Large scale aerobic composting of source-separated organic wastes: A comparative study of environmental impacts, costs, and contextual effects.

by

Rob van Haaren

Advisor: Prof. Nickolas J. Themelis, Columbia University,

Co-advisor: Prof. Morton Barlaz, North Carolina State University

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Executive Summary

This thesis describes research conducted to identify the best available technology for processing source-separated organic wastes, by means of a multi-criteria analysis (MCA): a) Environmental impact, b) cost, c) land area required, d) odor control and e) feedstock flexibility. A Life-Cycle Analysis (LCA) assessed the environmental impacts of each process. In conjunction with the financial and contextual (e.g., odor control) aspects that were examined in this study, this LCA compared four methods for disposing organic wastes: Three aerobic composting methods (windrow composting, aerated static pile, and in-vessel composting) and the use of yard wastes as Alternative Daily Cover (ADC) on a landfill. These methods were rated for each criterion and individual dominance scores were generated, using case-specific weighting factors for each criterion. As a result, a decision making model was created that can help communities and waste management companies in choosing the appropriate technology for a particular situation.

The LCA study showed that both the ADC and the in-vessel technology were most beneficial for the environment. The ADC scenario was also found to be the least costly, at an estimated $14 per ton with windrow composting coming next with $22 per ton. The Gore Cover, for a specific application, was estimated at $42/ton. The in-vessel technology was by far the most costly method of all four, with $147 per ton. The aerated static pile technology was rated best in the other three criteria, i.e. area needed, odor control and input material flexibility. Based on applying different sets of weighting factors for all five criteria, two technologies were rated as most preferable: the aerated static pile (Gore Cover system) and the use of yard wastes as ADC in landfills. Of course, the latter depends on the availability of sanitary landfills and demand for ADC in the area.

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CHAPTER 1: Introduction

According to the BioCycle 2006 State of Garbage study (R. van Haaren et al., 2008), 22.7 million tons of the organic fraction in the U.S. Municipal Solid Waste (MSW) were composted or mulched. Also, according to EPA reports, the recycling rate of yard wastes in 2006 (62%) was much greater than that of food wastes (2.2%) (EPA, 2006).

These recycling rates constitute the total tonnages of yard and food wastes that are processed by different methods. There is no data in the literature on tonnages processed by each type of composting facility; however, windrow composting is known to be the common practice. In the United Kingdom, for instance, windrow composting is the dominant technology, with 79% of all green waste processed, as compared to 11% for in-vessel composting and less than 1% for aerated static piles (R. Smith, 2007). Also, there is little information as to how these technologies compare in capital and operating costs, and in environmental impacts.

This study compares three composting technologies, together with a relatively new trend of using yard wastes as Alternative Daily Cover (ADC) in landfills, on the basis of five criteria: a) Environmental impact, b) cost, c) land area required, d) odor control and e) feedstock flexibility..

CHAPTER 2: Organic Waste Managing Technologies

As noted above, four organic waste managing methods were compared in this study. Three of them are aerobic composting technologies (windrow composting with turning, aerated static pile and in-vessel composting) and the fourth is use of green waste as an Alternative Daily Cover (ADC) on a landfill.

2.1: Windrow composting

Windrow composting (Figure 1) has been the common practice for large scale composting globally. It is carried out in piles of 2-3 meters high, 3-5 meters wide and up to a hundred meters long so as to keep the temperatures high and also allow some oxygen flow to the center core. The windrows are turned periodically with special turning machines to allow for heat release and expose anaerobic volumes to oxygen. Usually, these turners are equipped with watering attachments, which can supply water to the pile so as to attain a close to optimum moisture level. Windrow composting is less costly than the other technologies but it is more difficult to control and can generate undesirable emissions and odors.

Figure 1: A windrow turner at a composting site (www.communitycompost.org).

The feedstock processed in these facilities usually does not include food wastes. This is because they produce unpleasant odors that can cause problems with residents in the surrounding area. Also, birds may become a nuisance to the process when food is present in the piles.

In the Life Cycle inventory of Komilis and Ham (D. Komilis, 2004), yard wastes are modeled as feedstock in windrow composting. In that study, a 100 ton/day yard waste composting facility was compared with two municipal solid waste (MSW) composting facilities. The MSW feedstock was assumed to comprise three organic components, food waste, yard waste and mixed paper. The retention time of the yard waste in the facility was 24 weeks. The different stages in the process of windrow composting will be discussed in the LCA section below.

The bioconversion reactions occur mostly under aerobic conditions. The bulk of oxygen is supplied by turning the windrows, with a windrow turner. The aerobic conversion reaction can be expressed as follows:

$$(C_6H_{10}O_4)_x + 6.5\ O_2 \rightarrow (C_6H_{10}O_4)_{x-1} + 6\ CO_2 + 5\ H_2O \qquad (1)$$

where $(C_6H_{10}O_4)_x$ is a simplified formula (Themelis, 2000). This reaction is exothermic and releases about 616 kcal of heat per mole of organic matter.

In normal practice of windrow composting, oxygen is not always present for all biodegradable matter, e.g. in the core of the windrow. The amount available for biodegradable matter is a function of turning frequency and pile porosity. The benefit of turning frequently is to minimize anaerobic reactions and generation of methane according to the following *methanogenesis* reaction:

$$(C_6H_{10}O_4)_x + 1.5\ H_2O \rightarrow (C_6H_{10}O_4)_{x-1} + 2.75\ CO_2 + 3.25\ CH_4 \qquad (2)$$

Compared to the strongly exothermic aerobic reaction, anaerobic bioconversion ranges from slightly endothermic to slightly exothermic, depending on the structure of the $C_6H_{10}O_4$ molecule. It will be shown in a later section that there is hardly any methane emitted per ton of yard waste: 2.3E-05 kg of methane, as compared to 350 kg of carbon dioxide (CO_2). It can be surmised that some of the methane is oxidized by *methanotrophs,* bacteria that oxidize methane in the presence of:

- Sufficient oxygen supply;
- A suitable carrier that offers adequate nutrient supply and facilitates colony formation;
- Adequate moisture content and ambient conditions in the medium.

Some of the factors affecting the activity of the *methanotrophs* are pH (preferably between 6 and 8), temperature (optimum between 25 to 35 ^{o}C) and moisture content (L. Diaz, 2005). However, the optimal moisture content and the oxidation rate increase as organic matter content increases (Mette Christophersen, 2000).

2.2: Aerated static piles: Gore-covers

The dominant aerated pile technology is that of Gore-Tex, or Gore Cover (Figure 2). In 2006, about two million tons of organics were composted using the Gore Cover technology in over 20 countries (Entsorga, 2006). The technology consists of a concrete foundation with horizontal aeration tubes on its surface through which air flows upward into the waste pile. The organic wastes are usually shredded and then deposited on this floor, similarly to windrow composting. The entire pile is then covered by a special membrane cloth that keeps organic vapors and moisture in while allowing the passage of nitrogen, carbon dioxide and unused oxygen. The covers are kept in place by either sandbags, fire hoses or they are attached to bolts in small walls with rubber ropes (Walker Industries trip notes, 2009). Moisture and oxygen levels are kept at the optimum level for degradation to take place.

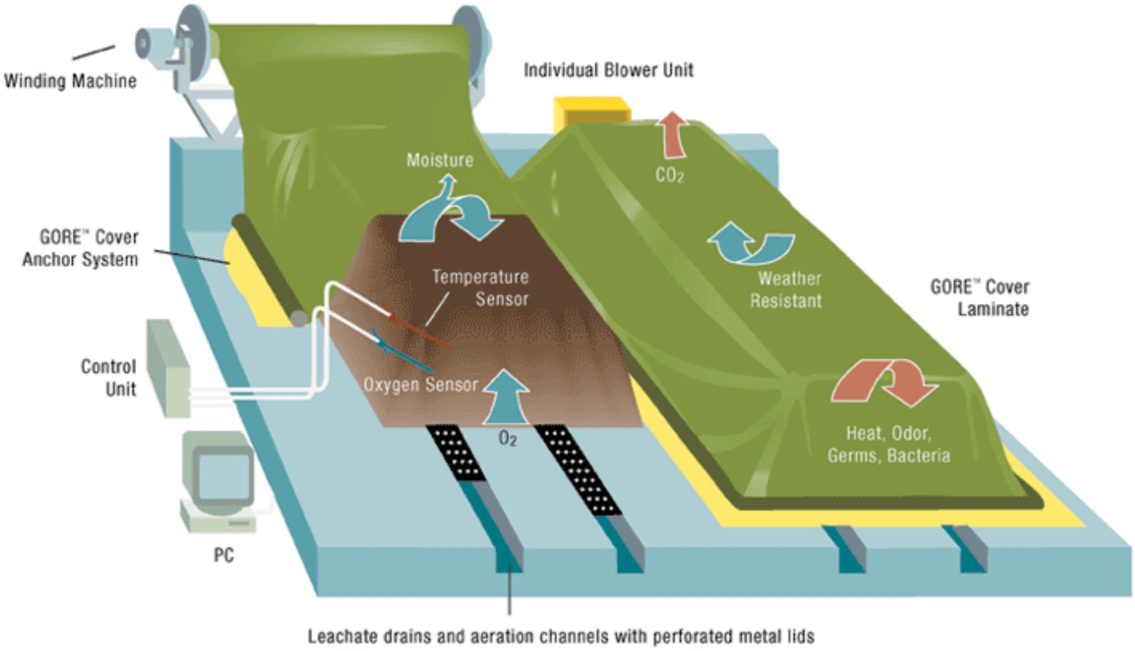


Figure 2: Schematic overview of the Gore Cover composting system. The cloth's fiber structure is weather resistant, lets moisture and carbon dioxide through, while keeping the heat, odors and bacteria inside. The central control unit keeps oxygen levels and moisture levels at an optimum by adjusting the aeration through underground channels (Gore Associates, 2008).

Similarly to the windrow composting equation (1), the oxidation taking place in aerobic conditions is represented as follows, now taking into account a 50%-50% mix of food waste and yard waste:

$$(C_{4.09}H_{6.35}O_2)_n + 4.4\ O_2 \rightarrow (C_{4.09}H_{6.35}O_{2.79})_{n-1} + 4.1\ CO_2 + 3.4\ H_2O \qquad (3)$$

Taking into account the atomic mass of the elements, it is calculated that the mass of air needed for the conversion of 1 kg of feedstock is about 6.9 kg, or 5.8 Nm^3.

The waste handling process of Gore Cover, as practiced at Cedar Grove, Seattle consists of:

1. Weighing the incoming feedstock;
2. Tipping materials in an odor-controlled building under negative air flow that

is then conveyed through a biofilter;

3. Premixing with front-end loader (FEL) and then materials are screened;
4. Transport to the piles with a conveyor belt;
5. Three phase biodegradation process (see below);
6. Screening of any remaining plastic pieces
7. Final aging process before using as soil amendment/low quality fertilizer.

Shredding is only necessary when particle size is too big to allow proper degradation. The biodegradation process consists generally of three parts and last for about 9 weeks. In Edmonton, California the retention time of organics is as follows:

- 1-4 weeks biodegradation under cover;
- 2-4 weeks post-rotting under cover;
- 2-3 weeks exposed curing (Entsorga, 2006).

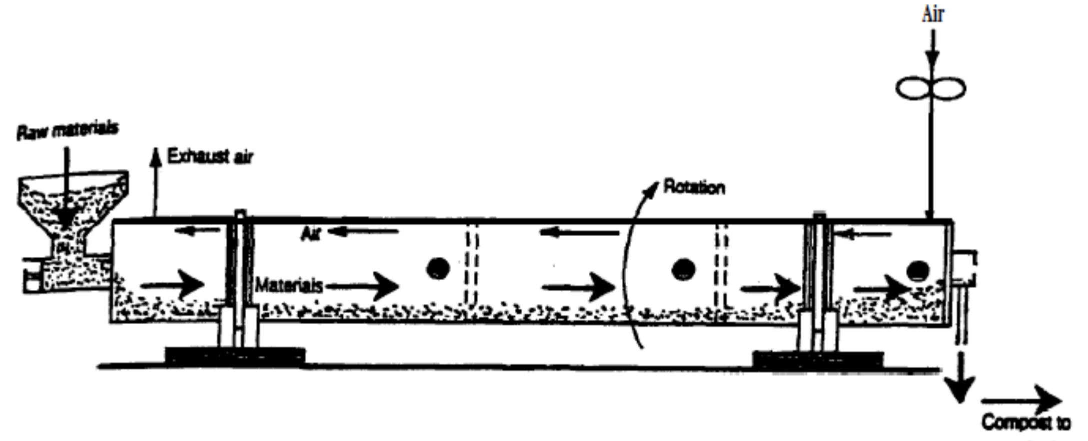
For the Gore Cover composting systems at Cedar Grove, Seattle and Niagara Falls, Ontario, the three stages take 4, 2 and 2 weeks of time, respectively (SUR Composting Report, 2006) (Walker Industries Visit, 2009).

Many variations are possible in the shape and structure of the Gore Cover plant. Piles in the Gore Cover system operated by Walker Industries in Niagara Falls, Canada, are deposited in between two low walls extending over the length of the pile. The cover is then connected to bolts in the walls by rubber ropes instead of using sandbags or a fire hose. This works better in the winter, since it prevents the attachments of the covers from being covered in snow and ice (Walker Industries trip notes, 2009). Also, the covers can be attached to a frame structure that can be opened up for loading and unloading, as is done at German operations of Gore-Tex. It is interesting to note that the Gore Cover system is used there to dry MSW before it is sent to the combustion chamber of a Waste-To-Energy facility (Walker Industries Visit, 2009). The Gore system can be designed for optimal conditions for each specific configuration of the pile.

With respect to cost and complexity of operation, aerated static piles are situated somewhere between windrows and the in-vessel technologies to be discussed in the next section. These facilities do not take up as much space as windrow composting but for optimal operation they require close monitoring of moisture and oxygen levels.

2.3: In-vessel aerobic composting in a rotary drum

In-vessel aerobic composting of organics (both yard waste and food wastes are suitable) is a method of processing waste that provides a high degree of control. It resembles a chemical reactor where all parameters (oxygen and moisture levels) can be optimized for the highest conversion rates. In a typical facility, the system consists of a rotating drum, an air blower and an air filtration unit. The drum rotates at 1-10 revolutions per minute. A typical rotating drum is approximately 3 meters in diameter; while the length of the drum can be up to 56 meters (Van Haaren, Nantucket trip notes, 2009).



source: Rynk et al.,1992.

Figure 3: Schematic representation of a rotating drum composting system. As the drum rotates, material is mixed and oxidized.

The rotating causes the material to tumble and this provides a good distribution of reactants which results in the high bioreaction rates of these systems.

The chemical conversion taking place is similar to that of the aerated static pile method as in equation 3. The process is carried out in two phases:

- 1-6 days: Active composting period in rotary drum;
- 1-3 months: Curing stage in windrows. (EPA, 1994)

The curing stage is necessary because the compost product of the bioreactor is not stable after it exits the rotating drum.

2.4: Use of Yard Wastes as Alternative Daily Cover

EPA regulations require that a 15 cm thick layer of soil be placed daily over the newly landfilled material, so as to reduce the emission of odors and keep birds, insects and vermin from reaching the MSW. Under 40 CFR Part 258.21(a):

"owners or operators of all municipal solid waste landfill (MSWLF) units must cover disposed solid waste with 6 inches of earthen material at the end of each operating day, or at more frequent intervals if necessary, to control disease vectors, fires, odors, blowing litter, and scavenging." (EPA, 2009 [1])

Soil is the common practice for daily cover on a landfill; however, tarps and sprayon mulch mixes are also used as ADC. In California, an estimated 2.1 million tons of source-separated yard wastes are shredded and used in landfills as Alternate Daily Cover (ADC, Stephens, 2007). The California Assembly has passed a bill that allows for this use of yard wastes to be counted as part of the recycling effort of a community (Haughey, 2001). However, some environmental organizations are questioning the environmental benefit of this use and suggest that this material should be sent to conventional composting facilities, such as windrow composters.

