EXECUTIVE SUMMARY TO THE FINAL REPORT

to the

National Association of Plumbing-Heating-Cooling Contractors

LIFE-CYCLE COMPARISON OF FIVE ENGINEERED SYSTEMS FOR MANAGING FOOD WASTE

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ABSTRACT

A life-cycle inventory methodology was developed and used to quantify total system materials, energy, costs and flows to the environment from acquiring, using and decommissioning five systems currently used to manage food waste. The default system for food waste management is the municipal solid waste (MSW) system; the food waste disposer (FWD), an appliance installed in kitchen sinks, diverts food waste from MSW to wastewater systems. Because the FWD is part of the wastewater collection system, the total impacts of each system include impacts from both collection and treatment/disposal systems. The five systems inventoried are a rural wastewater system, the FWD and on-site system (FWD/OSS); a municipal wastewater system (FWD/POTW); and three MSW systems- MSW Collection/ Compost; MSW Collection/Waste-to-Energy (WTE); and MSW Collection/Landfill. Specific examples are inventoried for each system that are representative of current practices. Inventory parameters for MSW systems were prorated to 100 kg of food waste inputs; parameters for wastewater systems were prorated to 100 kg of food waste plus 1031 kg of associated FWD carrier water. For MSW systems, parameters attributable to 100 kg of food waste inputs were multiplied by the ratio of 100 kg of food waste to the total MSW through the system over its design life. For wastewater systems, parameters were multiplied by the ratio of 100 kg of food waste and carrier water to the total solids and wastewater through the system over its design life. The five systems were ranked simply from high (#5)to low (#1) for twelve inventory parameters per 100 kg of food waste- land, total system materials, water, total system energy, total system cost, air emissions, acid gases, greenhouse gases, wastewater, waterborne wastes, solid wastes, and system food waste byproducts (sludge,

septage, compost, ash, landfill residues). The overall ranking (FWD/OSS, MSW Collection/WTE, FWD/POTW, MSW Collection/Landfill, and MSW Collection/ Compost) agreed reasonably well with the ranking of the five systems by total system cost. The rural FWD/OSS ranked highest, in large part, because the 100 kg of food waste and associated carrier water represent a larger fraction of total solids and wastewater passing through this system over its design life than for any other system. The MSW Collection/WTE ranked second overall. Burning food waste yields little exportable energy if system energy losses are included, and the recycling of food waste through wastewater systems should be encouraged for communities with WTE facilities, just as the recycling of other materials with no heating value, such as metal or glass, is encouraged. The FWD/POTW system ranked third overall, first for food waste byproducts requiring management (sludge) but low for land, total system materials, total system energy, total air emissions, acid gases, greenhouse gases and solid waste. Adding food waste to carbon limited wastewater systems contributes to a net removal of nutrients from effluent as these nutrients are assimilated with carbon into biomass and removed from the system as sludge. The MSW Collection/Landfill system ranked second lowest overall and lowest for cost; it ranked low, as well, for water, wastewater, waterborne wastes, total air emissions, acid and greenhouse gases, and food waste byproducts (landfill residues). The MSW Collection/Compost system ranked lowest overall; but is a non-essential system. If food waste and carrier water contributions are subtracted out, total system materials and energy are similar for the FWD/POTW and MSW Collection/Landfill systems, the two systems essential and required for basic public health and sanitation.

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1. INTRODUCTION, BACKGROUND, PROJECT OVERVIEW and OBJECTIVES.

1.1. *Introduction.* The food waste management research project is a comprehensive evaluation of the food waste disposer (FWD) and its impact on both solid waste and wastewater management systems. The FWD is used to grind food waste with water and to discharge the slurry to a household wastewater management system. In either a household or community, the FWD, in effect, transfers food waste from solid waste to wastewater management systems. There are land, materials, energy, cost and environmental impacts (air emissions, waterborne wastes and solid wastes) from the choice made in the kitchen to use a FWD.

1.2 *Background.* The World Commission on Environment and Development in its April, 1987 report, *Our Common Future*, and the International Protocol on Ozone Depletion signed in Montreal in 1987 introduced the concept of "sustainable development". At the core of the concept of sustainable development is the requirement that current practices should not diminish the ability of future generations to maintain or improve living standards; present systems should be managed to maintain or improve the resource base (Hancox, 1989).

Driving the "sustainable development" movement are the emerging concerns that human activities are producing global environmental change, disrupting soil, water supply, vegetation and ecological systems at levels which exceed carrying capacities and produce alterations potentially irreversible for the survival of humans.

Industrial facilities, over the past several decades, have been regulated as point sources of air and water pollution. They are increasingly being evaluated with respect to the environmental impacts of their products. Environmental management is undergoing a shift from applying "end of pipe" technology to applying the "precautionary principle". The precautionary principle is proactive and may be applied in the

* prevention of future damage, where prevention becomes an objective in its own right,
* avoidance of conflict that would arise if stressful conditions were knowingly allowed to continue,
* minimization of risk where causes and consequences are unknown or where valued environmental resources or assets are in potential danger, and
* protection of the assimilative capacity of natural systems for absorption, assimilation or restoration, ensuring that there is a cost-effective "natural" way of managing environments in the longer term (O'Riordan, 1994).

