A Life-Cycle Inventory of Alternatives for the Management of Commercial Food Waste

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ABSTRACT: Effective management of commercially generated food waste presents an opportunity for avoided global warming potential, renewable energy production, and renewable agrochemical production. The objective of this study was to compare two strategies for the management of commercial food waste. A life-cycle inventory was performed for food waste processed in a composting facility using windrows as well as for food waste buried in a landfill with and without energy recovery. The functional unit was one ton of food waste plus 0.3 tons of yard waste. The yard waste was considered because it is often used as a bulking agent for the composting of food waste. Total energy use and global warming potential (GWP) for each alternative were calculated. An offset for avoided fertilizer production was considered for the composting alternative. An offset for electrical energy production was considered for the landfill with energy recovery. The landfill without energy recovery alternative was inferior in both GWP and total energy use. Windrow composting was superior in terms of GWP and the landfill with energy recovery alternative was superior in total energy use with or without the fertilizer production offset. The optimal choice will depend on the feasibility of energy recovery, the priorities of the decision maker and factors that were not modeled.

INTRODUCTION

There is significant societal pressure to increase waste diversion from landfills, and the source separation of organic waste from both the residential and commercial sectors represents an opportunity for waste diversion. Many areas have recognized this opportunity, and source separated organics collection is becoming more common (Goldstein 2005). A number of cities and counties have begun collecting the organic fraction from food intensive commercial facilities (e.g. restaurants, grocery stores, cafeterias, etc.). Several cities have also begun source separated collection of organic residential wastes (e.g. San Francisco and Seattle). These source separated collection programs are providing opportunities for beneficial use of organic waste. Nonetheless, the EPA estimates that 97.6% of food waste is disposed of in landfills (EPA 2006), and the separate collection of source separated food waste can be expensive. Currently in the US, the vast majority of food waste that is not buried in a landfill is aerobically composted. The final compost has the potential to be used as a soil amendment. In

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some applications (e.g. organic agriculture), finished compost can replace mineral fertilizers or other agrochemicals. Societal and environmental pressures are creating momentum for the implementation of large-scale composting. The objective of this study was to evaluate the energy use and global warming potential (GWP) associated with aerobic composting and landfill disposal of commercial food waste. GWP for the purpose of this study only includes emissions of fossil fuel based CO_2 and all CH_4 emissions.

There has been some research on the life-cycle emissions associated with organic waste management. Diggelman and Ham (2003) used a life-cycle methodology to analyze various food waste management alternatives including in-vessel composting and landfilling with energy recovery. They did not consider windrow composting, which is more common. They also did not consider landfilling without energy recovery. Lundie and Peters (2005) also used a life cycle methodology to study various food waste management alternatives including landfilling and centralized composting. Their study does not consider energy production at the landfill, nor does it consider potential offsets from avoided mineral fertilizer production due to composting. The ORWARE (Organic Waste Research) model developed at the Swedish University of Agricultural Sciences provides an LCA for solid and liquid organic wastes (Sonesson 1998). Its broad focus does not include a detailed analysis of alternative composting and landfilling processes for food waste. The SWM-LCI model used in this study to model landfill emissions also includes a composting sub-model. The composting sub-model only considers mixed MSW or yard waste composting (Solano 2002).

METHODOLOGY

Two strategies for the management of commercial food wastes were evaluated in this study. The first strategy considers the processing of food waste in a large-scale windrow composting facility. The second strategy considers food waste that is sent to a landfill with and without energy recovery. These strategies represent the manner in which the vast majority of food waste is currently managed in the US. The functional unit under consideration is 1.0 ton of food waste and 0.3 tons of yard waste (i.e. branches). The yard waste is included because it is a necessary bulking agent to increase the free air space in the windrows. It also serves to increase the carbon-to-nitrogen ratio in the compost. The life-cycle inventory (LCI) does not include collection processes because it is assumed that the large scale commercial and industrial facilities producing the food waste will not require significant additional collection for source separated food waste.

Windrow Composting

The manner in which food waste is composted is presented in Fig. 1. and described here. Yard waste is utilized in the food waste composting process as a bulking agent and carbon source. After the yard waste is shredded in a horizontal grinder, it is mixed with food waste and screen rejects at the tipping floor. The feedstocks are mixed in a 2:2:1 volumetric ratio of food waste, shredded yard waste and screen rejects, respectively. After blending, the compost is piled into windrows. The compost remains in windrows for 60 days and is turned every other day. The windrows are assumed to be in an enclosed building with a biofilter odor control system in place. After active composting, the materials are screened. Some rejected materials are recycled into the initial feedstock and any excess is sent to a landfill.