Conditions in the landfill are mainly anaerobic. The water needed to generate the methane from the biomass wastes present in the landfill is either provided by precipitation or it is part of the moisture fraction of the waste. However, some aerobic reaction occurs either due to the oxygen contained in open volumes during the dumping process, or oxygen diffusing through the cover layer into the landfill. Typically, landfill gas contains equal volumes of methane and carbon dioxide and a small amount of nitrogen.

The depth of a typical landfill cell varies considerably, from 15 to 80 meters, depending on the landfill geometry and overall size. Similarly, the height of a daily cell varies but a value of about 10 feet represents a reasonable approximation. Landfill gas collection wells are typically installed incrementally after waste burial. Regulations require that wells be installed within the earlier of two years of placement of the final cover or five years after waste burial. However, at many landfills, gas collection systems are installed sooner, once an area of a landfill has an intermediate cover (Barlaz, 2009).

A cross-section of a landfill is shown in Figure 4. The working landfill cell is prepared with a liner and MSW is deposited daily. It is important to equip the landfill with an impervious layer (liner) to keep leachate from leaking into the soil and contaminating surface or groundwater.. More information about this can be found in Appendix B. When the cell reaches its final height, the final cover is placed after the gas collection system is installed. The EPA requires landfills over a certain size to collect and combust landfill gas under the Clean Air Act (EPA, 2009 [2]).

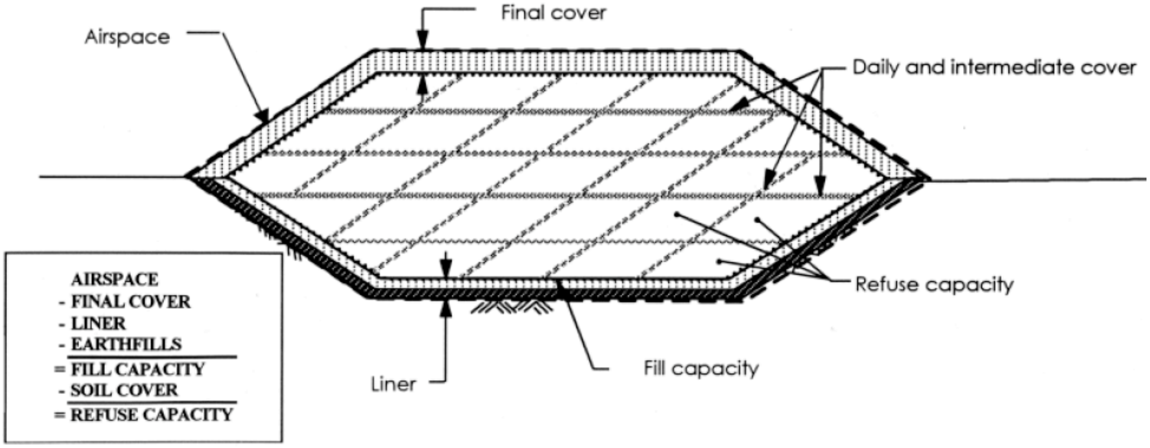


Figure 4: Schematic overview of the layers in a landfill. The cells are covered by daily covers and when they are leftand intermediate covers (Haughey, 2001).

In order to save space, some landfills scrape off daily cover soil before the next layer of MSW is deposited and the soil is then re-used. On the average, the volume ratio of MSW to soil in landfills is approximately 9:1 (Barlaz, 2009).

CHAPTER 3: Life Cycle Analysis

3.1: Methodology

The LCA was conducted using the SimaPro LCA software program (PRE Consultants, 2009). It consists of an extensive database of products and processes that provide an inventory of energy and material resources used and of chemical compounds emitted (waterborne, airborne and into the soil) during manufacturing a product or operating a process. This software program allows users to create their own database, by selecting relevant data entries from the SimaPro database. In the next stage, the program accounts for all the environmental impacts involved. In several categories (health effects, ecosystem effects and resource conservation) SimaPro generates a bar chart where all impacts are weighted, by means of appropriate weighting factors, it then integrates these impacts into one number for each competitive product or process.

In this case, the material and energy inventory of the four processes described earlier were developed, as well as their corresponding emissions, on the basis of information provided in the literature and company reports or obtained in plant visits.

In LCA studies, the same functional unit should be used in all methods. Also, it is very important to define the boundaries of the systems that are being researched so that a fair comparison is made. In the following, the functional unit and the boundaries of the four methods will be discussed.

3.2: Functional unit in LCA comparison

The functional unit in this LCA study is one metric ton (1000 kg) of source-separated yard wastes (also called "green wastes"). However, two of the methods discussed in this paper (aerated static pile and in-vessel composting) can also process food wastes because they are enclosed and emit relatively little odor. In contrast, if food wastes are admixed with yard wastes in the windrow composting and ADC scenarios, they result in the emission of undesirable odors; also, birds and insects can become a nuisance. For this reason, food wastes should not be mixed with yard wastes in the case of windrow and ADC disposal.

Ideally, the four methods should be compared using the same feedstock. However, the only available data for the Gore Cover and in-vessel technologies were for mixed feedstocks. Because of this, in the LCA study, it was necessary to use feedstocks of two different compositions in comparing the four methods. It is therefore useful to consider how the chemical compositions of yard wastes and yard and food wastes differ. Table 1 shows that food wastes contain 10% more moisture and 8.6% less volatile matter than yard wastes. Also, the non-combustible fraction is higher than for yard wastes.

Table 1: Average composition and heating value of typical waste streams in the U.S. From: (Tchobanoglous, Theisen, Vigil, 1993)

%	Moisture	Volatile matter	Fixed carbon	Non-combustible	kJ/kg as collected
Yard wastes	60	30	9.5	0.5	6,050
Mixed food wastes	70	21.4	3.6	5	4,180

Laboratory and pilot research have shown that the optimum moisture content for aerobic composting reactions ranges from 45-60%; also, temperatures should be maintained below 60 ^{o}C (Themelis, 2000). The 10% higher moisture content does not significantly affect the degradation environment in the reactors of the aerated static pile and the in-vessel aerobic composting scenarios. This is because these processes are provided with moisture control systems that keep optimum conditions within the bioreacting mass; as temperature and, therefore, evaporation increase, the control system adds water to keep the right moisture content in the reactor.

Table 2: Elemental composition of typical waste streams in the U.S. Besides the five elements below, other elements are present too, like phosphorus. From: (Tchobanoglous, Theisen, Vigil, 1993)

%	**Carbon**	**Hydrogen**	**Oxygen**	**Nitrogen**	**Sulfur**
Yard wastes	46	6	38	3.4	0.3
Mixed food wastes	48	6.4	37.6	2.6	0.4

Table 2 shows that the carbon and hydrogen content of the food and yard wastes are nearly the same. The only large relative difference is in nitrogen content. These two elements yield a higher nutrient content in the final compost product of the aerated static pile and in-vessel processes i.e. a more effective fertilizer replacements than the product from composting yard waste in windrows. The respective chemical composition of yard wastes and mixtures of yard and food wastes can be calculated from the fractional mass composition shown in Table 2 and the atomic weights of the elements. The result is as follows:

Yard waste: $(C_{3.83}H_{5.95}O_{2.38}N_{0.24}S_{0.009})_n$

Mixed food wastes: $(C_{4.00}H_{6.35}O_{2.35}N_{0.19}S_{0.012})_m$

where the 'm' and 'n' factors can be adjusted according to the length of the hydrocarbon chain molecule. As the chains become smaller during degradation, the molecules become more stable and the rate of conversion decreases (Themelis, 2000).

It can be seen that the chemical formula of feedstock containing food wastes differs little from that consisting only of yard wastes. The functional unit for the windrow and ADC scenario is one metric ton of yard waste: $(C_{3.83}H_{5.95}O_{2.38}N_{0.24}S_{0.009})_n$. The input of the aerated static pile and in-vessel processes can be generally anything between the above displayed yard waste and mixed food waste compositions. Typically, a 50%-50% mix would give a chemical formula of $(C_{3.91}H_{6.15}O_{2.36}N_{0.21}S_{0.011})_n$.

An important product of the biodegradation is the formation of ammonia. It occurs in all scenarios and a general explanation will be given here for that reason.

Ammonification and nitrogen losses

In the presence of water and sufficiently high pH and temperatures, ammonia is formed. Carbon present is used for the growth of new cells as well as a source of energy. When there is an insufficient amount of carbon or energy, unstable nitrogen results in ammonification. The C:N ratio is an important figure for ammonification in the composting process. An initial C:N ratio of 20:1 to 40:1 is recommended for fast composting rates (Graves et al., 2000). When the ratio goes below that range and the right conditions are present, ammonia is formed. The reaction equation is as follows:

$$R{-}NH_3 + H_2O \rightarrow R{-}OH + NH_3 + \text{Energy} \qquad (4)$$

Considering the feedstocks that are used in the analysis, the following C:N ratios are present:

Feedstock	**C:N ratio**
Yard waste	15.8
Yard and food waste mix (50/50)	18.3

These figures imply that ammonia formation may occur, even in the case of yard waste feedstock.

It was found that a significant amount of nitrogen is lost during the composting process, ranging between 3.7 to 69.2% when manure is the feedstock. Of this, 46.8 to 77.4% was emitted in a gaseous form, most of it as ammonia (NH_3) (Graves et al., 2000). For yard wastes, 4 to 35% of initial nitrogen present was emitted as ammonia in a experimental study (Insam et al., 2002). Projecting this onto the nitrogen available in one metric ton of yard waste in our study, between 0.54 and 4.76 kg of ammonia would be emitted. These ammonia emissions have ecological environmental impacts in the eutrophication/acidification categories and health impacts in the respiratory organics category.

3.3: System boundaries of the methods and software inputs

As noted earlier, it is important to define the boundaries of the process that is the subject of the LCA. In this section, the resource use and environmental impacts of each of the four processes, within the defined system boundaries, are incorporated in the impact assessment.

3.3.1: Windrow Composting

Boundaries of the system

The boundaries set in the yard waste composting facility (YWCF) in the paper of Komilis and Ham (Komilis and Ham, 2004) are shown in Figure 5.

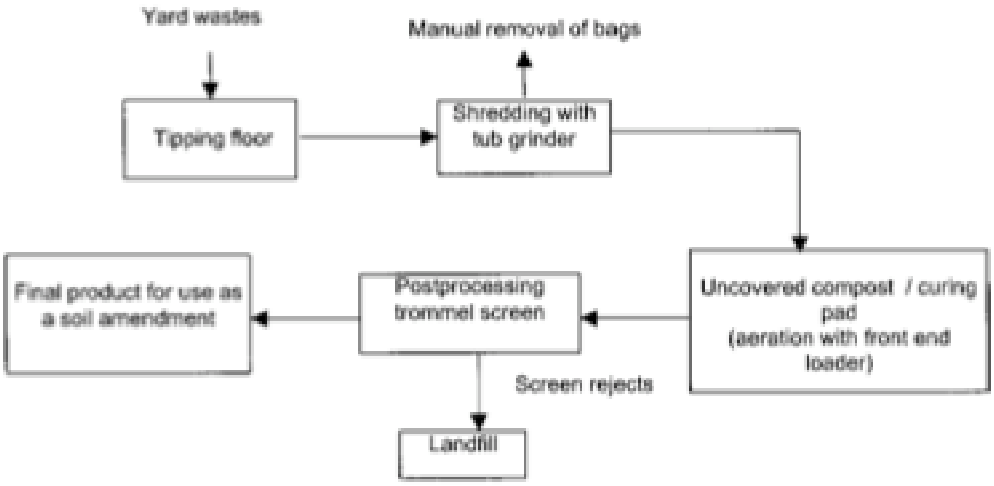


Figure 5: Overview of the yard waste composting facility process. The yard wastes first pass the tipping floor, then they are shredded and bags are removed. After that, the actual composting takes place and thereafter, screen rejects are removed (Komilis and Ham, 2004)

The above flow diagram shows the stages of the windrow composting process. Total energy requirements are 29 kWh/ton. This number includes fuel (71 %) and electricity (29 %) and compares to the 19.7 kWh of energy needed per metric ton of feedstock reported by White et al. (1995). It should be noted that the state of art in windrow composting includes a windrow turner and not a front end loader as was used in the study by Komilis and Ham. The use of a windrow turner would decrease the amount of fuel needed for operations. Electricity is included in SimaPro as the average mix of US-generated electricity and the fuel is assumed to be diesel. The associated diesel emissions are included in the airborne emissions. The input of air emissions is shown in Table 3.

Table 3: Air emissions per ton of yard waste feedstock, obtained from life-cycle inventory of Komilis and Ham (Komilis and Ham, 2004).

Emissions to air	**Amount (kg)**
Particulates	0.018
Nitrogen oxides	0.16
Hydrocarbons, unspecified	0.035
Sulfur dioxide	0.035
Carbon monoxide	0.082
Carbon dioxide, biogenic	350
Carbon dioxide, fossil	7.3
Ammonia	2.5
Hydrogen chloride	$2.5*10^{-7}$
Methane, biogenic	$2.3*10^{-5}$
Lead	$2.3*10^{-9}$

Table 3 shows that 2.5 kg of ammonia were released per 1000 kg of yard waste. This is approximately 18% of the initial nitrogen mass in the feedstock.

Waterborne emissions were also obtained from the same paper (Table 4).

Table 4: Water emissions per ton of yard waste feedstock, obtained from the life-cycle inventory of Komilis and Ham.

Emissions to water	Amount (kg)
Suspended solids, unspecified	$2*10^{-5}$
Solved solids	0.021
BOD5, Biological Oxygen Demand	$2.1*10^{-5}$
COD, Chemical Oxygen Demand	$1*10^{-4}$
Oils, unspecified	$2.5*10^{-4}$
Sulfuric acid	$1.5* 10^{-3}$
Iron	$3.7*10^{-4}$
Chromium	$6.9*10^{-9}$
Lead	$3.1*10^{-9}$
Zinc	$4.5*10^{-8}$
Solids, inorganic	0.26

These emissions however, are associated with the combustion of fuel and electricity use, not the leaching emissions to the ground from composting operations. It is assumed that this windrow composting plant has a leachate collection system that stores the slurry waste in a pond or an enclosed vessel before it is treated and disposed of in the sewer or is picked up by truck.

Avoided product: fertilizer

The end-product of windrow composting can be used as a soil amendment. This has a beneficial effect on the overall environmental impact of a process, since fertilizer production consumes a lot of energy. The effectiveness of the compost product can be compared to that of an average fertilizer by means of a mass balance.

Assuming a mass loss for windrow composting of 20% from the initial feedstock (Compost Science & Utilization, 2004), a moisture content of 34.8% for the compost product (White et al. 1995), and mass percentages of N, P and K nutrients of 2%, 0.3% and 0.8% respectively (Craig Cogger, 2002), the effectiveness of the compost product can be compared to a typical fertiliser. Fertilisers are usually characterized by means of their "NPK number", which denotes their nitrogen (as N), phosporus (as P_2O_5) and potassium (as K_2O) content. For instance, taking into account the atomic weight of the three elements, a (17-17-17) fertilizer contains 17% N, 7.4% P and 14.1% K.

On the basis of the above numbers, it is calculated that one ton of wet yard waste would yield a fertilizer with an 2-0.7-1 NPK number. This is 17 times less effective on a nutrient mass basis than a ton of (17-17-17) fertilizer. For the LCA, it is important to consider the fact that the use of the soil amendment replaces fertilizers. Therefore, the calculated mass of each nutrient in fertilizer that is avoided, because of the use of compost, is entered in the SimaPro analysis. Table 5 shows the avoided products for each element.

Table 5: Avoided products of the compost product of one ton of yard waste processed in the windrow composting facility.