The precautionary principle is likely to become a significant factor in altering the pattern of industrial activity and pricing (O'Riordan, 1994). Because the principle is as much political as it is scientific, industry is working more closely with non-governmental organizations and governments to define impacts of their products and processes and to help shape the evolution of regulation (O'Riordan, 1994).

1.3. ***Food waste overview.*** Food waste, as defined in this project, may be either solid or liquid material discarded during food preparation and cleanup or wasted from household storage. FWD food waste is a subset of household food waste; and current estimates indicate that approximately 75% can be processed through a FWD (Strutz, 1995). In both MSW and wastewater systems, food waste is mixed with other inputs to those systems.

Figure 1.1 gives a crude materials' balance for the production and disposal of products of photosynthesis (Kneese et al, 1970). Food waste is included with disposed products of food consumption by humans, products of which are respiration, garbage and sewage. From the 5000 million tons of dry organic matter produced by photosynthesis per day, 50 million tons of dry organic matter or 1% is disposed of as products of respiration, garbage and sewage. This is roughly the same order of magnitude as food storage and food-processing waste and one order of magnitude less than farm waste. Food waste diverted by FWDs is a small subset of this 1%.

Food waste generated on farms, during industrial food processing, in food distribution systems, or in establishments covered by wastewater pretreatment standards is not included in the scope of this project. Figure 1.2 illustrates potential wastewater and solid waste flows due to the production of food. This project involves quantifying the impacts and costs of a subset of the total impacts of food waste flows, primarily those added to wastewater systems and removed from MSW systems due to the use of the FWD.

Historically, food wastes from households have had a low resource value in the United States and have been disposed of either to MSW systems or through FWDs, kitchen sinks and dishwashers to wastewater collection systems. Quantifying food waste, in and of itself, has not been important. However, recent public concern over environmental impacts and costs related to the disposal of MSW is forcing a more accurate accounting of waste materials and their resource value, including food waste, and a reevaluation of how wastes are managed. More stringent effluent standards for municipal wastewater treatment systems, particularly for nitrogen and phosphorus, are driving current research to characterize wastewater influent. Rural on-site wastewater systems' lack of performance-based design standards have led to system problems and to experts discouraging the use of FWDs with rural wastewater systems. total impacts of food waste flows, primarily those added to wastewater systems and removed from MSW systems due to the use of the FWD.

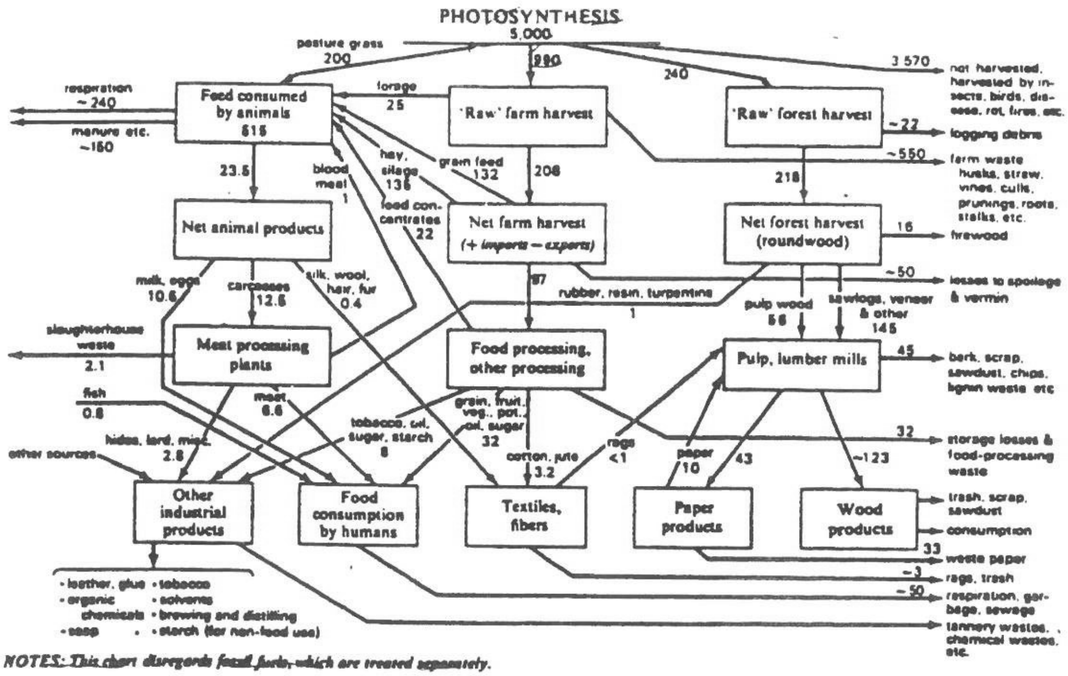


Figure 1.1. Production and disposal of products of photosynthesis (10^6 tons dry organic matter per day (Kneese et al, 1970).