Materials that pass through the screen are built into curing windrows. Curing windrows are turned weekly and curing lasts for 30 days. After curing, the compost is ready for application as a mineral fertilizer replacement. The assumption that the final compost is suitable for use as a fertilizer is based on the assumed purity of initial feedstock as well as the existence of local markets.

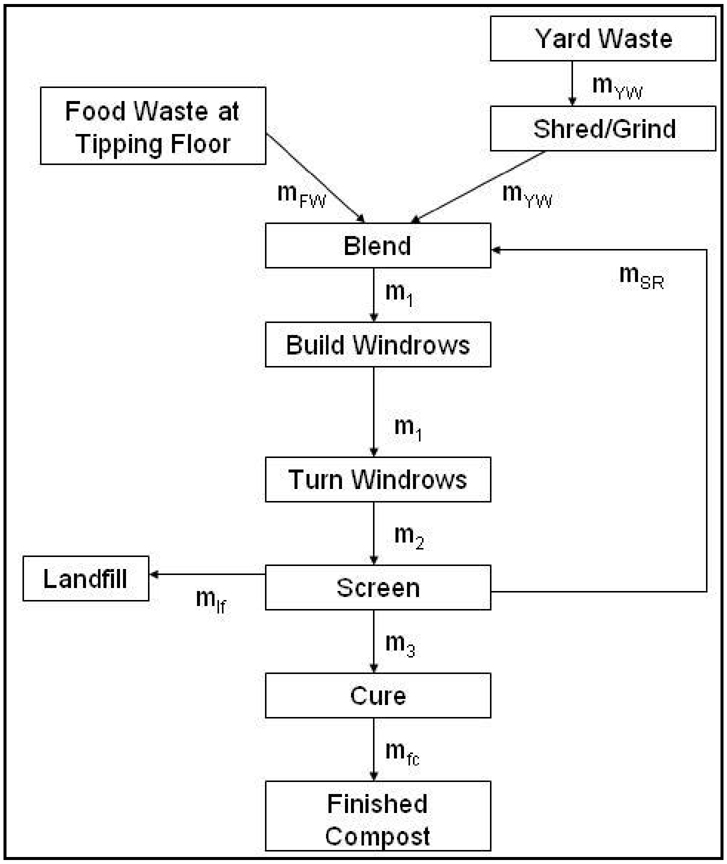

Fig. 1. Windrow composting mass flow diagram.

Windrow Composting Modeling

The processes included in the windrow composting alternative generate emissions in one of three ways (i.e. direct emissions, fossil fuel use, and electricity use). Direct emissions refer to emissions directly from the process and include fossil fuel combustion and biodegradation products. Emissions from fossil fuel use refer to the pre-combustion emissions required to extract, process, and transport fuels to the point of use. Electricity use refers to emissions generated at electrical utilities from the production of electrical energy. Table 1 lists all of the processes included in the windrow composting alternative and the types of emissions associated with each process. The data for fossil fuel pre-combustion emissions and energy use were developed from the NREL Database – Fuels and Energy Precombustion module (NREL 2004). Emissions associated with electrical energy use were developed from Dumas 1997.

Table 1. Emission types for each windrow composting process.

	Direct Emissions	Fossil Fuel Use	Electricity Use
Yard Waste Shredding	X	X	
Active Windrow Turning	X	X	
Biodegradation	X		
Odor Control			X
Screening			X
Reject Disposal	X	X	X
Curing Windrow Turning	X	X	
Front End Loader Use	X	X	
Office Area Energy Use			X
Fertilizer Offsets	X	X	X

The emissions and energy use for yard waste shredding are assumed to vary linearly with the amount of yard waste to be shredded. The energy and diesel fuel consumed per ton of yard waste was determined via linear regression of data from Diamond Z horizontal grinders. Windrows are turned to increase the free air space in the windrows, and to avoid anaerobic areas that generate emissions and odors. Free air space is essential for passive aeration to occur through the center of the pile. The emissions and energy use are assumed to vary linearly with the amount of compost to be turned. The energy and diesel fuel consumed per ton of yard waste was determined via linear regression of data from Backhus windrow turners.

