual revenue for UBC farm compost facility. In this way, the previous financial study can produce some more accurate results based on the various decomposition factors. However, the effect of PH value and temperature cannot be modelled by a simple linear relationship because they can vary dramatically based on different pile compositions and are not constant throughout the composting process. Therefore, the effect of PH values and temperature can be analyzed together with other more complicated influential factors and be monitored by odour measurement and control systems introduced in the next section.

Three linear mathematical models mentioned above are suggested based on literature review of compost process efficiency, but these models are very likely to be changed later because of various biomass composition and ambient conditions at UBC farm. More realistic mathematical models should be obtained in the laboratory so that more accurate annual revenue can be calculated. All input variables of pile size, moisture level and C:N ratio must be within the range of their top and bottom boundaries because anaerobic processes most likely occur if any factor is operated at a level exceeding the top and bottom boundaries. The consequences of anaerobic processes can be production of undesirable products, greenhouse emission, odor pollution and large amount of financial loss. The concept map below can illustrate the cause and effect of these five operation factors and the relationship among them.


Total annual revenue for UBC Farm compost facility
C:N Ratio
<25
Microbes transform nitrogen into ammonium
>35
Nitrogen becomes a limiting element
Moisture
<30%
Dormant microbes
Composting stops
>65%
Released heat absorbed by water
Lower temperature in pores
>65%
Water fills the pores
Slow oxygen transport
Pile Size
>125m³
Fresh air pores crush
Inadequate oxygen
Anaerobic Process
Odor emission
>8
Generate ammonia gas
PH
<7
Acetic acid production
Lower PH
Inactivate aerobic bacteria
Greenhouse gas emission
<10°C
Temperature
>70°C
Denature beneficial microbes

Odor Measurement and Control

The composting process is inherently odorous because volatile products are created by decomposition process. Studies show that the highest concentrations of volatile organic compounds (VOC) are detected during the first 2 to 7 days of the composting process. The Table 2 shows the compounds responsible for odor complaints during the composting process even if they are in a very low concentration.

Table 2 Classification of Odor Compounds with Source and Formation in the Composting Process (Technical Document on MSW Organics Processing, 2013)

Class compounds	Likely source	Formation/release pathway
Inorganic sulphur (hydrogen sulphide)	Leachate, septic wastes, biosolids	Anaerobic reduction of sulphate to sulphide, or anaerobic breakdown of amino acids
Organic sulphur (mercaptans)	Wastes subjected to anaerobic conditions	Anaerobic and aerobic breakdown of amino acids
Organic sulphides	Composting	Aerobic oxidation of mercaptans
Inorganic nitrogen (ammonia)	Processing of feedstocks with C:N ratio less than 15:1 (e.g., food waste and green grass)	Anaerobic decomposition of organic nitrogen; volatilization at high pH or temperature
Organic nitrogen (amines)	Composting	Anaerobic decomposition of acids
Fatty acids	Wastes subjected to anaerobic conditions	Anaerobic decomposition
Aromatics	Preliminary and primary waste processing, and composting	Breakdown of lignins
Methylethyl ketone	Composting, wood-based bulking agents	Breakdown of lignins
Terpenes	Composting, wood-based bulking agents	Present in wood products, such as woodchips and sawdust

Human responses to malodours by activating stress mechanisms which result in sleep disrupt and other harmful consequences that eventually cause adverse health outcomes. The industry, especially for composting processes, requires to have a predictable and clear set of emission criteria when planning their investment. Therefore, odor measurement and control are very important for UBC Farm, and two kinds of methods can be applied to mitigate odor problems. They are chemical analysis method and sensory method, and specific measurement techniques of each of them are summarized in Table 3. One of the differences between chemical analysis methods and sensory methods is that the prior one utilizes analysis instruments in chemical laboratory, while the rear one utilizes a mechanical device that has odorant receptors mimicking biological olfactory system.