Figure 1.2. HUMAN FOOD FLOWS

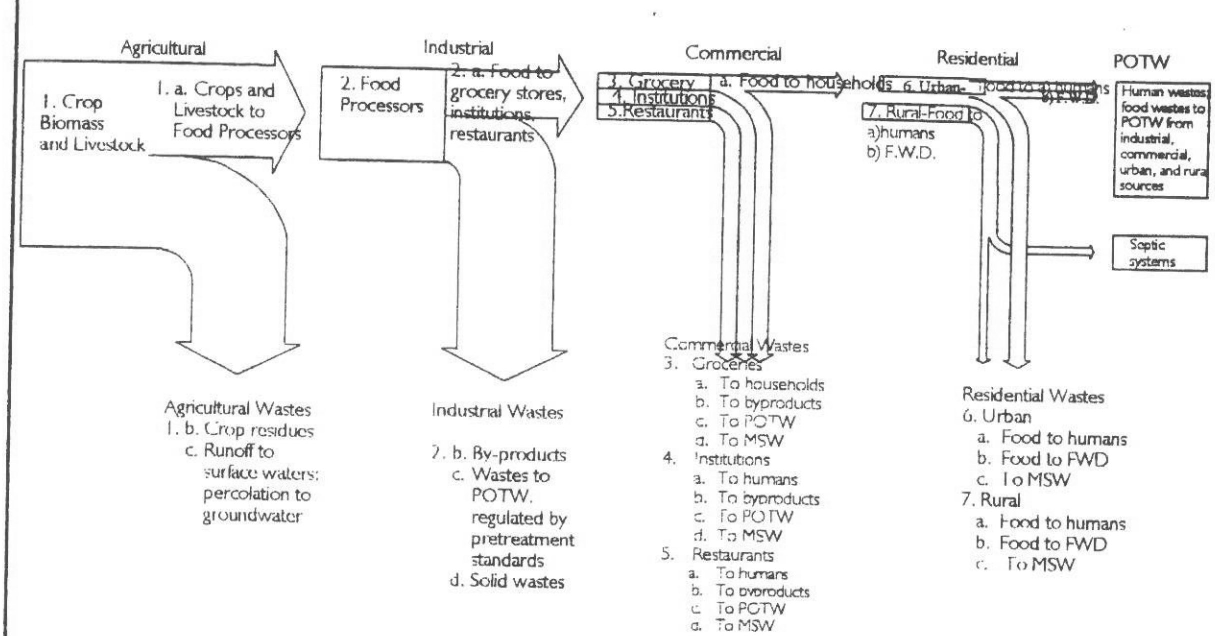


Figure 1.2. Human Food Flows

1.4. ***Project overview.*** FWDs are kitchen appliances which were introduced in the 1960s; today approximately 40% of U.S. households have FWDs (Carney, 1995). As a result, currently operating municipal wastewater systems are sized to include FWD food waste and carrier water loadings from 40% of U.S. households. Likewise, current municipal solid waste (MSW) systems are also sized to reflect this diversion of food waste through FWDs.

The overall goal of this project is first to develop a life-cycle inventory procedure and then to use this procedure on systems currently used to manage food waste. The life-cycle inventory developed for this project includes total land requirements, total system materials, total system energy, total system costs and total flows to the environment (air emissions, waterborne wastes and solid wastes) from the acquisition, use and decommissioning of a system. To make it possible to compare different systems, all parameters are prorated to 100 kg of food waste inputs to the system. For wastewater systems, the carrier water required to process 100 kg of food waste through a FWD is included with the 100 kg of food waste. Materials, energy, costs and flows to the environment attributable to 100 kg of food waste inputs are totaled for each system. The impacts of two alternatives, either all or no households with FWDs, are compared to the present situation (40% of households with FWDs).

In Chapter 2, the methodology is defined which will be used for the life-cycle inventory. Unit factors are defined for quantifying energy, waterborne wastes, air emissions, and solid waste embodied in materials, process equipment, and vehicles, fuels and electricity required for this project. Unit factors are expressed as Btu/lb of aggregate, lb water/lb of concrete or lb of CO_2/ lb of steel; these unit factors are the basis for comparing the five wastewater and MSW systems.

In Chapter 3, an average U.S. food waste, including composition and energy contents, is defined. The composition and energy of the assumed food waste is compared to the composition and energy of a calculated food waste, which is the calculated difference between

U.S. food production and U.S. food consumption. The percentage of food waste going to each of the five U.S. food waste management systems is estimated. An analysis is made of the fate of the average food waste as it is processed through each of the five systems.

In Chapter 4 the life-cycle inventory is used on the FWD. The results of this chapter are subsequently included with the wastewater systems. Total flows to the environment from the manufacturing, use and disposal of the FWD are added to those of wastewater systems.