The biological degradation of wastes during active composting is a complex phenomenon that results in the emission of CO_2, NH_3, and VOCs. The emission of NH_3 and VOCs can be lessened by the use of a biofilter. The yield of CO_2 and NH_3 were developed from Komilis and Ham (2003). The VOC yield was developed from Komilis et. al. (2004). The biofilters are assumed to have a constant removal efficiency of 80% and 35% for NH_3 and VOCs, respectively (Sonesson, 1996; Pagans, 2006).

Odor control systems work by pulling air from inside the active composting area through a biological filter. The emissions from the odor control system are due to the electrical energy used to power the fans. The relationship between fan horse-power and supplied flow rate is assumed to be linear. The energy required to run the fans was determined via linear regression of the power and flow rate data for GI Fans produced by New York Blower Co. The efficiency of the blower is assumed to be a constant at 65%.

After active composting and before curing, materials are passed through a screen. The screen is electrically powered. Some screen rejects are recycled into the original blend, and the rest are sent to a landfill. It is assumed that 35% of the materials are screened out, and that all substrates are screened with the same efficiency. The electrical energy use for the screen was determined by Diaz et. al. (1982). The life-cycle emissions from the disposal of screen rejects in a landfill are determined using the landfill module from the Solid Waste Management – Life-Cycle Inventory (SWM-LCI) model developed at North Carolina State University (Sich and Barlaz 2000). This model is discussed further in the Landfill Process section. For screen rejects, methane production in the landfill was assumed to be 10% of the default value due to the aerobic degradation that has already occurred.

Front end loaders (FEL) are used to blend materials at the tipping floor, build and tear down piles, and transfer materials around the composting facility. The emissions from FELs were determined by using an overall factor of 0.5 hp/tpd for FELs that was determined by Komilis and Ham (2004). The offices at composting facilities use electrical energy that result in emissions. The office space requirement is based on the amount of compost entering the facility. The office area required per ton of incoming material was developed by Komilis and Ham (2004). The amount of energy use in an office per unit area was determined from DOE (1994; 1995).

Composting Offsets

There are many potential beneficial uses for compost. Compost can be used in place of mineral fertilizers in certain settings. Organic farmers, who cannot use mineral fertilizers, are most likely to utilize the nitrogen content of the compost. Compost aids in soil moisture storage in agricultural settings and can be used to reduce run-off from medians or embankments. Compost is also used to suppress weeds and the risk of disease in certain plants. Compost can also be used as cover in landfills and it can potentially provide additional oxidation of CH_4 to CO_2. The environmental benefits of these uses are often difficult to quantify.

In this study, the finished compost is assumed to have value as a nutrient amendment and is used in place of mineral fertilizers for its nitrogen, phosphorus, and potassium content. The dry weight percentage of each nutrient was developed from Hansen et. al.

(2006). Nitrogen in compost is not as biologically available as nitrogen in mineral fertilizers, so a mineral fertilizer equivalent (MRE) of 0.30 was applied. It is assumed that there is an infinite demand for nitrogen in the finished compost. This means that all of the equivalent nitrogen leads to an equal amount of avoided nitrogen fertilizer production. Phosphorus and potassium offsets are limited by their demand in relation to the equivalent nitrogen use. Essentially, there is more available phosphorus and potassium in the finished compost than can be reasonably used by the plants given the nitrogen content. The ratio of nitrogen demand to phosphorus and potassium (i.e. 0.5 and 0.4) was determined from the NREL Database - corn and soybean production modules (NREL 2005a; NREL 2005b) assuming an annual rotation between soybeans and corn. The emissions and energy use associated with fertilizer production were developed from NREL (1998).

Landfill Process

Disposing of materials in a landfill is complex process. Materials must be buried in the landfill, daily and final covers must be applied, landfill gas and leachate must be managed, and the facility must be maintained during the operations, closure, and post-closure periods. This analysis considered two alternatives for landfill gas management. In one alternative, the landfill gas was collected and flared through year 40. In the second alternative, gas was converted to electrical energy between years 2 and 40. After year 40 in both alternatives, the gas was passively vented and it was assumed that 15% is oxidized in the landfill cover. Gas collection was assumed to begin in year 3. The collection efficiency in year 3 was 50%, this increased to 70% in year 4, and was 80% every year afterwards. These are judged to be fairly conservative assumptions and are likely to result in landfill emissions that are higher than is typical of a well operated landfill. The life-cycle inventory of the landfill alternatives were developed using the landfill module from the SWM-LCI model. The landfill module included in the SWM-LCI considers emissions from daily operations, gas and leachate collection and treatment, landfill closure, and post-closure monitoring. The emissions from each process were determined on a per ton of refuse basis. The generated electricity in the landfill with energy recovery alternative was assumed to lead to avoided energy production on the regional energy grid. The Mid-Atlantic regional energy grid was chosen for this study.