Fertilizer effectiveness (avoided products) of windrow compost product	Amount (kg) per ton of feedstock
Fertilizer (N)	10.4
Fertilizer (P)	1.6
Fertilizer (K)	4.2

In a preliminary calculation by Favoino (Favoino, 2008), it was found that one ton of dry matter compost product would replace 19 kg N fertilizer and, of course, avoid the use of energy needed for the production of the fertilizer. Assuming a mass loss of 20% during the composting process, he found that 15.2 kg N fertilizer would be replaced by 1 ton of input feedstock. If he would have calculated this figure on a wet product basis with a 0.348 moisture content (White et al., 1995), the 15.2 kg N would be reduced to 9.9 kg N. This compares to the 10.4 kg N calculated in the model used for this study.

3.3.2: Aerated static piles: Gore-covers

The electricity used for air blowing in the piles and operation of the monitoring system in an aerated static pile has been reported to be 0.75 kWh/ton (Gore Visit, 2008). Additional energy is used for rolling stock, (optional) shredders, screens and biofilters; information about these specific processes is not found, but it is known that the total cost for fuels and supplies is $50,000 and for electricity $20,000. Electricity consumption is therefore estimated at about 3.3 kWh per ton (at $0.15 per kWh) and approximately $40,000 of fuel, corresponding to about 15 kWh/ton.

Hydrocarbon emissions from a Gore Cover operation were studied in 2007 by a German group of scientists (Schmidt et al., 2009) using flux chamber technology. Six samples were taken on different positions on the Gore Cover pile. The reported values were converted from lb/1,000ft^2 to kg/metric ton, on the basis of the total weight of green wastes in the aerated static pile. Measurements were carried out for two types of feedstocks: green waste and green waste mixed with biosolids. The results of the measurements were as follows: 1.74 kg/ton of hydrocarbons for the green waste feedstock and 0.81 kg/ton for the green waste/biosolids mix.

Since it is assumed that biosolids are also added to the mixture for the Gore composting process, the value of 0.81 kg/ton of hydrocarbon emissions was used for the LCA of the Gore-Tex.

The carbon dioxide emissions were assumed to be the same as in the windrow composting scenario (350 kg), since the degradation process is the same and CO_2 can pass through the membrane Gore covers.

The ammonia emitted in the Gore Cover process is much lower than in windrow composting: Only 0.82 kg per ton are emitted, according to air emission studies at three different sites in the US (Gore summary of emission control data, 2009), as compared to 2.50 kg for windrow composting (Komilis and Ham, 2004). VOC emissions according to the same study are 0.09 kg/ton. The estimated total air emissions from the Gore Cover operation are listed in Table 6.

Table 6: Overview of the air emissions from the Gore Cover composting method. The carbon dioxide emissions are set equal to the windrow composting method due to lack of data.

Emissions to air	Amount (kg)
VOC, volatile organic compounds	0.09
Ammonia	0.82
Carbon dioxide, biogenic	350
Hydrocarbons, unspecified	0.8

Fertilizer yield

The total volume reduction during the Gore Cover process is about 35%. Since the feedstock has a higher nutrient content due to the food waste present (R. Zhang, 2006), the compost product has a higher fertilizer value than that from windrow composting. For 100% food waste, if all nitrogen, potassium and phosphorus in the feedstock are assumed to remain in the compost product, the avoided fertilizer for each element (NPK) 9.1, 1.5 and 3.0 kg per ton of wet feedstock input of the Gore Cover facility. Table 7 shows how the fraction of food wastes in the feedstock affects the elemental fertilizers replaced by the final compost product.

Table 7: Replaced elemental fertilizer per ton of wet feedstock going into the ASP Gore cover facility for three different fractions of food waste in the yard waste mix. Yard waste is assumed to have 20% mass loss and 60% moisture content of the compost product and food waste is assumed to have 20% mass loss and 70% moisture content of the compost product.

Fertilizer effectiveness	0% FW	20% FW	50% FW
kg N	6.4	7.49	9.13
kg P	0.96	1.16	1.46
kg K	2.56	2.72	2.97

3.3.3: In-vessel aerobic composting in a rotary drum

This method was assessed in an LCA study by Cabaraban et al. (Cabaraban, 2007). It was estimated that 0.86 tons $CO_{2,eq}$ were emitted per metric ton of feedstock, as compared to 1.54 tons CO_{2eq} for a bioreactor landfill.

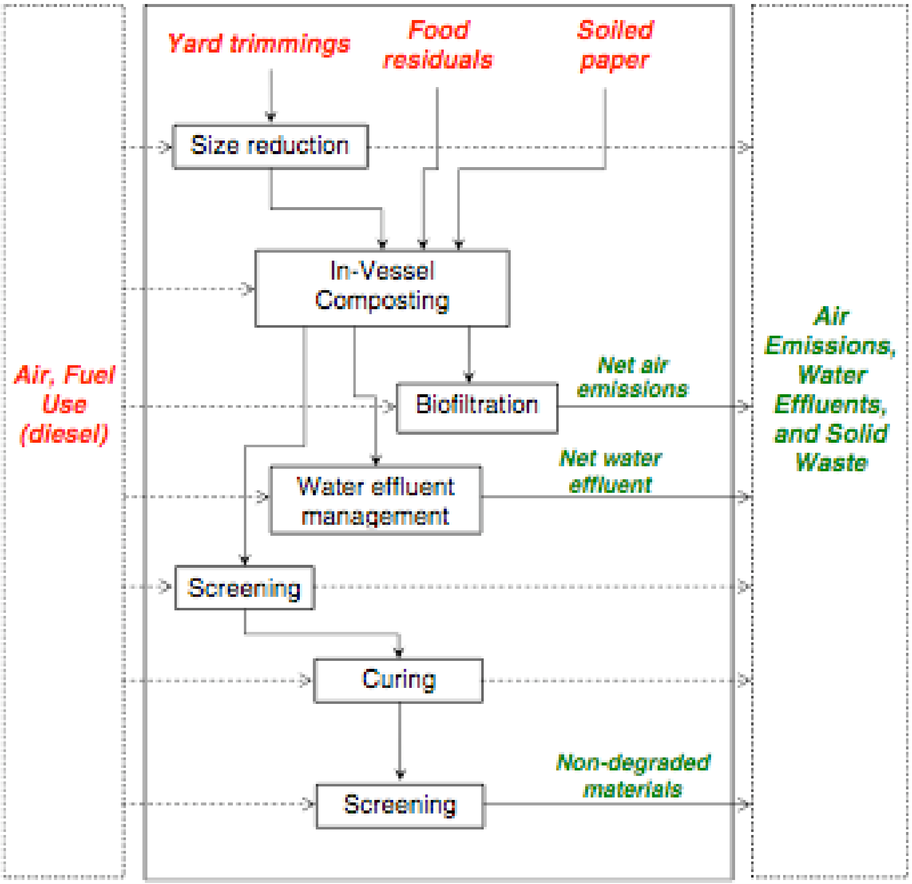


Figure 6: Schematic overview of the LCA process of in-vessel aerobic composting. Resources used and emissions are displayed with dotted arrows (Cabaraban, 2007).

The flow diagram of in-vessel composting (Figure 6) shows that in addition to yard wastes, soiled paper and food residuals can be processed by this method. However, the authors did not mention the composition of the feedstock in terms of mass percentages. The emission of CO_2 equivalents during the in-vessel composting was 0.36 tons per metric ton of waste processed. This is similar to the 0.35 tons of biogenic CO_2 released during the windrow composting process. For the entire process of in-vessel composting and the subsequent step of curing, 1.2 tons of CO_2 equivalents were emitted per metric ton of feed. Energy requirements were reported to be 55 kWh per ton of waste. Since no outline of the specific energy uses was given, it was assumed to be all provided by the electricity grid.

Other emissions from the in-vessel composting procedure are shown in Table 8.

Table 8: Emissions for rotary drum system per impact category and unit equivalents (Cabaraban, 2007)

Effect	per ton of feedstock	Unit equivalent
Global Warming Potential	360	kg CO_2
Acidification Potential	0.26	kg SO_2
Eutrophication Potential	0.045	kg N
Aquatic ecotoxicity	$5.9*10^{-4}$	kg Zn
Human toxicity (air)	$4.5*10^{-4}$	kg Pb
Human toxicity (water)	$3.7*10^{-3}$	kg Pb
Final solids	$4.2*10^{-3}$	m^3

Replaced fertilizer

With regard to the fertilizer value of the in-vessel process, tests in a laboratory rotary drum at the Indian Institute of Technology (Kalamdhad, 2009) showed that the mass fractions of elemental N, P and K in the compost product were 2.08, 0.462, and 0.736 percent, respectively. Assuming a mass loss of 20%, as in the case of windrow composting, this results in the values of Table 9.

Table 9: Avoided fertilizer products by the replacement with compost product from aerated rotary drum composting per ton of feedstock (Adapted from Kalamdhad, 2009)

Fertilizer effectiveness (avoided products) of windrow compost product	Amount (kg) per ton of feedstock
Fertilizer (N)	16.6
Fertilizer (P)	3.7
Fertilizer (K)	5.9

3.3.4: Use of Yard Wastes as Alternative Daily Cover

This method was assessed by looking at the differences between the use of a conventional daily cover (soil) and the use of yard wastes on a landfill. The major factors of resource and energy use are included in this study by using an air emission model, estimates for soil excavation and avoided fossil fuel burning.

Air emissions and landfill gas collection

The biogas generated in modern landfills is captured and can be used in a gas engine or turbine to generate electricity. The yard waste that is used as ADC in a landfill also decays partially and generates biogas. In order to determine the fraction of the yield of methane that can be expected from the yard waste, a decay model was used. This model, developed by Prof. M. Barlaz, calculates the fraction of methane generated, collected and emitted. The model considers three constituents of yard waste: grass (40%), leaves (40%) and branches (20%). All were assumed to contain 50% moisture. The decay function is expressed as follows:

$$\text{rate of decay} = w\,L\,k\,e^{-kt} \qquad (5)$$

where w is the weight of dry material, L is the CH_4 potential in liters/kg of dry material, and k the first order rate coefficient of the decay reaction.

The modeled landfill in this study is assumed to have a landfill gas collection system installed on average two years after MSW is deposited and covered with yard waste. Eight layers are deposited after the final cover is placed and the gas collection system is installed. The landfill cells are filled evenly with 1,500 tons/day, over an area of 47 acres. With a total capacity of roughly 6 million cubic yards it takes approximately 4 years to fill up. The collection of landfill gas in this time period is incrementally increased over time: During the first two years, gases (methane and carbon dioxide) generated by the decay process are emitted. Then, in the third year, a quarter of the gases are collected while the remainder is still emitted. In the fourth year, collection efficiency is 50%. After the fourth year, 75% is collected and this remains so until the end of the modeled time frame (20 years). This system of phased collection is the current practice of landfills in the United States (Barlaz et al., 2009). Especially because most of the methane is generated in the first years of the degradation process, it is important to take this into account.

This was not done in a study by the research group of Los Angeles County Sanitation District (LACSD, 2008). They assumed a collection efficiency of 91% for the LFG collection system. According to the yard waste memo by Dr. M. Barlaz (Barlaz, 2008), 9% of all the methane is generated already in the first 6 months of degradation, this means that the estimate of 91% can only be valid if the collection system is installed before the first six months of landfilling and that the LFG collection system will be 100% efficient after this period.

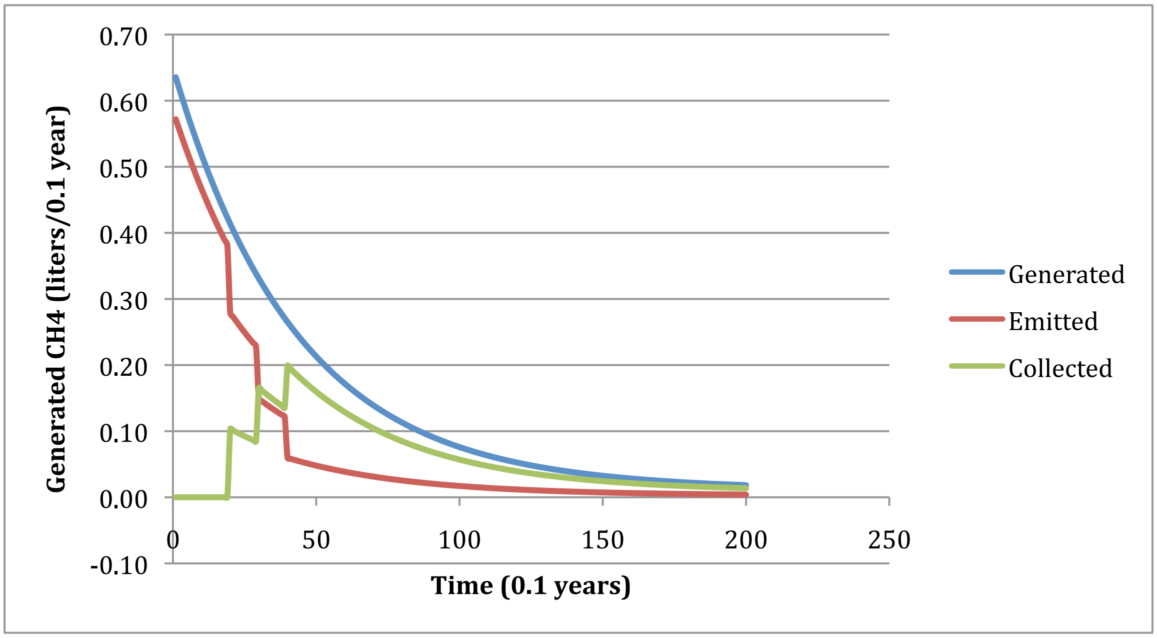


Figure 7: Proportion of landfill gas emitted and collected over a time period of 20 years (using LFG generation model of Prof. Barlaz)

The Barlaz model (Figure 7) indicates that, per metric ton of yard waste, 15.9 standard cubic meters of methane are released into the air and 12.1 are collected, over 200 years. A small fraction (10%) of the generated methane is oxidized in the process. The collected gas corresponds to 458 MJ of thermal energy in the form of natural gas.

According to the Barlaz' yard waste model (Barlaz, 2008), 54.5 kg of CO_2 are emitted per metric ton of yard waste deposited as ADC. Part of the carbon content of the yard waste is sequestered in the landfill. Especially branches are slowly biodegradable because of their high lignin content. This benefit is accounted for by not including any emissions on this part of the total carbon content in the model.