Two wastewater systems are included- a municipal system (a publicly owned treatment work (POTW)) and a rural wastewater system. For the POTW it is assumed that the collection system includes FWDs in 40% of households. For the on-site system, either the household has or does not have a FWD; the impact of the FWD is the difference in materials, energy and costs between these two differently sized systems. Three MSW systems are included; municipal collection of MSW is followed by a compost facility, a waste-to-energy (WTE) system or a landfill. Total flows to the environment from a MSW collection system are added to each MSW system. Because construction and maintenance materials, capital and operating energy and costs are facility specific, a facility was chosen for each system except for the on-site wastewater system. The Madison Metropolitan Sewerage District (MMSD) is the POTW used for this project. The City of Madison's MSW collection system was used, followed either by the Dane County, WI. Landfill, the Columbia County, WI. Compost Facility, or the Hennepin County, MN. WTE Facility. For the on-site system, land, materials, energy, costs etc. are the difference between two systems, one designed for a household with a FWD and one for a household without a FWD. Chapters 5, 6, 7, 8, and 9 give assumptions, calculations and results of life-cycle inventories for the difference in on-site systems, the municipal wastewater collection system and POTW, the MSW collection system and landfill, the MSW collection system and compost facility and the MSW collection system and WTE facility, respectively.

Chapter 10 compares the total flows to the environment for each of the five systems. The total for each is the sum of flows to the environment from 100 kg of food waste passing through each system plus flows due to system materials and energy sources all expressed per 100 kg of food waste inputs. Chapter 10 gives the final project conclusions.

1.5. ***Project objectives.*** In summary, the objectives for the project are to:

* Develop a life-cycle inventory methodology, which can be used to quantify total system materials, energy, costs and flows to the environment (air emissions, waterborne wastes and solid wastes) from acquiring, using and decommissioning a wastewater or solid waste management system, and assemble unit factors for the inventory.

* Apply the life-cycle methodology to a specific example of each of five systems used to manage food waste- a conventional on-site wastewater management system, a municipal wastewater treatment plant, and municipal collection of MSW followed by a landfill, compost facility and a waste-to-energy (WTE) facility.

* Determine the composition and energy content of an average food waste for the U.S.

* Determine the fate of 100 kg of the average food waste passing through each system.

* Quantify materials, energy and costs attributable to 100 kg of food waste inputs to each MSW system and to 100 kg of food waste and associated FWD carrier water inputs to wastewater systems.

* Quantify the total mass flows to the environment (air emissions, waterborne waste and solid waste) from food waste, system materials and energy sources for each system all attributable to 100 kg of food waste inputs.

* Compare total materials, energy, costs and flows to the environment of the five systems.

* Identify operational advantages and disadvantages of each system, issues related to the management of food waste in each system, trends in technology and trends in laws and regulations pertaining to each system.

* Summarize the environmental impacts of the use of the FWD.

CHAPTER 2. *LIFE-CYCLE INVENTORY- BACKGROUND, METHODOLOGY, UNIT FACTORS- EXECUTIVE SUMMARY.*

The objectives of Chapter 2 are to define the life-cycle assessment (LCA) or inventory methodology and to develop the unit factors used in this project. The present situation for most municipalities is that they neither ban nor mandate the use of FWDs. Food waste is going to both wastewater and MSW systems. For all municipal systems, the current size, energy consumption, capital and operating costs include the diversion of food waste from MSW to wastewater systems from 40% of households. It is assumed that even if all or no households used a FWD, the changes in system size, energy consumption,and sosts of municipal systems would be negligible. The reasonableness of this assumption is addressed in chapters dedicated to each system. Only the rural wastewater system requires a redesign to accommodate FWD inputs. To make it possible to compare diverse systems (municipal with rural, wastewater with MSW), all materials, energy, and costs are based on the same inputs to each system. For this project, 100 kg of food waste inputs (and associated carrier water for wastewater systems) was chosen as the basis of comparison.

Unit factors quantify materials, energy, costs, waterborne wastes, air emissions, and solid wastes embodied in materials, process equipment, and vehicles, fuels and electricity required for this project. Unit factors are expressed as ft^2 of land per 100 kg of food waste, BTUs of energy per 100 kg of food waste, or pounds of material or pollutant attributable to 100 kg of food waste inputs.

Figure 2.1 is a generic life-cycle inventory with inputs of land, raw materials, energy and financing; three stages- system acquisition, use and decommissioning; and outputs to the environment of air emissions, waterborne wastes, solid wastes and products. For system acquisition, inputs include land requirements, construction materials, capital energy, and capital costs necessary to produce a functioning system. Raw material inputs include aggregate, concrete, aluminum, asphalt, copper, glass, paint, steel and wood. Fuels include natural gas, coal, refined petroleum, and wood.

The second stage quantifies the impacts of using a system over its design life. System components and process streams are defined for the use of each system and 100 kg of an average U.S. food waste, defined for this project in Chapter 3, is the input material. The second stage begins with the input of 100 kg of food waste into a wastewater or MSW collection system and ends with the export of air emissions, waterborne wastes to the environment, the application of sludge, septage or compost to an end use and the disposal of ash, treatment plant residues or MSW in a landfill. For wastewater management systems, carrier water necessary to process food waste through a food waste disposer is added to food waste inputs. Transformations to this 100 kg of food waste as it passes through a system are defined and quantified, including physical, chemical, and biological processes such as aerobic or anaerobic respiration. Other inputs during system use include maintenance materials and operating energy.