RESULTS

The results of the life-cycle inventory are presented in Table 2. The energy recovery from the landfill produces more energy than is used in the landfill process, so the value is negative. The landfill with energy recovery alternative is superior in energy use, but composting is superior in GWP. The landfill without energy recovery is inferior to the other alternatives in both categories.

Table 2. Net Emissions from each of the Alternatives.

Category	**Units**	**Windrow** (w/out offsets)	**Windrow** (w/ offsets)	**Landfill with Energy Recovery**	**Landfill without Energy Recovery**
Energy Use	kBtu	200	100	-800	800
GWP	CO_2 Equivalents	30	20	800	1,000

*Negative values mean the produced energy was greater than the energy used.

The offsets from avoided fertilizer production provide a significant decrease in energy use and GWP for the composting alternative, but they do not change the relative rank of the alternatives. This means that the final use of the compost does not significantly affect the optimal decision. The proportion that each process in the windrow composting alternative contributes to the gross energy use and GWP is shown in Fig. 2. Odor control electrical energy use leads to the most energy use and GWP in the composting alternative. The energy use varies substantially with the GWP. It is to be expected that these two categories would mirror one another since most of the emissions are from the combustion of fossil fuels which use significant energy and emit significant CO_2.

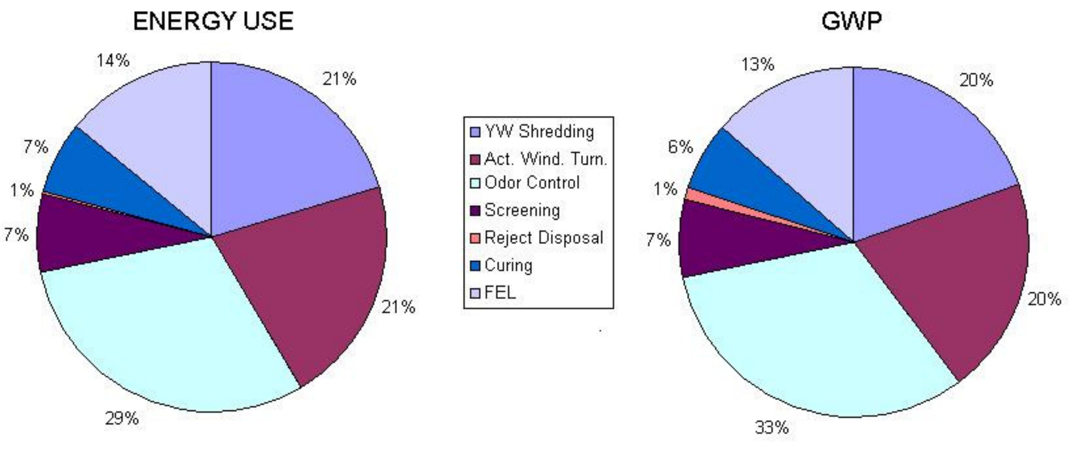

Fig. 2. Percent contribution of each process to total energy use and GWP. These data do not reflect the offsets associated with fertilizer use.

CONCLUSIONS

Landfilling without energy recovery was found to be inferior to windrow composting and landfilling with energy recovery in both net energy use and GWP. When landfill gas is recovered for beneficial use it provides the lowest net energy use of all three alternatives, whereas, windrow composting results in the lowest GWP. The results are sensitive to assumptions regarding fugitive emissions from landfills and additional work is in progress to explore this sensitivity. These results are based on assumptions that (1) there were no methane emissions from possible anaerobic areas in the windrows, and (2) high quality source-separated food waste is provided as a feedstock. Furthermore, the consideration of avoided mineral fertilizer production due to composting did not change the rank of windrow composting compared to either landfill alternative in either category.

Further work to understand the state-of-the-practice will be helpful to confirm these assumptions. Analyzing the life-cycle emissions of other types of composting facilities would allow further comparisons to determine if some other form of composting is superior. An uncertainty and sensitivity analysis would provide valuable information on the robustness of the results in the face of variability and uncertainty in input parameters. Finally, a more precise analysis of the compost market in the region of interest would also be useful to ensure that there is a market for the product and to provide more accurate offset estimates.

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