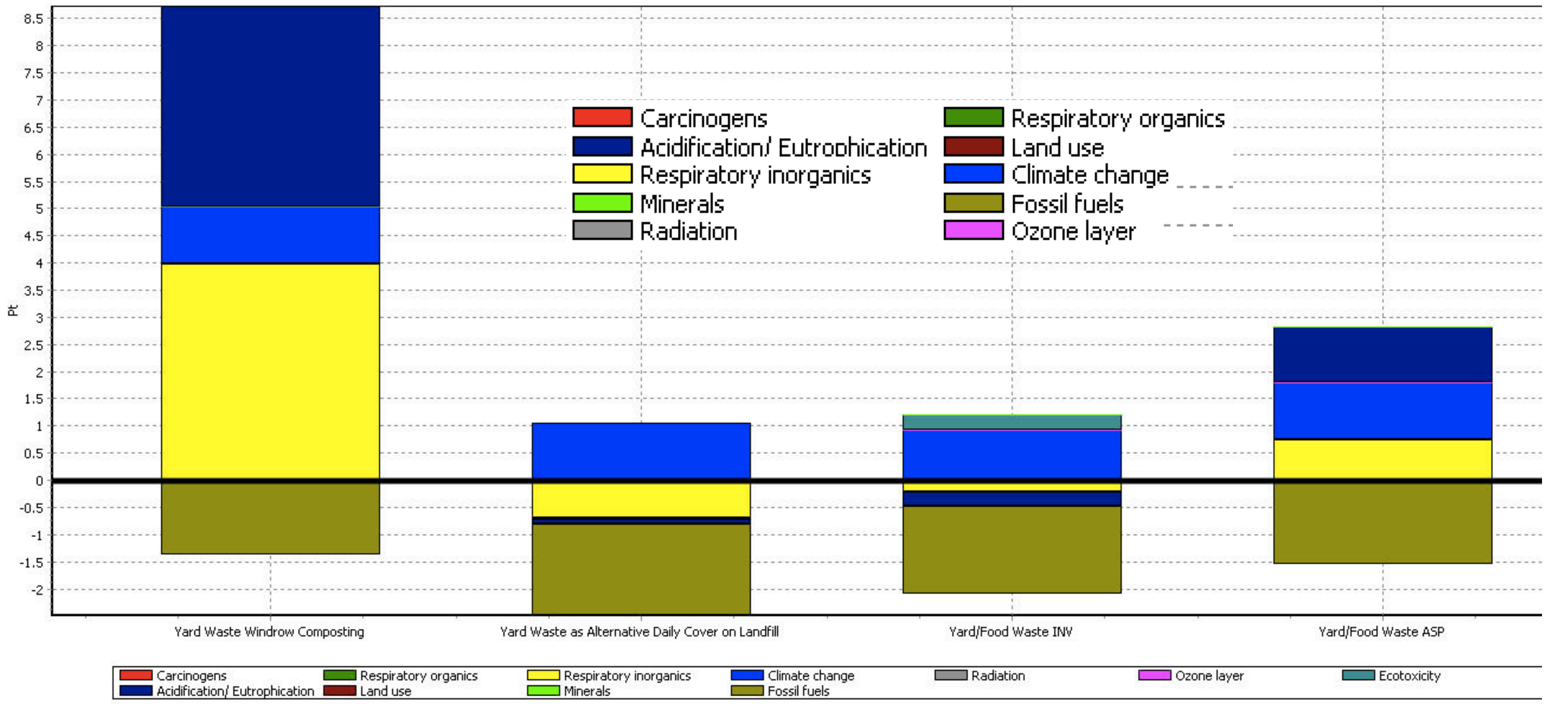
Avoided soil excavation

When yard wastes are used as a daily cover instead of soil, the excavation of soil is avoided. The required thickness of the daily cover is 15 cm (6-inch) for soil and 22.5 cm (9-inch) for Source Separated Yard Waste (SSYW)(Barlaz, 2008). Because of the large difference in bulk density of soil and SSYW, the use of SSYW represents a considerable saving in energy and labor. With a yard waste and soil density of 200 kg/m^3(Theodore, 2008) and 1600 kg/m^3(V. Blouin, 2004), respectively, 3.3 m^3 of soil are avoided for each metric ton of yard waste used as ADC. In terms of tonnages in the landfill, this would mean that the mass ratio of cover to MSW is reduced from 1:4.5. for soil, to about 1:27 for yard waste. These ratios are derived by assuming a covered MSW layer of 3 meters with a 9:1 MSW to soil volume ratio (Barlaz, 2009)

3.4: Results

All the inventories of emissions and energy uses discussed above were included in the life-cycle analysis. The result is an impact assessment of windrow composting, the Gore-cover technology, in-vessel composting and the use of yard waste as ADC which is shown in figure 8 below. SimaPro converted the emissions and energy uses to environmental impact categories and the different methods can be compared in this way. The y-axis of the figure is expressed in terms of Ecopoints, a means of measuring different kinds of environmental impacts. One Ecopoint is defined as the total environmental burden ("damage") caused of an average European citizen over the course of one year. The thick black horizontal line is the zero-line, which denotes what effects are beneficial for the environment (below the zero-line) and what are the damages to the environment (above the zero-line).

Figure 8 presents in graphical form the results of the Life Cycle Analysis using the SimaPro program.



Comparing 1E3 kg 'Yard Waste Windrow Composting', 1E3 kg 'Yard Waste as Alternative Daily Cover on Landfill', 1E3 kg 'Yard/Food Waste INV' and 1E3 kg 'Yard/Food Waste ASP'; Method: Eco-indicator 99 (E) V2.05 / Europe EI 99 E/E / single score

Figure 8: Results of the LCA on the windrow composting, ADC, in-vessel and Gore-cover composting scenario. The bars represent different environmental impacts, denoted in the legend. The thick black line is the zero line: anything above it is an environmental impact and bars below it are beneficial for the environment.

The Windrow composting method is shown to have the worst effect on the environment:

- 2.5 kg/ton of ammonia emissions contribute to both the acidification/eutrophication and respiratory inorganics categories;

- The biogenic carbon dioxide produced by the biodegradation is the biggest contributor to climate change.

Using yard waste as an alternative daily cover has the lowest overall environmental impact of all four methods. It is shown that methane emission is the main contributor to negative impact on the environment. It is due to the part of LFG that is released primarily in the first months after the yard waste ADC is deposited on the landfill. The largest positive contribution of this process is due to the methane gas that is collected by the LFG collection system.

The in-vessel aerobic composting scenario derives its beneficial score mainly from the avoided product of fertilizer. The relatively large amount of energy used in this process gives the in-vessel technology its largest positive impact on the environment in the form of climate change.

As can be seen in Figure 8, the Gore Cover composting scenario (ASP) has similar climate change impacts and fossil fuel use benefits compared to the windrow composting scenario. The big difference between these two methods is due to the ability of ASP to reduce ammonia emissions, which lead to both impacts in the eutrophication and respiratory inorganics categories.

Table 10 shows the individual scores of each process and the list of contributions to the total scores by each single process. It can be seen that ammonia (2.5 kg air emissions) is the biggest contributor to both the windrow composting scenario and the Gore cover method.

Table 10: Process contributions to environmental impact scores of all methods analyzed. The total scores are in the top row. The Gore covered method is denoted as ASP, Aerated Static Pile.

Substance	Compartment	Unit	Yard Waste Windrow Composting	Yard Waste as Alternative Daily Cover on Landfill	Yard/Food Waste INV	Yard/Food Waste ASP
Total		Pt	7.36	-1.43	-0.89	1.28
Remaining substances		Pt	0.01	0.77	0.60	0.02
Ammonia	Air	Pt	7.70	0.00	-0.35	2.40
Carbon dioxide, biogenic	Air	Pt	1.43	0.22	1.47	1.43
Oil, crude, 42 MJ per kg, in g	Raw	Pt	0.20	-0.02	0.07	x
Coal, 26.4 MJ per kg, in grou	Raw	Pt	0.14	-0.01	0.90	x
Gas, natural, 46.8 MJ per kg	Raw	Pt	0.07	-1.55	0.35	x
Carbon dioxide, fossil	Air	Pt	0.07	-0.11	0.16	x
Sulfur oxides	Air	Pt	0.06	-0.45	0.35	x
Carbon monoxide	Air	Pt	0.02	0.00	0.00	0.00
Particulates, < 10 um	Air	Pt	0.02	-0.01	0.05	x
Particulates, unspecified	Air	Pt	0.01	0.00	0.07	0.00
Energy, from coal, brown	Raw	Pt	-0.01	x	-0.02	-0.01
Nitrogen oxides	Air	Pt	-0.01	-0.26	-0.51	-0.43
Methane	Air	Pt	-0.01	-0.01	-0.02	-0.01
Particulates	Air	Pt	-0.04	x	-0.13	-0.07
Sulfur dioxide	Air	Pt	-0.10	0.00	-0.26	-0.12
Carbon dioxide	Air	Pt	-0.16	x	-0.26	-0.14
Energy, from coal	Raw	Pt	-0.19	x	-0.31	-0.17
Dinitrogen monoxide	Air	Pt	-0.27	0.00	-0.43	-0.24
Energy, from oil	Raw	Pt	-0.28	x	-0.49	-0.24
Energy, from gas, natural	Raw	Pt	-1.30	x	-2.12	-1.13

An overview of the contributions of the different impact categories is shown below (Table 11). The net total scores are shown in the top row.

Table 11: impact categories contribution to total score in the LCA.

Impact category	Unit	Yard Waste Windrow Composting	Yard Waste as Alternative Daily Cover on Landfill	Yard/Food Waste INV	Yard/Food Waste ASP
Total	Pt	7.36	-1.43	-0.89	1.28
Carcinogens	Pt	0.00	-0.04	0.01	0.00
Respiratory organics	Pt	0.00	0.00	0.00	0.02
Respiratory inorganics	Pt	3.97	-0.67	-0.21	0.74
Climate change	Pt	1.06	1.06	0.91	1.04
Radiation	Pt	0.00	0.00	0.00	0.00
Ozone layer	Pt	0.00	0.00	0.00	0.00
Ecotoxicity	Pt	0.00	0.00	0.29	0.00
Acidification/ Eutrophication	Pt	3.69	-0.10	-0.26	1.03
Land use	Pt	0.00	0.00	0.00	0.00
Minerals	Pt	0.00	0.00	0.00	0.00
Fossil fuels	Pt	-1.37	-1.67	-1.63	-1.55

3.5: Results of LCA study

On the basis of the LCA study, the use of yard waste as an alternative daily cover (ADC) is concluded to be the best way to process yard wastes. It is preferred over windrow composting because it has no negative effect from ammonia emissions and the GHG emissions are small, in comparison to the CO_2-emissions of the windrow. The ADC process has two other benefits: a) methane is recovered in the process, and b) it avoids the excavation of heavy soil for use as daily cover.. The corresponding avoided fossil fuel, for digging up and moving the soil, is similar to the energy savings by avoiding the manufacturing of the fertilizer replaced by the in-vessel composting of one ton of yard and food wastes.

An important distinction should be made between the methods that can process different feedstocks. If source-separation is done in a way that yard waste and food waste are collected separately, then disposal of the yard waste in a landfill as ADC and disposal of the food waste in an in-vessel aerobic composting facility would be the best options. However, if they are collected together, windrow composting and ADC cannot be applied due to odors. In that case, in-vessel composting or the Gore Cover composting method should be applied, depending on the respective emissions in a particular case.

3.6: Discussion of LCA Results

The factor of transport of feedstock is not accounted for in this study. Some technologies allow facilities to be located near municipalities where the waste is generated. This gives them an advantage over facilities that cannot be located near the point of generation because of the emissions that are associated with transport. However, preliminary calculations showed that transport is a minor contributor to the overall impact assessment: the biogenic emissions from biodegradation, for instance, are far larger than the emissions related to the transport of the waste with trucks.

Also, in this study it was assumed that the yard waste in the ADC scenario would replace a layer of soil. However, in some U.S. landfills tarpaulins or other types of ADC are used instead of soil. LCA comparison with such covers was beyond the scope of this study.

CHAPTER 4: Cost Study

In addition to comparing the environmental impact of the four methods of organic waste processing, it is essential to also put these methods side by side in terms of capital and operating costs. The final unit of comparison that is calculated for each technology is $/metric ton of feedstock. This number includes repayment of the capital cost of the plant (annualized over 15 years at an assumed 6% interest rate) and operation and maintenance (O&M) costs.

The cost per ton of feedstock for a site usually decreases as the annual throughput of the facility increases. Therefore, in order to make a fair comparison, a fixed throughput for all plants was chosen of 40,000 tons/year. This is a common figure for industrial scale composting plants.

In the following sections, each method is analyzed separately. As will become apparent, some methods require a larger initial investment than others. The extra cost for systems often translates into higher controllability of odors and better throughput per area. This extra investment can therefore be interesting in the case of a composting plant near municipalities where odors must be limited and where land is expensive.

Costs are divided into initial investment and O&M and costs. Because of the lack of data, assumptions are made about cost categories using data available from other systems. Also, it is important to note that initial investment costs have been annualized assuming a 15-year lifetime of the system and a 6% interest rate. The costs of the land are included in the operation and maintenance costs under the category 'Site Lease'. The final results of the calculations were then compared with sources found in composting reports and surveys.

The revenue from end products of composting are not taken into account in this study, since the quality of the products of various composting technologies differ widely from location to location, as do the prices for which the end products are sold. Sometimes quantities are given away for nothing (Nantucket Visit 2008, Appendix B), or it is sold for prices ranging from $10/ton (Clemson University, 2009) to $31 per ton (Cedar Grove composting, 2009).

4.1: Windrow Composting

Turned windrow composting is common practice in industrial scale composting plants. However, some plants are more sophisticated than others and therefore investment costs range considerably. For instance, preparation of the site that includes paving is a significant part of the total investment but it is not a necessity for a composting plant. Komilis and Ham reported costs for a 100 ton/day composting plant that was equipped with a leachate collection system where the site was paved for $180,000 per hectare. About 5.5 hectares were used for the plant so the total paving job was $1,000,000, amounting to a third of the total cost. Of course, such an investment contributes to a lower environmental impact of the system. Fortunately, the same study was used as a source of data for the LCA study, so the costs are in line with the environmental impact. Table 12 shows the different cost categories adapted to a 110 ton/day facility (or approximately 40,000 tons per year).

Table 12: Breakdown of costs for the windrow composting method for a 110 ton/day facility (Komilis and Ham, 2004)

Capital Cost category	Cost
Paving	$1,100,000
Grading	$82,500
Fencing	$22,000
Building	$550,000
Leachate system	$110,000
Engineering cost	$550,000
Tub Grinder	$275,000
Windrow turner	$220,000
Legal	$165,000
Screens	$220,000
Front end loader	$198,000
Total	**$3,492,500**

The total cost for a 40,000 ton/year plant was then annualized assuming a 15 year lifetime and 6% interest of repayment. This resulted in a total cash flow of $5,635,000. In order to calculate the dollars per ton, this amount was divided by the total tonnage processed in the plant's lifetime, resulting to about 9 $/ton. Note that this does not include the cost for land property, which is included in the O&M costs discussed below.

Operation and maintenance for a 40,000 ton/year windrow composting add up to about $473,000 annually, or 12 $/ton. Labor (including overhead) and site lease are the biggest contributors to the operation costs with amounts of $264,000 and $110,000, respectively. Table 13 shows the O&M costs of such a facility.

Table 13: Operation and Maintenance costs for a 40,000 tons/year windrow composting plant

O&M Cost category	Cost
Labor	$187,000
Overhead	$77,000
Windrow turner	$27,500
Tub grinder	$55,000
Screens	$5,500
Front end loader	$5,500
Building	$5,500
Site lease	$110,000
Total	**$473,000**

The range of costs in windrow composting was studied by Steuteville and reported in the magazine BioCycle in 1995. Although the data is outdated, it shows the difference in costs per ton due to extra steps in the process (shredding and screening). Displayed below is a table with the results of his survey. The total cost per ton in our analysis amounts to 21 $/ton, which is in line with the values for facilities equipped with screening and shredding in Steuteville.

Table 14: Results of a cost survey done on composting plants in BioCycle magazine (Steuteville, 1995)

Facility	**Throughput (tons/yr)**	**Operating ($/ton)**	**Capital ($/ton)**	**Total ($/ton)**	**Description**
Atlantic Co., NJ	22,000	11.8	10.2	22	Materials shredded and screened
Bozeman, MT	2,000	6.5	1.5	8	No shredding or screening
Bluestem SWA, IA	70,000	7	4.2	11.2	All materials shredded and screened
Des Moines, IA	23,500	n/a	n/a	20-25	All materials shredded, most screened
Lehigh County, PA	17,000	8.1	10.4	18.5	Only brush shredded, most screened
St. Petersburg, FL	16,600	n/a	n/a	25.6	Composted mulch
Three Rivers, MI	2,700	n/a	n/a	17.2	Materials shredded, not screened.

4.2: Aerated static pile (Gore Cover)

Cost information about the aerated static pile method was provided by the Gore company itself. It is a standard cost outline that Gore project managers use to estimate the financial forecast of the project. Of course, the total costs are very much dependent on the context of each particular case: Is the site expensive? Does it need preparation before it can be used as a composting site?