System decommissioning includes materials and energy required to remove a system. It is assumed for this project that no materials are required for decommissioning and the energy and cost of decommissioning are 25% of the cost to install the system.

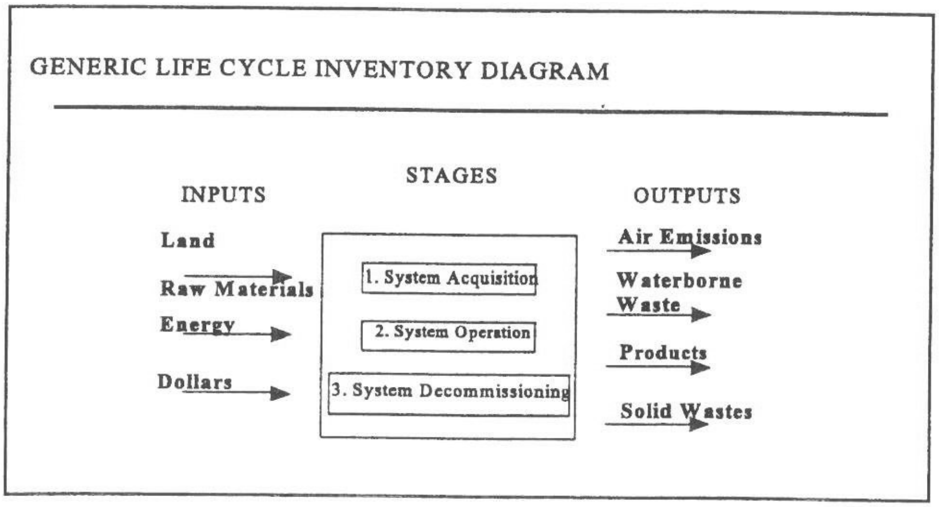


Figure 2.1. Generic life cycle inventory diagram.

Outputs are total flows to the environment, including air emissions, water and waterborne wastes, and solid wastes, from the materials, energy sources and food waste over the design life of the system, all prorated to 100 kg of FWD food waste. Tables ES2.1, Summary of system materials, energy and costs, and ES2.2, Summary of life-cycle emissions from acquisiton, use and decommissioning a system, are examples of tables that are developed for each of the five food waste management systems.

The list of tables and unit factors which follow are developed in Chapter 2 and used throughout this project to complete the life-cycle inventories. The life-cycle inventories are the basis for comparing the five food waste management systems.

p.22	Table 2.4.	Physical and chemical properties of construction materials and fuels.
p.25	Table 2.6.	Summary- energy embodied in materials.
p.34	Table 2.16.	Summary table for embodied wastes in materials.
p.35	Table 2.17.	Quantity estimate of materials in 10,000 ft^2 industrial building.
p.36	Table 2.18.	Summary of materials in 10,000 ft^2 industrial building.
p.40		It is assumed that process equipment is steel and the embodied energy and wastes are those for steel.
p.42		It is assumed that vehicles are steel and the embodied energy and wastes are those for steel.
p.43	Table 2.21.	Energy embodied in water.
p.47	Table 2.22.	Embodied and combustion energy in fuels.
p.47	Table 2.23.	Energy embodied and fuel composition of 1 kWh of electricity.
p.50	Table 2.25.	Table summarizing air emissions, water and waterborne wastes and solid wastes for energy sources.
p.49		The value of 2343 Btu/ton-mile and 5.2 mpg of diesel fuel will be used for tractor-trailer fuel use for this project.
p.51		For single unit trucks a value of 3136 BTU/ton-mile, 7.85 mpg for diesel and 7.20 mpg for gasoline will be used (Courtesy of Franklin Associates Ltd.).
p.53	Table 2.27.	Maintenance materials for industrial buildings.
p.53		No materials are used for decommissioning and the energy and cost of decommissioning is 25% of the cost of installation.
p.56	Table 2.28.	Summary of system materials, energy and cost.
p.57	Table 2.29.	Summary of life-cycle emissions from acquisition, use and decommissioning of a system.

Table ES2.1. Summary of system materials, energy and costs.

	Acquisition	Use	Decommissioning	Total	Per 220.5 lb FW	
Land, ft^2						
Materials	lb	lb	lb	lb	lb	%
construction, maintenance materials, fencing						
process equipment, vehicles						
electricity(1)						
natural gas						
diesel fuel(4)						
gasoline						
FWD materials						
water(2)						
food waste						
Total						
Energy	Btu	Btu	Btu	Btu	Btu	%
embodied in construction and maintenance materials						
embodied in process equipment and vehicles						
electricity-fuels						
natural gas						
diesel (4)						
gasoline						
FWD material						
water(2)						
food waste(3)						
Total						
electricity-kWh						
Costs						

(1)Table 2.23.

(2)Assumes facility water of 25 gal water/day, all embodied water in diesel (attributed to acquisition stage)and electricity and 2.1 Btu/ lb water.