Table 3 Odor Measurement and Control Techniques of Chemical Analysis Methods and Sensory Methods (Brattoli, et al., 2011)

Chemical Analysis Methods	**Sensory Methods**
GC with various detectors such as MS, FPD and FID	Dynamic olfactometry
Detector tubes	Static olfactory-triangular odor bag method
Devices for monitoring a specific constituent such as H_2S analyzer	Rating odor intensity and hedonic tone

The purpose of odor measurement and control is to effectively detect and regulate the five aforementioned operation factors timely so that any odor caused by anaerobic process can be identified early in order to avoid further financial loss for UBC Farm. Both chemical analysis methods and sensory methods have their advantages and disadvantages which are described below, so these methods can be utilized according to the specific circumstances.

1) For Chemical Analysis Methods (Brewer & Cadwallader)

   I. Advantages

      - Accurate and reproducible results
      - Applicable for checking odor emissions from some industries

   II. Disadvantages

      - Due to the large number of compounds involved in odor emission from composting facility, it is not practical to analyze all of the compounds in order to assess odor impacts
      - Difficulty in determining which compounds should be used in the regulation since the odor detection thresholds can vary substantially
      - Cannot determine the total odor strength because of possible synergy, inhibition or masking effects with the mixed chemical compounds

2) For Sensory Methods (Bokowa, 2012)

I. Advantages

- Able to determine the odor category, predict odor intensity regardless of its category and help identify odor sources
- Analysis of hazardous chemicals that could not be submitted to an odor panel
- Allows one to recognize an unknown air sample under the presence of odor coming from different sources
- Provide fast, real-time and continuous monitoring in the field near sources and receptors

II. Disadvantages

- Does not provide indications on the chemical composition or harmful features of the analysed air
- Cannot provide any evaluation of odor quality unless the odor has been previously acquired by analyser
- Unable to provide results in terms of odor concentrations unless a correlation model between output signals and odor concentrations have been previously constructed and tuned

In the UBC farm project, sensory method like electronic nose (e-noses), is highly recommended because it can provide more detailed information using more automated functions. Electrical nose can be positioned near the odor sources of the site, such as beside the compost pile, and the odor data from e-noses is sent to OdoWatch software which models the atmospheric dispersion and displays the site's odor plume. The purchase and installation prices of e-noses and OdoWatch are within in 8000$ in total, and this amount should be included in the capital cost. Even though the price is not cheap, but it is still preferable to have a good odor monitoring device like this in order to control and avoid future financial loss from anaerobic process.

Compost Source

In 2014 UBC produced 1000 tonnes/year and 100 tonnes/year of food and yard waste respectively. Only 20% of the food waste was non-contaminated, and 15% was contaminated to such an extent that it was thrown into garbage. No food waste has been sent to Harvest Power in the past, however almost all of the yard waste was sent to Harvest power.

According to Bud Fraser, the in-vessel composting facility at UBC will be coming to the end of its life at any time. If this happens there is a possibility that all waste might be diverted to Harvest Power in Richmond.

The model for 'Compost Source' shows three tables, the first table shows the current situation at UBC. The second table shows 'Total Savings', if the waste is diverted to UBC farm instead of Harvest Power. The model assumes that only 20% of waste is diverted to the UBC Farm resulting in total savings of $11,600/year. The third table shows the remaining waste (other than the waste sent to UBC farm) which is sent to Harvest Power and the cost associated with it. Since table 2 assumes that 20% of the waste is diverted to the UBC Farm, the remainder of 80% (table 3) is then diverted to Harvest Power, which will cost 73,400/year.

All the boxes highlighted in blue can be change and modified. The advantage of this model is that according to the future situations and statistics, this model will still produce a valid result. For example: it is expected that in 2015 the total food waste will be 1300 tonnes. If the value of total food waste in table 1 is changed to 1300 (from 1000), all the values in table 1, table 2 and table 3 will change accordingly. Same working principle applies to tables 2 and 3, if in the future more than 20% of the waste is diverted to the UBC Farm and less than 80% of the waste is diverted to Harvest Power, changing the values will give new amounts of total savings and total cost.