The outline was created for a 40,000 tons/year project (16 covered aerated static piles), Table 15:

Table 15: Capital costs outline for a 40,000 ton/year Gore Cover composting plant

Capital Cost Category	Cost
General	$150,000
Site Work	$150,000
Paving	$1,000,000
Concrete	$600,000
Buildings	$500,000
Leachate System	$100,000
Storm Water System	$300,000
Electrical Equipment	$400,000
Equipment	$1,500,000
Engineering	$200,000
Legal	$200,000
Gore Cover System	$2,250,000
Total	**$7,350,000**

According to Gore-Tex, this cost model is typical for a site with ideal site conditions, so that no extra preparation, in terms of grading, is needed before the construction starts. The Gore Cover system is the largest category in the capital costs. This includes the rolling system and Gore cover sheets. One cover costs about $75,000. From an aerial photograph of the Cedar Grove composting site (Figure 9) it can be seen that approximately two thirds of the windrows are covered (Cedar Grove, 2009). The rest is in the curing stage and are uncovered.

Figure 9: Aerial view of the Gore covered composting site in Cedar Grove, Seattle.

With 16 windrows, an estimated 12 windrows are covered, which costs $900,000. This is a little less than half of the cost for all Gore components. After annualizing the total cost and assuming a 15 year lifetime and payback period at 6% interest, the calculated cost per ton is $20/ton.

Operation and maintenance costs are also provided by Gore in the same cost model for a 40,000 tons per year facility (Table 16).

Table 16: Annual operation and maintenance costs for a 40,000 tons/year Gore composting plant

O&M Cost category	Cost
General & Administration	$75,000
Insurance	$50,000
Fuel/ Supplies	$50,000
Contracted Services	$10,000
Payroll	$250,000
Repairs and Maintenance	$100,000
Electricity	$20,000
Accounting and Legal	$25,000
Residual Disposal	$20,000
Host Benefits	$35,000
Site Lease	$100,000
Gore Replacement Cost (2 covers/year)	$150,000
Total	**$885,000**

It can be seen that the payroll for workers is the largest item in the O&M costs. It is nearly the same as the $264,000 of payroll in the windrow composting scenario. Electricity amounts to $0.5/ton, i.e. about 3.5 kWh/ton, assuming a $0.14/kWh electricity price. According to the Gore Visit notes (Gore Visit notes, 2008), the energy needed for the blowers, computers and probes amounts to 0.75 kWh/ton (Gore trip notes, 2008). Electricity and fuel are also used for the rolling stock, grinders, screens and biofilters.

A study done by Gore (Gore Associates, 2008) has shown that Gore Cover composting sites have a shorter residence time and up to 4 times higher throughput (in the composting area) than at conventional windrow composting sites. Therefore, the Gore site requires a smaller composting area for the same throughput. However, because the Gore site can be located closer to municipalities where the land is more expensive, it is assumed that the overall cost of the land is the same as for windrow composting.

Gore incorporated the cost of replacing the covers in the model. Replacing two covers per year would amount to $150,000 dollars. With 16 windrows and three quarters of them covered at a particular time, this would mean that the covers are expected to last for roughly 6 years.

The total O&M costs are $885,000 per year, or $22/ton. Adding the cost of capital ($20/ton), results in $42/ton total. This is in line with correspondence with Brian Fuchs of Gore Tex, who stated that the costs of Gore composting are $40 ± $10, with the error increment depending on the size of the plant. Small plants can go up to $50/ton and large ones to $30/ton (Brian Fuchs, 2009). The Gore plant at Cedar Grove reported a tipping fee of $42/ton (Gore trip notes, 2008). This is for a 160,000 tons/year plant and includes profits.

4.3: In-vessel aerobic composting with a rotary drum

In-vessel rotary drum composting is very capital intensive. Unlike the other composting methods, it involves a lot of heavy machinery. Also, turning, loading and unloading of the rotary drums is very labor and energy intensive (55 kWh of energy, as stated earlier). In return for this high cost, this system has a lower land area requirement and offers high process control.

Capital costs for this method (Table 17) are estimated by using cost data for a 40,000 ton/year plant. In addition to the rotating drum cost, there are other costs similar to those encountered in windrow composting and aerated static pile. Table 17 shows all the capital costs.

Table 17: Capital costs for a 40,000 tons/year in-vessel rotary drum plant.

Capital cost category	Cost
Rotating Drums (18)	$4,500,000
Front End Loader	$315,000
Surface Concrete and Asphalt	$307,000
Leaf Shredder	$200,000
Buildings	$500,000
Engineering	$200,000
Legal	$200,000
Total	**$6,272,000**

The capital cost of the rotating drums was scaled up from a 2,200 ton/year cost model, which was stated to be $250,000 for a 6 tons/day plant. Thus, 18 rotating drum reactors are needed for a 40,000 ton/year composting plant. The front end loader category was not scaled up with the same factor, because it is not constantly used like the rotating drums. Instead, a factor 3 was used. Likewise, a factor 4 was used for the leaf shredders. The same was done with the surface concrete and asphalt: a factor 5 was applied, assuming that approximately 1/3 of the asphalted area needed was used for the actual device and that 2/3 of the area is offices and other ‘common’ equipment.

The capital cost per ton, assuming a 15-year lifetime period at 6% interest, amounts to $17/ton. Other sources report capital costs of in-situ vessels to be between 3.3 and 8.25 million dollars, i.e. about 8 to $21/ton.

A breakdown of in-vessel operation and maintenance costs could not be found in the literature. However, an EPA report (EPA [3], 2009) provided the operation and maintenance costs per dry ton of handled waste in in-vessel composting. It stated that O&M costs vary widely because of the different technologies and throughputs of plants. A 1989 survey (Alpert et al., 1989) found operation and maintenance costs between $61 and $534 per dry ton, which is 31 to $267/wet ton, assuming a 50% moisture content. A more recent study found composting cost of $100 to 280/dry ton ($50 to $140/wet ton) with in-vessel composting on the high end of this range (o'Dette, 1996) (EPA, 2000 [1]). Another source estimated the cost to range from $188 to 250/dry ton (Shammas, 2007). Again, with a 50% moisture level, this is approximately 94 to over $125/wet ton, which is the desired unit in this study. Averaged out, O&M costs of about 130 dollars were assumed.

According to the EPA, the following items are to be taken into account in estimating costs for a specific in-vessel compost plant:

- Land acquisition.
- Equipment procurement, including the composting vessel, loading equipment, conveyors, air supply equipment, temperature monitoring equipment, and odor control equipment.
- Operation and maintenance labor.
- Additives, such as bulking agents, to be used in the specific vessel selected.
- Energy (electricity and fuel for equipment).
- Water and wastewater treatment.
- Equipment maintenance and upkeep.
- Product distribution expenses and marketing revenues.
- Regulatory compliance expenses such as permitting, product analysis, process monitoring, record keeping and reporting;
- Preprocessing equipment. (EPA, 2000 [2])

Adding up the above numbers results in an estimate of total capital and O&M costs of about $150/ton for a 40,000 ton/year operation.

4.4: Use of yard waste as an alternative daily cover on a landfill

For the ADC-scenario, there is no need to have a plant built to process the waste. The method replaces the use of soil in a landfill with waste. For the landfill owner, this means that there is no need to dig up as much soil, plus there is more landfill space to use in an existing landfill. Two separate streams of waste go into the landfill, municipal solid waste (MSW) and source-separated yard waste (ADC). These materials are charged different tipping fees. For example, a landfill in Azusa, California, charges $14 per ton for incoming yard waste that is used as ADC (Azusa, 2009). In comparison, the median MSW tipping fee in the year 2000 in California was $34 per ton (CIWMB, 2000).

With regard to the total cost of ADC scenario, it depends from what perspective costs are evaluated. If the company owns a landfill, then a decision to use yard waste as ADC can save in capital and operating costs for heavy machinery. Less soil excavators and dump trucks will be needed and the front end loaders and landfill crawlers used to spread out the daily cover will keep their function but they will be spreading out a different material. Typical prices of soil excavators and dump trucks are $250,000 (Caterpillar 345 cl excavator) and $100,000 (Caterpillar 740 Articulated Dump truck) (ironplanet.com, 2009). According to EMCON, the cost to import and place soil on a landfill is about $2 per cubic yard (EMCON, 1997). Assuming a 1-million cubic yard landfill, approximately $500,000 would be spent on depositing soil. Shredding of MSW typically costs $8 per ton, with approximately $4 per ton for both O&M and capital costs (Fitzgerald, 2009).

The value of space in a landfill is also important in considering the difference between using soil and ADC. With a $30/ton tipping fee for MSW at a 1 million cubic yard landfill, the value of the space saved by using ADC is approximately $3,000,000 (assuming refuse to soil ratio increase from 4:1 to 9:1) (Haughey, 2001). In addition, the landfill owner can charge a tipping fee for the incoming yard waste, as in the case of the Azuza landfill mentioned earlier.

If the landfill is not owned by the waste managing company, the yard waste can be brought to the closest landfill. A tipping fee of $14 per ton is assumed for the costs (like the Azusa, CA landfill), without including transport costs.

For the overall comparison, it is assumed that the landfill is not owned by the organic waste managing company and that the cost is therefore equal to $14 per ton.

4.5: Results

The capital costs and O&M costs of the four the organic waste processing methods are shown in Table 18 below.

Table 18: Capital and Operation and Maintenance (O&M) costs per ton of handled waste for four different methods.

Cost per ton of input feedstock ($)	Windrow composting	Aerated static pile (Gore technology)	In-vessel aerobic composting	Alternative Daily Cover on landfill
Capital Cost	9	20	17	-
O&M Cost	12	22	130	14 (tipping fee)
Total Cost per ton	21	42	147	14

The capital costs for the Gore technology are higher compared to the in-vessel composting technology. This is because the Gore technology needs more paving and concrete compared to the in-vessel technology because the residence time is longer. Also, the equipment costs for Gore are higher than those for the rotary drum.

The ADC method has the lowest cost of all four methods, at 14 $/ton. This figure is just the tipping fee of a landfill. However, from the perspective of the landfill owner, the use of yard waste as daily cover will actually result in additional revenues, because of the increased refuse capacity and the lower use of soil, in combination with a tipping fee as an extra income.

The in-vessel aerobic composting scenario has operation and maintenance costs far exceeding any other method. This is probably due to high energy needs and high maintenance cost of the rotating drums.

With $21 and $42/ton, windrow composting and Gore-covered aerated static pile composting are in the mid-range of the four processes.

CHAPTER 5: Operation and output effects study

In addition to assessing the environmental impact and costs of the several organic waste processing methods, it is also important to rate these methods in terms of their usability and flexibility. For example, a method may be cost effective and have minimal environmental impact, but strong odor emissions can lead to problems with surrounding communities. A number of criteria have been selected in order to assess the most important of these issues. The list includes:

- Area needed
- Odor problems
- Input material flexibility (ability to handle difficult to compost materials)

It is critical to note that these criteria are very location specific. Some locations require strict odor control because municipalities are nearby. In the Multi-Criteria Analysis, weighting factors can be adjusted accordingly to assess these issues: one company might find odor problems for a specific site more important than the area needed for the composting operations.

5.1: Area needed

The area needed for composting operations can be divided in two parts: An area for administration/maintenance and another for the actual composting operations (tipping area, leachate collection system and the area needed for the windrows/composting systems). The first is not very much dependent on the size of the plant. In contrast, the latter is directly proportional to the throughput of the composting facility. Retention times affect the area needed and therefore a high degradation rate is desirable. For industrial scale plants, offices and administration only take up a small part of the total area needed. For example, in the Gore plant at Cedar Grove only an eighth of the total area is for administration and maintenance; the rest is mostly covered windrows and room for the trucks to load and unload.

Because of the shorter residence times required by the Gore Cover technology, the throughput of feedstock per square meter and unit time is much higher than in windrow composting (Figure 10).. At Marburg, Germany, the specific throughput was increased from 1.99 metric ton/m^2/year to 8.85 metric ton/m^2/year. (Gore Associates, 2008)

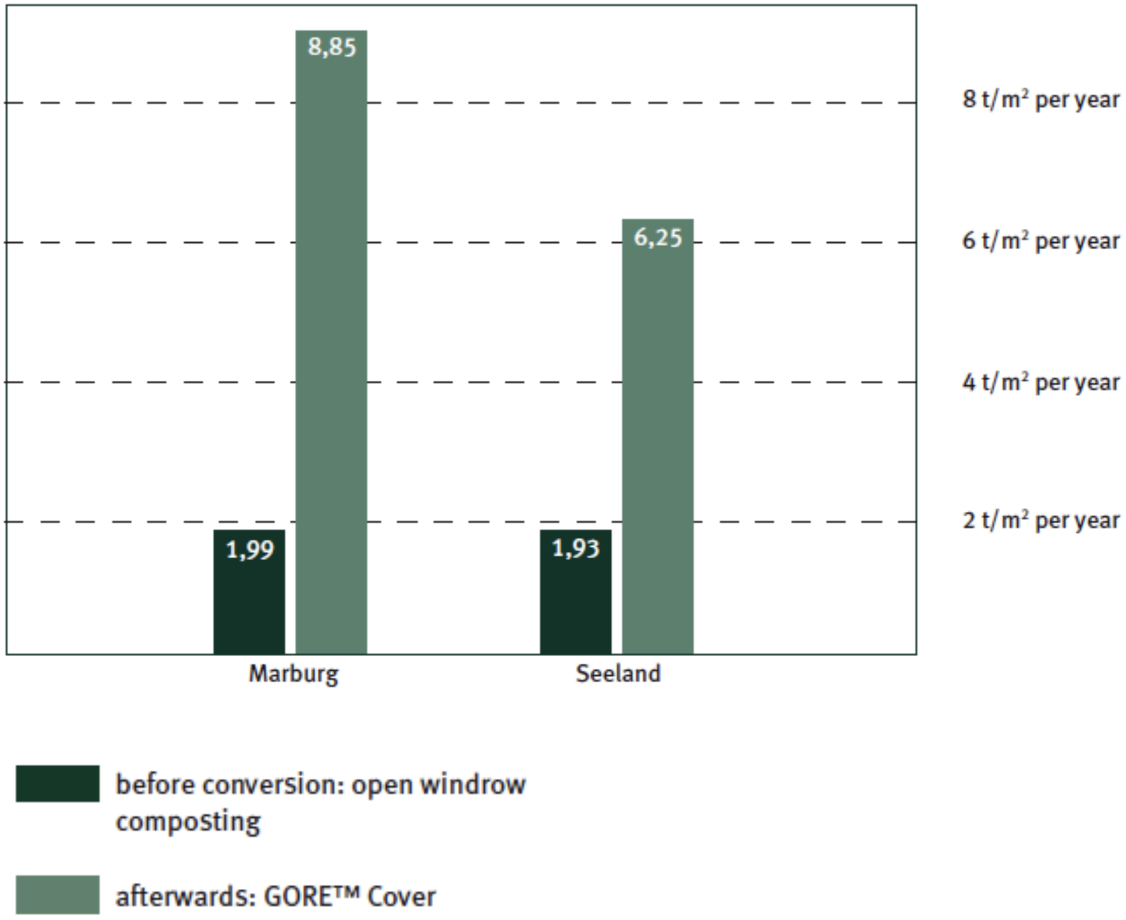


Figure 10: throughput per unit area of composting plants in Germany. After the plants were converted to the Gore system, their specific throughput was 3 to 4.5 times higher (Gore Associates, 2008).

The specific throughput, which depends on the bioconversion rate, is higher for the Gore Cover method because it provides oxygen at a higher rate to the waste, as compared to windrow turning. As stated in paragraph 2.2, approximately 5.8 Nm^3 of air is needed for the conversion of 1 kg of organic matter. Adequate provision of oxygen to the waste is therefore crucial to acquire high conversion rates. Windrow turning relies on both oxygen infiltration through pores in the pile and the filling of the pores with oxygen as the windrows are turned, both of which are less effective than the continuous forcing of air through the pile in the Gore Cover method. As was stated before, the retention times are 8 weeks for Gore and 24 weeks for the open windrow composting method. This is in line with the increase that is found for the specific throughput.

The rotary drum technology requires a small active composting area for the first stage of degradation in the rotary drums. It has a short residence time in the drums as was mentioned in paragraph 2.3 (1 to 6 days). However, the curing stage takes up to 3 months of time. According to the Clean Merseyside Centre in the United Kingdom, a 30,000-tons per year in-vessel composting plant requires about 8,700 m^2 of composting area (Merseyside Centre, 2005). This amounts to 3.4 tons/m^2 per year, primarily because of the large windrow area needed for the curing stage. In-vessel technologies can therefore be rated somewhere in between windrow and Gore covered composting with regard to land requirement.