(3)Assumes 2000 Btu/lb food waste (Tchobanoglous, 1993).

(4)Assumes 0.134 ft^3/gal and 54 lb/ft^3 diesel fuel.

Table ES2.2. Summary of life-cycle emissions from acquisition, use and decommissioning of a system.

	Materials**		Energy sources***		Food waste*		Total	
	lb/system life	lb/220.5 lb FW	lb/system life	lb/220.5 lb FW	lb/system life	lb/220.5 lb FW	lb/system life	lb/220.5 lb FW
Air emissions								
particulates								
nitrogen oxides								
hydrocarbons (other than methane)								
sulfur oxides								
carbon monoxide								
carbon dioxide								
aldehydes								
other organics								
ammonia								
lead								
methane								
kerosene								
HCl								
Water vapor-FW								
Total air emissions								
Solid and construction waste								
Compost								
Water and waterborne wastes								
water								
acid								
metal ion								
dissolved solids								
suspended solids								
BOD								
COD								
phenol								
oil								
sulfuric acid								
iron								
ammonia								
chromium								
lead								
zinc								
Total water wastes								
Total								

*Plus water used in the facility/day.

**From materials in buildings and maintenance materials, process equipment and vehicles.

***Includes embodied and combustion emissions for fuels and electricity.

NA- not available

CHAPTER 3. *DETERMINING THE QUANTITY, COMPOSITION AND DESTINATION OF FOOD WASTE- EXECUTIVE SUMMARY.*

Objectives of Chapter 3 include defining the composition, energy content and quantity of food waste going into MSW systems and wastewater management systems from information in engineering sources. Potential food waste, the difference between U.S. food production and consumption, as measured for the USDA from nutrition science data bases, is determined for comparison. A rough mass balance on food waste and an estimate of the amount of food waste going to each waste management system is made.

Conclusions.

1. The composition of food waste is assumed to be $C_{21.53}H_{34.21}O_{12.66}N_{1.00}S_{0.07}$ (Calculated from Table 4.3, Tchobanoglous, 1993).

2. Food waste is 30% solids and 70% water (Morgan, 1994). Food solids are 95% decomposable (Baldwin and Ham, 1996) and 5% ash (Tchobanoglous, 1993).

3. Food energy is 2000 Btu/lb wet food waste (Tchobanoglous, 1993).

4. FWDs transfer 0.21 lb wet food waste (calculated from Table 3.8/ person/day from MSW to wastewater systems; they contribute associated carrier water of 2.2 lb/person/day (Ketzenberger, 1994).

5. The 1990 value of 8% food waste in MSW discarded (EPA530-R-96-001 (Franklin Associates, Ltd.)) will be used to determine food waste in MSW.

6. Potential food waste quantities, as determined from the difference between food production and food consumption, appear to have increased during the ten year period from 1980 to 1990. Food waste in MSW appears to have decreased. Present data bases are inadequate to assess these conflicting trends.

7. Only a portion of the potential food waste- food production minus food consumption- is accounted for in MSW and in wastewater from kitchen sinks, dishwashers and FWDs. A reference in the literature also observed that when food wasted is compared to food available for consumption and to the amount of food thought to be eaten, a gap remains that is

unexplained (Wenlock, Buss, Derry, 1980).

8. Food waste increased in all categories- energy, carbohydrate, fat and protein- between 1980 and 1990. Carbohydrate represents the most and protein the least wasted food parameter.

9. About 75% of potential food waste can be processed through a FWD (Strutz, 1994). Beverages and liquid foods, such as dairy products, are disposed of to a wastewater system whether or not a household has a FWD; fibrous plant materials and relatively ungrindable solids like bones, etc., that are not processed through a FWD, become solid waste.

10. The largest impact of the FWD is to wastewater suspended solids' loadings. FWDs contribute 34% and 28% of the total suspended solids and volatile suspended solids' loadings, respectively. FWDs contribute 85% of the suspended solids and volatile suspended solids of food waste related activities.

11. FWDs contribute about one quarter of the BOD and COD loadings; they make a relatively small (less than 5%) contribution to nitrogen and phosphorus loadings.

12. Food wastes from kitchen sinks and dishwashers contribute N, P, BOD, COD and solids to wastewater loadings, even if FWDs are not used.

13. Food wastes are a source of soluble, readily degradable carbon in wastewater. Although it has not been quantified, FWDs increase the supply of this carbon source. Carbon sources in wastewater impact the oxygen uptake rate, the rate of denitrification and the biological phosphorus uptake rate (Henze et al, 1994). Of particular importance is the concentration of the soluble, readily biodegradable carbon source; it is the dominant rate limiting factor in nutrient removal processes (Henze et al, 1994).

14. No information was found regarding national trends in flows and loadings from households, in lb/c/d, to wastewater treatment plants. Information on inputs to wastewater systems from household appliances is all from the 1970's. In light of the changes in food processing and packaging and dollars spent for food away from home, it seems reasonable to conclude that food waste entering wastewater systems based on measurements taken in the 1970's are too high for the 1990's.