Conclusion & Remaining Questions

This interactive model is to serve as a base framework for a bigger more complete model that analyzes and relates all the different variables affecting the successful implementation of a compost facility at the UBC Farm. In its current form this model is a compilation of work done by previous students as well as some value added knowledge for areas we felt needed more information.

The purpose of the model is to provide the decision makers with a tool that should aid in helping select the correct plan of action for building a compost facility at the UBC Farm. In order for this to be an effective tool, it must first be a complete tool. The hope is that this base framework can identify gaps in knowledge that need to be further explored and answered before moving forward with implementing a compost facility.

There are many remaining questions that need to be answered to complete this model, some known and some unknown. We have tried to identify some key questions that are worth researching which should help contribute to a more complete model. These should serve as a good first step for future research projects, and they are listed below.

- Can UBC provide the farm facility with non-contaminated compost?
- How will the farm facility handle contaminants in the compost?
- If the farm facility receives only non-contaminated waste, will this be enough volume to fill the facility? If not, then what happens?
- Are there government grants to supplement this type of initiative?
- More thorough research into a compost facility is required. Since, it is very likely that animal bedding might not be used, there need to be calculations done in order to finalize the recipe for the compost pile in order to optimize C:N ratio as well as to use all the waste being directed to UBC farm. The reports done till date (Toren, 2014) finalized 10 no. of piles in a year with a mass of 50 tonnes per pile. The 50 tonnes pile included 11 tonnes of animal bedding. In case animal bedding is not used the pile recipe has to be recalculated.

The key conclusion is that based on the current research there currently isn’t a financially viable option for a compost facility at the UBC Farm. Some other major source of funding needs to be sourced in order for this project to become a reality.

References

Bokowa, A. H. (2012). Ambient Odour Assessment Similarities and Differences between Different Techniques. *Chemical Enigneering Transactions, 30*, 313. doi:10.3303/CET1230053

Brattoli, M., Gennaro, G. d., Pinto, V. d., Loiotile, A. D., Lovascio, S., & Penza, M. (2011, May 16). Odour Detection Methods: Olfactometry and Chemical Sensors. *Sensors, 11*, 5290-5322. doi:10.3390/s110505290

Brewer, M. S., & Cadwallader, K. R. (n.d.). *Overview of Odor Measurement Techniques.* University of Illinois, Department of Food Science and Human Nutrition, Urbana. Retrieved April 10, 2015, from http://livestocktrail.illinois.edu/uploads/sowm/papers/p59-74.pdf

Jones, C. A., Koenig, R. T., Ellsworth, J. W., Brown, B. D., & Jackson, G. D. (2007). *Management of Urea Fertilizer to Minimize Volatilization.* Washington State University , Department of Land Resources and Evironmental Sciences, Pullman. Retrieved April 10, 2015

Richard , T., Trautmann, N., Krasny, M., Fredenburg, S., & Stuart, C. (1996). *Cornell Composting Science and Engineering* . Cornell Wate Management Institute, Ithaca. Retrieved April 10, 2015, from http://compost.css.cornell.edu/science.html

Ryckeboer , J., Mergaert, J., Vaes, K., Klammer, S., De Clercq, D., Coosemans, J., . . . Swings, J. (2003). A Survey of Bacteria and Fungi Occuring During Compositng and Self-Heating Processes. *Annals of Microbiology, 53*, 349-410.

(2013). *Technical Document on MSW Organics Processing.* Evironment Canada, Ottawa.

The Composting Process. (2015). (University of Illinois Extension) Retrieved April 10, 2015, from Composting in the Home Garden: http://urbanext.illinois.edu/compost/process.cfm

Toren, E. (2014). *Feasibility of and Suggested Methods for Operating a Compost Facility at the UBC Farm*.

Vivier, C., Hyde, K., Edara T., Durrant D. *(2014) UBC FARM COMPOST FINANCIAL FEASIBILITY PROJECT.* UBC Farm Compost Financial Feasibility 10Dec2014.pptx