5.2: Odor problems

Composting of organic waste often is paired with odors. Odors emitted from the waste processing can become problematic if the site is located near municipalities. Many large MSW composting facilities throughout the US have been shut down because of odors. This happened to facilities in Portland, Oregon, Dade County, Maryland and Pembroke Pines, Florida, mainly because they were not equipped with an odor control system (Epstein, 1996). Other plants had to modify their operations because of similar reasons.

A windrow composting plant in the Niagara district of the Province of Ontario has had to deal with these issues since 2002 (SUR Composting Report, 2008). A pledge to divert 60% of the MSW from landfills led to a decision to separate organic waste and to put it in bins. Two-thirds of the households purchased these bins and also started separating plastic, glass and paper. At the composting site, the source-separated organics were mixed with woodchips as a bulking agent and the mix was shredded. The diversion rates increased to 46% but by 2004 residents started complaining that odors from one of the two composting plants caused headaches, nausea and sore throats between May and August. The windrows were shut down and the municipality spent over 1.5 million dollars on a vapor extraction and treatment system and also introduced windrow size restrictions. However, odors still remained a turn-off for residents and public participation fell from 80% to 20%.

Generation of odors occurs mainly in the first stage of degradation because the decomposition rate is highest at that point. Also, the odor generation is very much dependent on the feedstock used. Rapidly decomposing biosolids generate more odors than clean yard trimmings, for instance. Odors also depend on the type of composting system, operation of facility. Indoor composting in an airtight building gives the possibility to pump the air through a biofilter before it is emitted to the atmosphere. At the Materials Recycling Facility (MRF) in Nantucket visited by the author, a company called Waste Options installed an ingenious odor control system. They pump the odorous air from the buildings through underground pipes to a 20,000 ft^2 building filled with a 3 feet high pile of woodchips. Under this layer of woodchips, there is base of porous gravel under which the pipes are located. The air seeps through holes in the pipes and then moves up through the layer of woodchips where it is filtered from odorous compounds. The system is very cost-efficient and effective in odor control (Nantucket Visit notes, 2009).

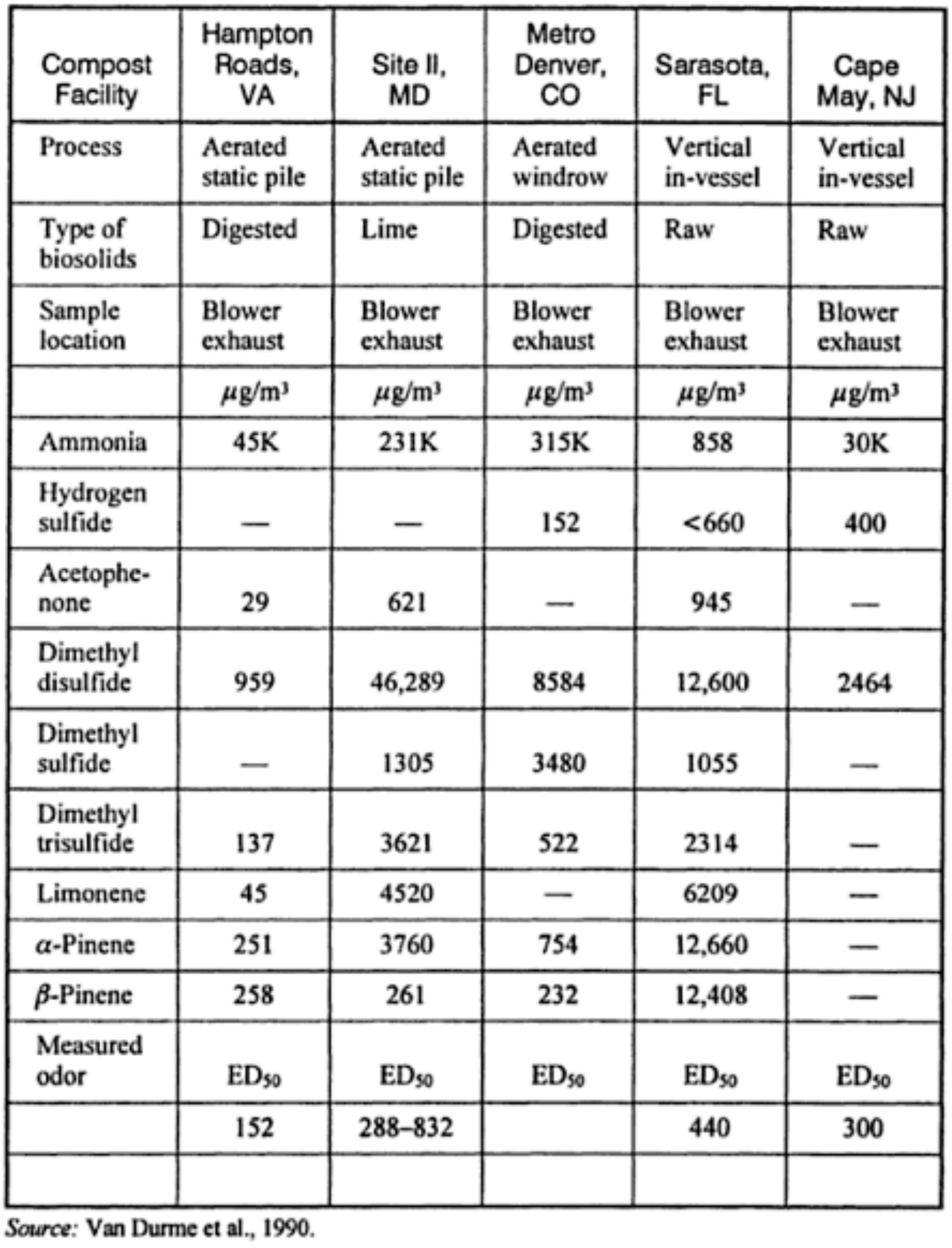
Of course, open windrow composting has more problems with odors than enclosed methods. Feedstocks with high odor generation are therefore not used in windrow composting. Several states in the US have put restrictions on building composting plants nearby municipalities and hospitals. In New York, for instance, a 500 feet buffer is required for MSW and biosolid composting plants and 200 feet for yard waste composting. Maine requires a buffer of 500 feet for any type of plant and New Jersey a minimum buffer distance of 150 feet for leaf composting sites. California set it at 300 feet for any composting plant (Epstein, 1996).

Odors are often expressed by a dilution-to-threshold ratio (D/T). The ED_{50} number is the number of dilutions required for 50% of a group of people to detect the odors. Common odorous compounds in composting are ammonia (NH_3), hydrogen sulfide (H_2S), dimethyl disulfide ($(CH_3)_2S_2$), dimethyl sulfide ($(CH_3)_2S$) and limonene ($C_{10}H_{16}$).

Temperatures and moisture in the pile also affect odor generation in composting. According to Epstein (Epstein, 1996), odor generation decreases as temperatures in the pile increase. This would infer that odors are higher in winter than in the summer, but this is not necessarily true: Van Durme (Van Durme, 1990) compared odors from a composting plant throughout the year and found that levels measured in June were higher than in October. The moisture content in the piles positively affect odor levels generated. Thus, controlling moisture in the piles makes it possible to optimize degradation and minimize odor problems.

Since so many parameters affect the odor generation in a plant, it is difficult to compare individual facilities.. Table 19 presents the results of a study by Van Durme (Van Durme, 1990) that measured concentration of several odorous compounds at different types of facilities. It can be seen that there is a wide range of Effective Dose (ED_{50}) values within the same type of facility, even for the one with the same feedstock. Therefore, it is not possible to conclude from these measurements which operation is better than another.

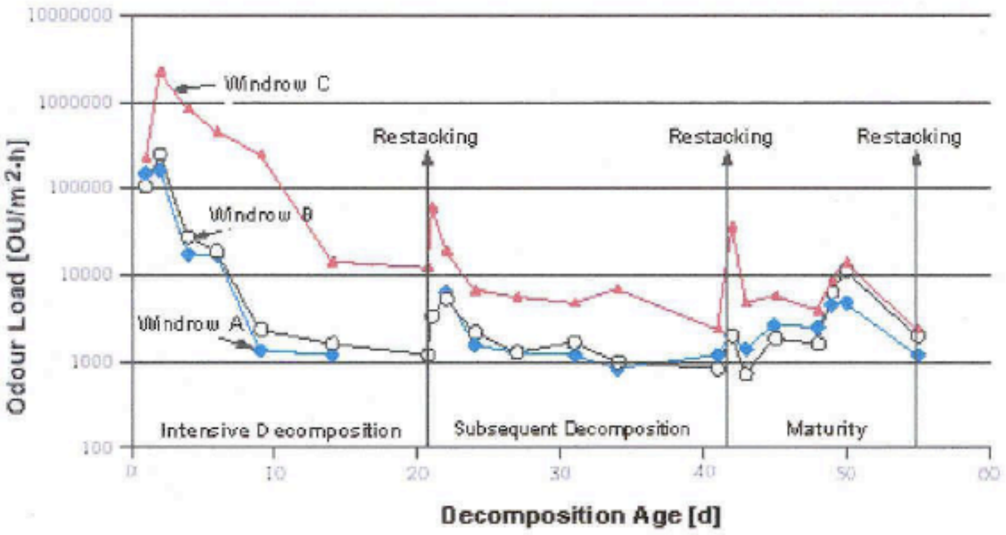
Table 19: Measurements of odorous compounds in the blower exhaust of different types of composting facilities in the U.S.



Compost Facility	Hampton Roads, VA	Site II, MD	Metro Denver, CO	Sarasota, FL	Cape May, NJ
Process	Aerated static pile	Aerated static pile	Aerated windrow	Vertical in-vessel	Vertical in-vessel
Type of biosolids	Digested	Lime	Digested	Raw	Raw
Sample location	Blower exhaust	Blower exhaust	Blower exhaust	Blower exhaust	Blower exhaust
	μg/m³	μg/m³	μg/m³	μg/m³	μg/m³
Ammonia	45K	231K	315K	858	30K
Hydrogen sulfide	—	—	152	<660	400
Acetophenone	29	621	—	945	—
Dimethyl disulfide	959	46,289	8584	12,600	2464
Dimethyl sulfide	—	1305	3480	1055	—
Dimethyl trisulfide	137	3621	522	2314	—
Limonene	45	4520	—	6209	—
α-Pinene	251	3760	754	12,660	—
β-Pinene	258	261	232	12,408	—
Measured odor	ED_{50}	ED_{50}	ED_{50}	ED_{50}	ED_{50}
	152	288–832		440	300

Source: Van Durme et al., 1990.

A better way is to look at sites that have changed their method of operation because of odor problems. Walker Industries, a company that owns a composting site and a landfill in Niagara Falls, Canada, changed from conventional turned windrow composting to the Gore Cover method because of odor problems. Residents in the neighborhood of the Niagara Falls plant were complaining about odors and nausea caused by these odors (Walker Industries Visit, 2009). Figure 12 shows the odor load at various points in time during the decomposition process (Gore Associates, 2008). The y-axis is logarithmic.



Windrow C: Open windrow composting
Heap A+B: Composting with membrane covers
Re-stacking: Re-stacking a heap
Intensive decomposting: Phase I of intensive rot (high rate composting)
Subsequent decomposition: Phase II of intensive rot (stabilization)
Maturity: curing (Phase III)
Decomposition age [d]: Number of composting days
Odor load [OU/m²h]: Odor flux [OU/m²h]

Figure 11: Odor load during the decomposition process of open windrow composting and composting with membrane cover (Gore Associates, 2008)

With more than 170 Gore systems installed around the world, Gore claims that odor emissions have been reduced by at least 90% and some have reached reductions up to 97%. In terms of odorous emissions, testing was done at Cedar Grove, where they found reductions in VOC of 89% and reductions in ammonia of 55% in emissions per ton of input waste between an uncontrolled pile and a Gore covered pile. It should be noted though that these tests were performed in the same time period, while conventional windrow composting needs a longer time period to decompose the waste. This means that total odors emanating from a ton of composted waste is likely to be even higher in practice for open windrow composting.

There is no known site to have changed their method of operation from a rotary drum system to Gore, or vice versa. It seems that both systems, when operated with a biofilter odor control system, can perform their tasks without causing significant odor problems for the surrounding residents.

Using compost as ADC has proven to effectively reduce odorous emissions coming from the landfill. Olfactometry experiments carried out by Hurst (Hurst, 2005) showed that odors from the MSW layer underneath a 10 cm compost layer are reduced by 69-97%, depending on the bulk density of the compost (higher bulk density showed better reductions). Unfortunately, the experiments were not performed on fresh yard waste, which is the material used as ADC in this study. As the fresh yard waste is not stabilized yet, more odorous emissions may be emitted from the ADC material itself. Care should be taken with the feedstock of the material, if any food waste or biosolids are present in the waste used as ADC, significantly more odors can be generated. The same counts for open windrow composting. In the following, the material input flexibility will be discussed in more detail.

5.3: Input material flexibility

The input feedstock for composting facilities differs from technology to technology and site to site. Often, odor problems restrict certain materials to be composted in systems that have insufficient odor control systems installed. Also, the degradation rate can be affected by a fluctuating input. The input material flexibility here is defined as follows: The degree in which the waste processing plant can handle fluctuations in input material mixes. In the following, the types of composting plants discussed in this study will be evaluated on this matter.

In turned windrow composting, strictly yard wastes are used as feedstock. Source separated organics from municipalities containing significant amounts of food waste have caused odor problems in the past. This happened in Niagara Falls, Ontario, where residential food and biosolids were collected and mixed in with grass trimmings, leafs and small branches (Walker Industries trip notes, 2009). Although adding nitrogen rich food waste can improve the biodegradation rate by optimizing the C:N ratio, it is not recommended in terms of odors.

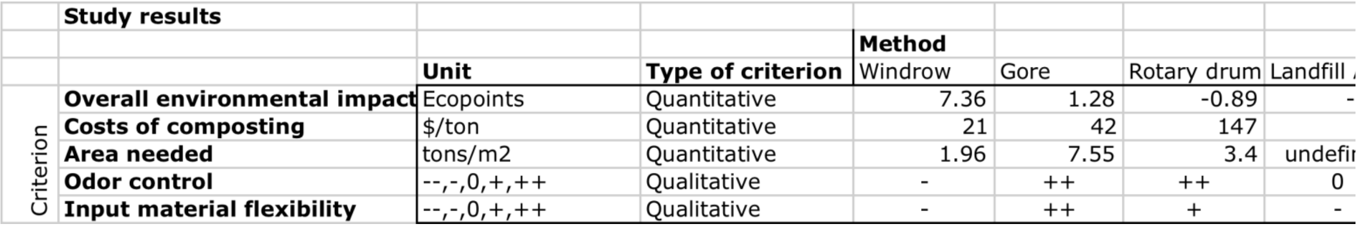
The Gore Cover technology has addressed the odor problem to an extent that it can actually compost even more odorous biodegradable materials like biosolids, slurry from a wastewater treatment plant and manure. Mixing with these nitrogen rich materials gives a better C:N ratio for optimum degradation. The controllability in the Gore system gives an extra benefit while handling these different ‘recipes’. Depending on the incoming waste mix, aeration in the piles and consequently moisture content and temperatures can be adjusted to get the highest decomposition rate and therefore the shortest retention times (Walker Industries trip notes, 2009).

In-vessel composting technologies like the rotary drum system can also handle more odorous materials as a feedstock, as long as a biofilter system is installed to clean the exhaust gases. Temperatures can be controlled to some extent by changing the aeration in the tube.

CHAPTER 6: Multi Criteria Analysis Results

Table 20 summarizes the results of this Multi-Criteria Analysis:

Table 20: Overview of the final results for the four organic waste processing methods. Both quantitative and qualitative scores are assigned to criteria.