15. No data exists on what is actually occurring in kitchens to determine the fate of a particular food waste and in light of nutrition scientists' studies of food discards, it may not be possible to get unbiased information from households on this subject. Whether a particular food waste is disposed of through the FWDs, a dog, the toilet, a backyard compost pile or the MSW stream, all impact the disposition and composition of potential household food waste.

16. No data was found which quantified the particle size distribution of food waste from

kitchen sinks, dishwashers of FWDs, even though the function of the FWD is particle size reduction. Both increased solids' loadings due to FWDs and the particle size reduction of food waste through a FWD will impact wastewater treatment processes.

17. Food waste in MSW has declined as a percentage of the total MSW stream (from 13.9% to 6.7%), and in the amount generated per person per day (from 0.37 lb/c/d to 0.29 lb/c/d). Food waste disposers (at the rate of 0.21 lb wet food waste/c/d) from 40% of the households in the U.S. can account for most of the decline.

18. Recovery rates for food waste in the U.S. MSW stream, presently, are reported as essentially zero; food waste processed through a FWD is not counted as source reduction or recycling.

19. Food waste has the highest moisture content and biodegradability, one of the highest densities and one of the lowest heating values of MSW organic compounds.

20. Hypothetical MSW streams, assuming all or no households have FWDs, indicate that there is little impact to total tonnages of MSW, heating value content or density of MSW whether or not households use a FWD at the rate assumed (0.21 lb wet food waste total solids/c/d); the largest impacts are to MSW moisture content and biodegradability.

21. The destination of food waste in the U.S. is shown below in Figure ES3.1. About half of the food waste in the US goes to wastewater systems and half goes to MSW systems. Wastewater food waste includes contributions from dishwashers and kitchen sinks. Twelve per cent of food waste goes to on-site systems and 37% goes to POTWs; 41% goes to MSW landfills and 10% to MSW waste-to-energy systems. A negligible amount is currently being composted.

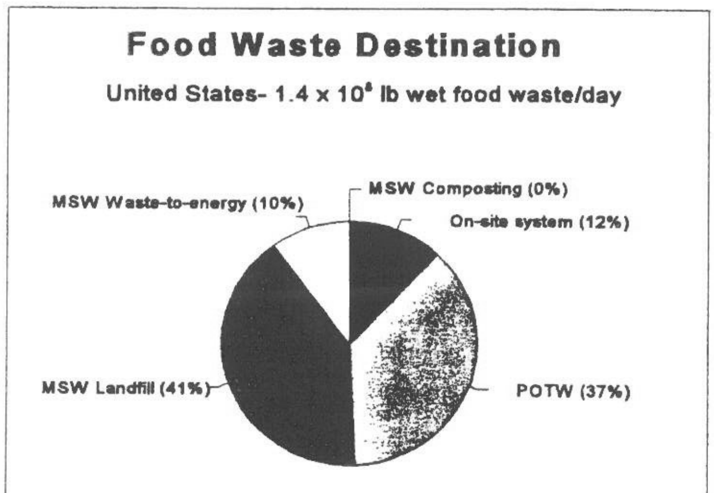


Figure ES3.1. Food waste to five waste management systems.

CHAPTER 4. *FOOD WASTE DISPOSER- EXECUTIVE SUMMARY.*

The food waste disposer is a kitchen appliance which grinds food waste with carrier water, and transfers it into a wastewater collection system. This technology facilitates the rapid removal of wet, highly putrescible material from a municipal solid waste to a wastewater management system. Chapter 4 summarizes the materials, energy, financing and flows to the environment from acquiring, using and decommissioning a food waste disposer.

Impacts of a FWD over its design life are quantified, include those from acquisition (manufacturing, transporting and installing), use (FWD operation) and decommissioning of a FWD over its total life cycle. A FWD processes 2464 lb of food waste and 25,455 lb of carrier water over its design life; impacts will be prorated to 100 kg (220.5 lb) of food waste and associated carrier water (2273 lb). **The ratio (220.5 lb + 2273 lb) divided by (2464 lb + 25,455 lb) is 0.089; all parameters will be multiplied by this value.** Flows to the environment from food waste passing through the FWD are added to flows to the environment generated from energy sources to operate the FWD (burning fossil fuels, etc.) and to those embodied in system materials.

The life-cycle inventory for the FWD includes the following facts and assumptions:

* The ISE Model 333 ½ HP household-size FWD has a 12 year design life.
* The household has 2.63 persons.
* Carrier water to use the FWD is 1 liter per person per day.
* Dry total solids loadings through the FWD are 0.0291 kilograms per person per day; food waste is 30% solids and 28.5% VSS.
* The FWD is used for 0.6 minutes per day.
* The FWD weighs 17.27 pounds with packaging; 95% of FWDs are eventually

landfilled in the US.

* The area in FWD manufacturing buildings is 387,000 ft^2, the building design life is 25 years and 3,225,000 FWD are produced each year.
* The average round-trip distance to a distribution center is 1958 miles in a fully loaded tractor-trailer carrying 2200 units; the gas mileage is 5.3 mpg.
* Installation of a FWD involves a 20 mile round trip in a single unit truck which gets 20 mpg.