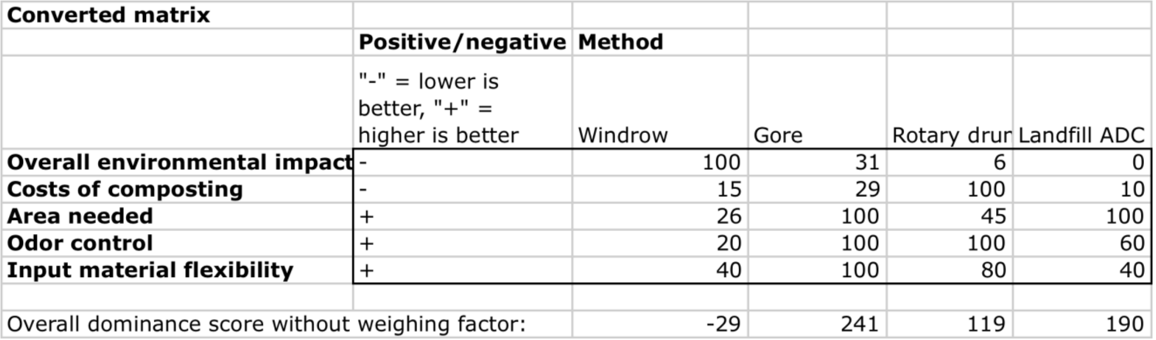
	Study results						
				Method			
		Unit	**Type of criterion**	Windrow	Gore	Rotary drum	Landfill
Criterion	**Overall environmental impact**	Ecopoints	Quantitative	7.36	1.28	-0.89	-
	Costs of composting	$/ton	Quantitative	21	42	147	
	Area needed	tons/m2	Quantitative	1.96	7.55	3.4	undefi
	Odor control	--,-,0,+,++	Qualitative	-	++	++	0
	Input material flexibility	--,-,0,+,++	Qualitative	-	++	+	-

The area needed for the alternative daily cover scenario is undefined. It is clear that sending the waste to a landfill does not require use of land (as it replaces the use of soil), so it would be given a value higher than any other method. In order to keep the comparison fair, the ADC landfill scenario is assigned a value equal to that of the highest composting value (7.55 tons/m^2 for Gore).

Two of the four methods (Rotary drum and ADC) show a negative value for the overall environmental impact. This means that they are beneficial for the environment

When the qualitative and quantitative scores are converted into a scale of 0 to 100, the results of this study can be presented as shown in Table 20.

Table 21: Scores for each method per criterion after the qualitative and quantitative values have been converted to a 0 - 100 scale. An extra dominance score without weighting factors is calculated in the lowest row.



Converted matrix					
	Positive/negative	**Method**			
	"-" = lower is better, "+" = higher is better	Windrow	Gore	Rotary drur	Landfill ADC
Overall environmental impact	-	100	31	6	0
Costs of composting	-	15	29	100	10
Area needed	+	26	100	45	100
Odor control	+	20	100	100	60
Input material flexibility	+	40	100	80	40
Overall dominance score without weighing factor:		-29	241	119	190

The overall dominance score displayed here shows how the methods are rated for the case when each criterion contributes the same to the overall score, i.e. the all weighting factors are assumed to be equal to 1. Also, the "positive/negative" column shows whether the scores are inversely related or not. A "plus" sign means that the higher the score for the criterion, the better it is for the overall dominance score. A "minus" sign obviously means the opposite.

These scores are not conclusive in the absence of weighting factors. Weighting factors are very subjective from person to person, from company to company, and even from state to state. One might decide that the environmental impact is far more important than the cost associated with the process. Others might assess for a specific location where there are competitors around with low tipping fees and therefore assign a higher weighting factor to the cost of composting criterion. Before this model can be used, companies or project managers have to determine values for weighting factors that are applicable to the location at hand. The equation to calculate the overall dominance score S_d per method for n criteria, taken into account each individual weighting factor $w_{s,I}$ and criterion score $c_{s,I}$, is expressed by Equation (6):

$$S_d = \sum_{i=1}^{n} w_{s,i} \cdot c_{s,i} \qquad (6)$$

In order to show how the weighting factors can influence the decision making results, examples of factors used by three companies are shown in Table 11.

Below are the weighting factors for three example companies:

Table 22: Examples of weighting factor lists for different types of companies and specific site conditions.

Weighting factors (0.1-1)			
Company name	**"Eco-minded"**	**"Eco-wallet"**	**"Wallet-friendly"**
Overall environmental impact	1	1	0.2
Costs of composting	0.1	1	1
Area needed	0.1	0.2	0.4
Odor control	0.9	0.7	0.2
Input material flexibility	0.1	0.3	0.7

Company “Eco-wallet” could be in a state where the government has set high environmental standards but there is plenty of land and landfill tipping fees for organic wastes are fairly low. Therefore, the company appreciates a low environmental impact and low costs, while there is no shortage of land and input material flexibility is not important either. Odors are still of importance because of nearby low dense population.

Company “Eco-minded” promotes itself as the most eco-friendly way of composting. It wants to compete with other composting plants by ensuring less environmental impact at a higher price. There is plenty of land but the people around are very sensitive to odors.

Company “Wallet-friendly” strives for cost-efficiency. It does not assign high values to environmental impact but land is more scarce and there is a need for input material flexibility due to fluctuating feedstock inputs. Odors are not much of a problem because of rural location of plant.

Applying the weighting factors of these three companies to the results of this study yields Table 23:

Table 23: Dominance scores for three types of companies after applying their specific weighting factors.

Company Eco-minded scores			
Windrow	Gore	Rotary drum	Landfill ADC
-76.8	76.3	86.4	67.0
Company Eco-wallet scores			
Windrow	Gore	Rotary drum	Landfill ADC
-83.1	60.6	-3.1	64.5
Company Wallet-friendly scores			
Windrow	Gore	Rotary drum	Landfill ADC
8.1	95.3	-7.2	70.5

For “Eco-wallet”, the MCA scores a slight preference for the ADC scenario over the Gore covered method, while for “Wallet-friendly” the best option is modeled to be the Gore-covered method. “Eco-minded” scores a slight victory for the rotary drum system due to the low weighting factor for costs.

CHAPTER 7: Conclusions

In conclusion, some of the technologies examined are superior to others with regard to a particular criterion. Considering all five criteria and assigning the same weighting factor to all five, windrow composting is rated below the ADC landfill scenario in four out of five criteria (overall environmental impact, costs, area needed and odor control). It is even with ADC in the fifth (input material flexibility). Therefore, windrow composting cannot be selected by the model.

The rotary drum scenario is rated below the Gore Cover method in three out of five criteria: It is more costly, requires more land, and has lower input material flexibility because it does not have the sophisticated measuring and control equipment of the Gore-Tex method. On the other hand, it has a slightly lower environmental impact according to the LCA-study.

Applying different weighting factors to each criterion showed that the Gore-covered composting method and the landfill ADC scenario are superior to the other methods. They both score good/perfect on all criteria and share the highest rankings for every criterion. While ADC use of yard wastes is superior in costs, the Gore Cover system is rated much higher in terms of odor control and input material flexibility.

From the results it can be seen that the decision making model finds a preferred method for sites with a certain input of weighting factors. By applying the right weighting factors for each criterion, waste management companies and municipalities can get a better insight as to what method would be preferable for each specific case.

Economic factors are, in general, the major influence for companies to choose a specific processing method. In almost every case, there is some sort of competition in a community which strongly affects whether the facility will actually receive waste material from individuals or companies. For example, if a person can choose to send his/her waste to two different processing plants and one is cheaper than the other, he/she will most likely choose the cheapest plant. Waste processing in Nantucket confirms this theory: they operate the most expensive processing method for organic waste (rotary drum system). Because it is an island, the only processing plant has a natural monopoly and can therefore afford to run an expensive plant.

Government influences the selection of a process by means of regulations and financial incentives. If the present trend of sustainability continues, governments may provide the incentives for more expensive but also more environmentally friendly methods of processing organic waste. This would positively influence the cost criterion for these methods.

The following section discusses shortcomings in the available data used in this study methodology used and the potential for further improvement of this methodology.

CHAPTER 8: Discussion and Future Research

This section discusses possible concerns regarding the validity of the data used.

Feedstock difference

In the LCA study, the different methods use different feedstocks. It is unfair to score a particular method with a feedstock that is more likely to emit substances such as ammonia and thus have a high impact on the total LCA scores, versus another process where yard waste is the feedstock. The in-vessel and Gore Cover scenarios use a mixed feedstock and therefore are expected to have higher ammonia emissions than they would have processing yard waste. Although these two processes provide means for controlling ammonia emissions (biofilters or Gore covers), the environmental impact would have been lower if they were processing yard waste.

Ideally, the four methods should be compared on emissions at the same site and with the same input feedstock. With regard to the ADC scenario, an odor measurement difference should be determined for a landfill using green waste as ADC and conventional soil as the daily cover. A focal point of such a study would be the emission of ammonia.

Ammonia emissions

Ammonia emissions (airborne) was a large contributor in the environmental impact assessment of Chapter 4. The ammonia emission emitted per ton of organic waste input for the windrow scenario was assumed to be 2.5 kg per ton, according to the study of Komilis and Ham; this contributed almost 85% of the total environmental impact. No other references were found that give a full air emissions report and therefore, the data might not be representative for an average windrow composting facility. It should be noted though, that the Gore Cover method also has a big ammonia contribution: it represents about 60% of total impact. An independent study of ammonia emissions from all processes is necessary to firm up this point.

ADC scenario

The ADC scenario in this study lacks sufficient measurement data for air emissions. For instance, ammonia formation is not included in the Barlaz model although it has a large impact on the total environmental impact assessment. Ideally, similar air emission studies to the one performed in the windrow composting scenario should be done on a landfill using yard wastes ADC. Also, the cost for this scenario is based on one tipping fee found for organic waste that is sent to the ADC landfill. Since yard wastes replace soil on the landfill it is fair to say that no area is needed at all, except for some storage space and a shredder. Another unknown factor is the effect that passage of LFG through yard waste ADC has on emissions to atmosphere vs. passage through a layer of soil.

Cost study

Lack of data in the cost study is mostly due to the fact that it is classified information. Gore Associates kindly provided a cost model. This model was used in developing some of the costs of the three other processes.

A full cost survey may be sent out to many organic waste processing plants to get a much better overview of the typical processing costs. Since this is proprietary information, the names of the responding facilities would be maintained confidential.

Selling of compost product

The output product of the composting scenarios can be sold at a certain price. The same applies to the collected landfill gas in the ADC scenario. The cost assessment did not take this into account, but it is possible to include it in further studies.

MCA shortcomings

In a MCA, criteria are supposed to be unrelated. Some of the criteria in the MCA done here are related: Input feedstock flexibility relates to odors because some of the methods are equipped with odor control and therefore can accommodate food wastes and biowastes. However, although the same cause leads to two different benefits, these benefits should not be counted as one.

Finally, the decision making model using MCA can be tested on real companies. This can be done with companies that are planning to build a composting facility or with companies who have recently started such operations. After a discussion of the results, the strong and weak points of the model can be identified and the Multi-Criteria Analysis improved accordingly.

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Appendix A – Walker IMS trip notes July 7, 2009

Visit of Gore-cover operation of Walker IMS Company, Niagara Falls, Ontario – July 7, 2009

By Rob van Haaren – Jr. Research Associate, Earth Engineering Center, Columbia University

Met with Brian Fuchs – Gore Cover; Greg Robles and Jacqueline Elston– Walker IMS

Introduction

I was picked up at Buffalo airport by Jacqueline Elston, an employee of the Walker IMS company. As we drove to Walker IMS, she told me about the company. It employs about 400 people, it is family-owned and the fifth generation Walkers are in the Board. Last year, Walker IMS got in touch with the Gore company. At that time, it was running a 40,000 tons/year windrow composting plant. They also own and operate limestone quarries and a landfill that is almost full now.

They receive waste from the Niagara Falls area and some of the biosolids come from Toronto. The mixture is yard trimmings, leafs, small branches, some residential food waste and biosolids mostly from curbside and green bins. Plastic is the biggest contamination of the feedstock. The composting windrows and also the leachate ponds are not covered, so municipalities around the site were complaining about odors. This was Walker's primary reason to contact Gore.

A design and construction process began and Gore tested and confirmed that the technology was applicable for the waste mixture and the location conditions. This total design and construction process will take about 6 months. The plant is not completely finished at this moment: an office will be built and the leachate system is not optimized in terms of odors yet.

The system

The site is paved, has an enclosed tipping area and a composting area with 16 windrows. The estimated throughput is approximately 40,000 tons/year and will be able to completely replace the windrow composting operations on a much smaller area. The waste is brought into the tipping area by trucks where it is mixed into a nice homogeneous mix to get the ideal recipe for biodegradation. Leachate collected from the composting process is recycled to the feed by spraying it into the mixing machine. Two 75 hp electric motors keep a negative air pressure within the enclosed tipping area and the building air with outside and the air is pushed through a biofilter (the German 'GEWITRA' report shows how much this biofilter filters out). At least one electric motor runs 24/7, the second is there as a reserve in case of repairs.

Figure 12: Tipping area with biofilter on the left (enclosed within walls). The organic waste is delivered here and the building is kept at a lower air pressure than outside, to prevent odors from being emitted.

The composting area is open, has 16 windrows (eight for phase 1 and four for each phase 2 and 3) and has a leachate collection system under each windrow. The leachate is led to a central tank where it is processed before it's sprayed into the mixer. When the company was running their uncovered windrow composting operations, leachate found its way to the pond and from there it was let into the sewer. Presently, the company pays a lot of attention to odor control. Greg Robles of Walker IMS told me that they are very careful with small puddles at random places (in the windrow area), because those can generate more odors than a whole windrow. Also, the leachate collection system is not optimized yet. Greg showed me an open pit where leachate accumulates. A bubbling system will be installed in the future to keep it moving and reduce odors.

The three phases have retention times of respectively 4, 2 and 2 weeks. The piles are only moved when they go from one phase to the other, they are not turned within a single phase. Temperatures and moisture contents are as follows:

Phase 1: Temperatures run 55-80 C, moisture 65-55%

Phase 2: Temperatures run 55-70 C, moisture 55-50%

Phase 3: Temperature are by purpose controlled down 55-40 C, moisture by purpose is controlled down to 45%.

Unique about this site are the small two foot walls on both sides of each windrow. The normal operation for Gore is for the feedstock to be piled onto a flat floor and the covers to reach the floor where they are held in place by placing sandbags on top of the edges. In the Walker site, all the material is dumped in between the two small walls and the covers are led over the walls. Attached to the covers are rubber ropes, the covers are tightened by putting these ropes around bolts in the walls (see figure 13). The top of the walls are covered with a rubber material in order to keep the covers from wearing out (Brian Fuchs of Gore-Tex recommended that the covers be replaced anyway after a 4 to 5 year period – UV sunlight is the main contributor to wear). Compared to the way conventional covers are kept in place (sandbags), this system seems to be working faster: the rubber ropes can easily be tightened around the bolts be a single person. Another benefit is that in winters the cover edges will not be covered with a big pack of snow, which is a problem in many conventional sites at this latitude or further north.

Figure 14: The composting area with the vertical walls to which the covers are attached with rubber ropes. On the right, a pile is being transported from one windrow to the area.

The 'recipe'

The waste mix or 'recipe' is a very important term in the Gore composting process. In the start-up of the plant, many measurements are made to find the optimum degradation mix. Moisture levels, oxygen levels and C:N ratios are kept at the optimum level by mixing in leachate, adding oxygen by aeration and adding bulking agent that is delivered by local residents. Greg said it getting the right mix and the optimum degradation is "more like an art than a science".

Brian Fuchs showed me some screenshots of the software that they run. Two probes are stuck into the pile, one for oxygen and one for temperature. The temperature probe measures at five different depths. The parameters can be adjusted in the software and the system will react to the new settings. For instance, oxygen levels are set to be in between 6% and 8%. Whenever it goes above 8, the aeration is shut down or lowered. When O2 drops below 6%, aeration is activated or increased.

The right recipe is critical for odor control: Above the Gore covered windrows hardly any smell was noticeable. This was surprising, especially when I saw and smelled the biodegrading materials underneath the cover. According to multiple reports, odors are reduced by 90 – 97% with the Gore cover system.

Resources and costs

Aeration is provided by a 2hp (max) electric motor per windrow. A 75 hp electric motor runs the negative aeration and biofilter in the tipping area. A ton of waste entering the facility is transported as follows:

- to the tipping area by truck
- from the mixer to the first covered stage pile by front end loader (FEL)
- first stage to second stage pile (FEL)
- second stage to third uncovered stage pile (FEL)
- third stage to temporary dry storage in part of the tipping area (FEL)*
- from temporary storage to outside the facility by truck.

*the third stage is only covered in warmer climates

The Gore covered facility is operated by 4 to 5 people. One works on the mixer, two are loading and unloading piles and one does the winding and probing. There is one winding machine which is used to cover and uncover the waste with the Gore membrane cloth. It can be operated by one person because it is equipped with sensors that keep the machine from hitting the walls.

Figure 15: Winding machine at the Walker compost facility. Sensors on the sides keep the machine from hitting the walls and make it possible to be operated by one person. The Gore membrane cloth is simply rolled off the machine to cover the pile. The sides are secured to the wall with rubber ropes.

Because Walker still uses the windrow area, they have excess capacity. In total at the green waste processing plant, they have 5 FELs. I think that three FEL would be sufficient for the Gore part of the composting plant: Two for loading/unloading and one for the tipping area (see attached photographs). Greg said that a FEL plus operator costs about CDN$75/hr and this includes fuel. The total capital costs and O&M costs for this site are not provided, but this is the general rule of thumb for Gore covered systems: Total capital costs for a 40,000 tons/year plant range between 8-12 million US dollars and the O&M costs for the Gore system alone is about 1.5-3 dollars/ton. If receiving, grinding, screening, water management, etc are added, costs can go up to 15-20 $/ton.

The tipping fee of organic waste differs per customer. Greg said it is about 50 to 55 Canadian dollars per metric ton. Customers also pay some sort of set fee, all depending on their contract with Walker.

The final compost product is sold for CDN$10 per cubic yard. We smelled the product and it was very earthy. There were no unpleasant odors or anything.

Mass loss and moisture loss

Overall, in the Gore covered composting process, a lower moisture content of the product is achieved as compared to the feedstock: It is decreased from 55-60% to 40%. The mass loss including the moisture loss was reported to be about 30%, although I thought that this was too low.

The landfill

As stated in the introduction, Walker Industries also runs a landfill. From the road on the way home I had the opportunity to take some pictures of the landfill operations. As a daily cover, they used contaminated soil (a waste product from one of the limestone process operations) instead of clean soil or ADC. They never used their green waste as a daily cover and I think that makes perfect sense because they just built a multi-million dollar plant to take care of that waste. After the final cover is deposited, they install a landfill gas collection system to collect the methane.

Going back home

After the tour, I drove back to the airport with Brian Fuchs and his 9-year old son who came along on this trip. At the airport, Brian showed me some pictures of the different types of Gore covered plants that are in use around the world and we talked about the legislation/design/construction process for Gore covered sites. It seems that the Gore technology is applicable in almost any part of the world even with more severe weather conditions. Every site can have its specific adaptations depending on the conditions in and around the site. The Gore people keep in touch with the managers of the facility, if there is any problem they come over to work it out. This also ensures that the Gore product quality is kept at a high level.

Appendix B – Nantucket trip Waste Options notes, July 19, 2009

Author: Rob van Haaren

Met with: Nelson Widell (Peninsula Compost)

I visited the waste processing centre while I was on a-weekend-off in Nantucket. Brian Fuchs brought me in contact with Scott Woods and he arranged a tour through the facility for me. Nathan (Nelson Widell, Peninsula Compost), an employee who has worked there since 2000 showed me the landfill, the MRF (Materials Recycling Facility) and the rotary drum composter in Nantucket.

The passage below, comes from the website of Nantucket Waste Options (www.wasteoptions.com/nantucket.htm):

It was in 1997 that Waste Options signed a 25-year contract with the Town of Nantucket. As part of the contract, Waste Options would operate the Town's landfill, operate its constructed Materials Recycling Facility (MRF), and build a state-of-the-art co-composting facility at their Madaket site. In the two years that followed, Waste Options has cleaned up the landfill, restored eight acres of wetlands, shipped eight barge loads of tires off island, reduced the population of seagulls at the landfill from 25,000 to just several hundred, and increased Nantucket's recycling rate from 17 percent to 42 percent, ranking it as the community in Massachusetts with the highest rate of recycling. Since the composter began operation in December 1999, that rate has jumped to close to 90%.

Recycling of household waste

The residents of Nantucket can bring their household waste to the MRF for free. There is a clear explanation for every specific waste stream that can be handed in. Mixed paper, newspaper, PET bottles, mixed plastics, metal cans and glass are some of the separate bins that they have. The bulk of organic wastes is brought in by big trucks, that are weighed before and after to measure the amount brought in. Most people have bins in their houses where they separate waste before they take it out. In the pictures below, the area is visible where Nantucket residents park their cars (left picture) and separate their waste in the different bins (right picture).

Figure 16 a,b. a: MRF collection area. b: Residents of Nantucket separating their recyclable waste.

Actually, what the people don't see, is that all the different papers and plastics are processed in just two ways. As can be seen in Figure 17 below, there is one collection area for paper and one collection area for plastics. There is no clear reason for this wasted effort, but what both Nathan and I thought was that it makes the people feel better about it and it gives the opportunity for future dedicated processing methods for the specific types of waste.

Figure 17: Inside view of the material recycling facility

Plastics

The plastics are processed in the following way:

1. Loaded onto a conveyor belt by a front end loader Bobcat.
2. By a magnet, most metal is taken out to ensure a clean stream.

3. Six pickers pick out dirty package material that cannot be recycled (for instance, a tube of ketchup with a fair amount left in it). This is sent to the organic waste stream that will be discussed later. They also pick out aluminum cans and other metals that were not extracted by the magnet.
4. The clean plastics are then compressed and tightened to approximately 6 by 6 by 4 feet bales and shipped out to another facility for further processing.

Figure 18 a,b,c,d. a: Plastic pushed onto a conveyor belt and separation of metals by magnet at the end. b: Place where the plastic stream enters the picking room. c: Temporary storage of contaminated plastics that are separated out of the plastic stream. I also spotted some cardboard and paper. This is later mixed in with the organic waste that enters the rotary drum digester. d: Sludge from a Wisconsin WWTP that is also mixed in with the rotary digester.

Paper

The newspapers, office paper and any other mixed papers are all baled together and shipped out for further processing.

Glass

Glass (of all colors) is thrown in a big dumpster. According to some of the residents it is the funniest material to recycle at the recycling centre. So now and then, a full dumpster is sent out of the facility and an empty one is brought back.

Metals

The metals that are separated are compressed and baled like the paper. In the picture below, bales of aluminum and metals are stored because of the current low prices they receive for them.

Figure 19: low metal prices pushed the managers to store bales temporarily in their hall.

Organics

Organic waste is brought in by trucks. Nathan said that some of the trucks do not have enclosed containers and that these cause odors as they drive past municipalities to the Waste Options facility. They pay the following tipping fees for different types of waste:

- $120/ton for MSW
- $180/ton for bulky material
- Flat fees for slurry that comes from WWTP's.

It is collected and loaded into the rotary drum (diameter approx. 12 feet, 185 feet long), together with contaminated plastics that were separated by the pickers. The picture below shows the very beginning of the drum where the waste enters the apparatus which rotates at about 1 RPM. Temperatures are at about 160F (71 ^{o}C) in the first part of the drum, and 180F (82 ^{o}C) at the end. Air and water are added to improve decomposition. As much as 60,000 ft^3/min of air is added. The retention time of the waste in the drum is about 3 days.

Undersized material (less than 1-inch), or unders, passes through the screen for processing as compost. Oversized material, or overs, is conveyed to a baler for landfill disposal (Waste Options Website).

The unders go to an area where it is aerated in piles for curing (or maturation). The material stabilizes there for 21 days. Then, a vibration screen takes out pieces bigger than 3/8 inch which are sent to the landfill and small but heavy particles (like glass, stones) are put in a container. The compost then can be used as a soil amendment/fertilizer for gardening purposes. It is marketed in the Nantucket community and some of it is even donated to the recycling people as a 'take it or leave it'.

Besides this line, they also have a special shredder to make woodchips out of big branches. All of this waste is reused as landscaping material. Some of the clean, non-odorous organic waste is windrowed on top of the landfill and is turned every couple of weeks.

Note that the contaminated plastics that were added at the beginning of the rotary drum are separated again later. This is to digest as much of the food remains in the plastics as possible. However, the separation comes with huge costs and both of us concluded that there should be a better way to dispose of this waste properly.

Figure 20 a,b,c,d. a: mixed waste entering the rotating drum. b: Outside view of the rotating drum. c: End piece of the drum where the unstabilized material is falls out of the device. d: Conveyor belt that transports the waste to an area where it is windrowed and aerated for curing.

A biofilter ensures cleaning of air from the enclosed compost buildings. The cleaning system costs $120,000 and is very low maintenance. It consists of pipes and pumps that bring the air from these buildings under an enclosed area with a pile of woodchips. The odors are filtered out by the woodchips and clean air is emitted from the top of the building. The woodchips have to be replaced with fresh woodchips every two years.

Figure 21: Biofilter system with a 20,000 ft^2 area of woodchips that clean the odorous air from the composting processes.

Other materials

Other waste streams that are not discussed in the tour are covered on the Nantucket Waste Options website. I will include them here to be complete:

All construction and demolition (C&D) materials are delivered to the C&D processing building, which is large enough to hold at least one week's worth of C&D waste. Clean construction wood, pallets, etc., are sent to a chipper after removing any usable wood to place at the Take It or Leave It for citizen use. Hard to separate demolition, etc., is crushed and separated. All clean wood is chipped and beneficially used. Metals are sent to the metal staging area. Concrete and rubble, stone, etc., is stockpiled for re-use. Non-recyclable wastes, asphalt shingles, etc., is disposed of in the lined cell. Old boats, furniture, etc. comes to the C&D processing building. Dirt and fill materials from construction sites are screened and the component parts sent to the proper area, i.e., metals, wood, sand, soil and bricks.

All large appliances (less refrigerants) are deposited at a special trailer for delivery to the staging area. All refrigerants are delivered to the rear of the MRF, where freon is safely removed by a specialist and a sticker attached before removal to the metal pile.

Hard to manage waste (HTMW) such as mattresses, box springs, rugs, couches, stuffed chairs, etc., are collected at the HTMW trailer. They are then shipped to a merchant in Hyannis where cotton, wood and other components are removed to be recycled and reused. All tires are delivered to the tire staging area. The rims must be removed and placed in the metal pile. The tires are then sent to recyclers on the mainland.

The landfill

The landfill is pretty old (several decades). It has a capacity of 1.6 million cubic yards and takes up 21 acres. It is not prepared with a liner so the Nantucket government decided that it would be better to empty it and dispose of the waste in a proper way. A neighboring pond of water is believed to be contaminated by the leachate from the landfill. They started mining the day after I visited the site. Most of the waste in the landfill is so old, that there is hardly any LFG generated anymore. It contains approximately 30% plastics, 15% metals and 55% soil and organics. At the moment, two new landfills are prepared and one is being prepared with a double liner and they are used as the current landfill now. Glass is used as an ADC material. Also, it has a leachate collection system that ensures that nothing ends up in the nearby ponds.

Figure 22: New landfill where glass is used as Alternative Daily Cover.

The mining is going to be a big task: all the material is being separated in four streams: metals, plastics, bulky material and soil/small non-metal particles. This is done by a huge "Trommel" separation device (see figure below).

Figure 23: A McCloskey 621 Trommel device separating bulky waste (in foreground). This device is used for the mining of the old landfill.

Resources and costs

About 20 people work at the MRF, landfill and composting facility together on a typical day. For the mining of the old landfill, 3 extra people are needed for the next months. 6 people are needed for picking at the MRF, 3 people work as administrators and one person works on the balance, one for screening, and there is one full time employee for repairs. Some more employees are needed to help people separating their waste, operate a front end loader and to keep the site clean.

Total capital costs for the site were about 6.5 M$. Operation and Maintenance costs for the site are big: 2.6 – 2.7 M$. The electricity bill is about 400 k$, since the site consumes 1.7 GWh annually. The tonnage of total materials handled is about 38,000, which would mean that only O&M costs for all types of materials averages at 71 $/ton.

Appendix C – Gore Trip notes, May 30th, 2008

Morton Barlaz

Brian Fuchs from Gore

NC Vasuki

Nelson Widell – Peninsula Compost

We spent about an hour with me describing the goal to understand the state-of-the-practice and Brian presenting the Gore Technology. We then went into a more free-flowing discussion of where this technology fits. Take away messages for me:

- the Gore technology is quite good, based on what I saw at Cedar Grove in WA, a well run Gore plant can be quite clean and odor free (see reference below)
- The issue is cost as in WA they were getting a tip fee of $42 a ton. I pointed out that this was high for yard waste and everyone agreed that economics are critical. The economics that must be considered are the transport fee plus the tip fee. In many cases, if a load is brought to a transfer station, the tip fee at the transfer station will include the cost to transport and then dispose of material at a landfill. In parts of the NE, the tip fee for a local compost facility will be lower than that of the landfills that receive waste in VA and PA.

Specific points

- Nelson Widell is building a facility in DE the same size as Cedar Grove (160,000 T/yr)
- It was permitted in May, 2008 and they hope to be running in March, 09. Feedstocks will come from within 50 miles of Wilmington, DE and the tipping fee will be lower than the landfill. Nelson was counting on corporate drive to "compost." He spoke of national corporate accounts.
- Nelson said that he had very strong markets for the end products as top soil. He could market for $10/ton of $5/yard and was not worried about market saturation (personally I am a bit skeptical here, the high value market is bagged material and I cannot imagine that demand expanding forever. The alternative is bulk sales and at some point it would seem that the sales price will have to drop. Of course, if the tip fee covers costs + a margin, then you can afford to give it away).
- Gore covers are guaranteed for 4 years, they seem to last longer, harshest application is Edmonton, CA
- Retention time:

    - Phase 1 – 4 weeks under cover
    - Phase 2 – 4 (2: says Brian Fuchs) weeks under cover
    - Phase 3 – 2 weeks exposed
- Energy for the blowers, computers and probes (temp and oxygen) <0.75 kWh/ton (this does not include the rolling stock, grinders, screens, biofilters). Brian thought this power demand would not increase as the food waste % increased. The blowers turn on and off based on oxygen content.
- Fastest growing market is for biosolids
- The machine that puts the cover over the windrow can move in 4 directions so one machine can cover all windrows
- Gore is putting three units in the Toronto area, each will handle curbside residential collection of FW and YW (food waste and yard waste).

Comments on Feedstock

- Low hanging fruit is a commercial plants that process fruits and vegetables, the Philly farmers market. Then comes supermarkets.
- Nelson sees about 2% contamination by weight based on a <u>rigorous</u> contract with the waste generator. If a load is contaminated, he takes pictures and then sends it to the landfill at the generators expense. He budgets at about 5% residual and says that groceries can provide excellent feedstock. (I believe that there are regional issues here. For example, at the Kroger's waste drop in OH, there was lots of OCC in the waste that should not be there – this leads me to wonder how people will separate food waste if they cannot get OCC right. However, the need to recycle is different in NJ vs. OH and this may explain the difference. Also, this is easier to implement if a loader dumps at the compost plants. It is dumps at a transfer station, you need an inspector there.
- Brian Fuchs sees more contamination with residential which was not the problem in WA. However, in WA, participation was relatively low and one can infer that the people that participated wanted to get it right

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