Summary.

Table ES4.1 (Table 4.17) gives the summary of materials, energy and costs for a FWD over its design. Figures ES4.1 through ES4.8 (Figures 4.7 through 4.14) are calculated from Table ES4.1. Figures ES4.1 and ES4.2 show the distribution of materials by stage and by category. Over the life-cycle of the FWD, water represents 90% of the materials required, by weight; the consumption of water occurs primarily during use of the FWD. Subtracting food waste and carrier water, Figure ES4.3 shows that water is 98% of system materials. Figures ES4.4 and ES4.5 show energy distributions by stage and by category. Over 80% of the total system energy is in food waste; most (84%) of the energy is accounted for during the use of the FWD. Figure ES4.6 shows that, minus food waste, 53% of FWD energy is embedded in FWD materials and 45% is embedded in fuels. Figures ES4.7 and ES4.8 show the breakdown of costs by stage for both a low and high estimate. The acquisition stage accounts for between 78 and 87% of the total life-cycle costs of the FWD.

Table ES4.2 (Table 4.20) gives a summary of life-cycle emissions from acquisition, use and decommissioning of the FWD. Figures ES 4.9 through ES4.15 (Figures 4.15 through 4.21) are calculated from Table ES4.2. Figure ES4.9 shows total flows to the environment by source; food waste contributes 90% and materials contribute 9% of the total flows. Figure

ES4.11 shows total flows by type; water and waterborne waste make up 99% of the total flows to the environment, most is carrier water. Air and solid wastes each make up 1% of the flows to the environment. Figures ES4.12 shows air emissions by source. Energy sources contribute 57% of the total air emissions, which are mainly carbon dioxide generated during

Table ES4.1. (Table 4.17.) Summary of materials, energy and costs of a FWD over its design life.

	Table #	Acquisition	Use	Decommissioning	Total			Total no FW	
Land, ft^2	4.200	0.0072	0	0	0.0072	0.0006			
Materials		lb	lb	lb	lb	lb/100 kg FW	%	lb/100 kg FW	%
construction materials	4.4, 4.5	1	Neg.	Neg.	1	0.1	0	1	0
process equip., veh.	4.6	1	Neg.	Neg.	1	0.1	0	1	0
electricity*	4.1	16	40	Neg.	56	5.0	0	16	1
natural gas	4.1	6	Neg.	Neg.	6	0.5	0	6	0
diesel fuel	4.8, 4.9, p.161	2	Neg.	Neg.	2	0.1	0	2	0
gasoline	p. 162	6	Neg.	2	8	0.7	0	8	0
FWD materials	4.7	17	0	0	17	1.5	0	17	1
water	4.11, 4.18, 4.19	2910	25455	Neg.	28365	2538.5	92	2910	98
food waste	4.16	0	2464	0	2464	220.5	8	0	0
Total		2958	27959	2	30918	2767.0	100	2960	100
Energy		Btu	Btu	Btu	Btu	Btu/ 100kgFW	%	Btu/ 100kg FW	%
embod.-materials	4.4, 4.5	3437	Neg.	Neg.	3437	308	0	3437	0
embod.-process equip. /veh.icles	4.6	16504	Neg.	Neg.	16504	1477	0	16504	2
electricity	4.1	69023	173090	Neg.	242113	21668	4	69023	7
natural gas	4.1	146667	Neg.	Neg.	146667	13126	2	146667	15
diesel	4.8, 4.9, p.161	41537	Neg.	Neg.	41537	3717	1	41537	4
gasoline	p. 162	150000	Neg.	37500	187500	16780	3	187500	19
FWD material	4.7	527373	0	0	527373	47197	9	527373	53
water**	4.11, 4.18, 4.19	6111	53455	Neg.	59566	5331	1	6111	1
food waste***	4.16	0	4927654	0	4927654	441000	80	0	0
Total		960651	5154198	37500	6152349	550604	100	998151	100
Costs-low, $	4.14	77.04	14.82	6.76	98.62	8.83			
Costs-high, $	4.14	169.09	14.82	11.02	194.93	17.45			
Electricity, kWh	4.1	7	16	Neg.	23	2			

*Table 2.23.

**Table 2.21.

***Assumes 2000 Btu/lb food waste (Tchobanoglous, 1993).

Neg.- Assumed to be negligible.

the combustion of fossil fuels. Figure ES4.13 shows solid waste by source. Solid wastes are about half attributable to post-consumer FWDs and half to materials. Figures ES4.14 and ES4.15 show water and waterborne wastes by source and by type. Food waste contributes essentially all of the water and waterborne waste. Figure ES4.16 is an overall summary of life-cycle materials, energy, costs and flows from a FWD. As shown in Figure ES4.10, if food waste and carrier water are subtracted out, there are 3100 lb of water and waterborne waste, air emissions and solid waste over the life cycle of a FWD. Ninety four per cent of the total is water and 5% is air emissions. **The flows without food waste and carrier water are the tradeoffs for flows from a MSW collection system and managing food waste as a solid waste.**

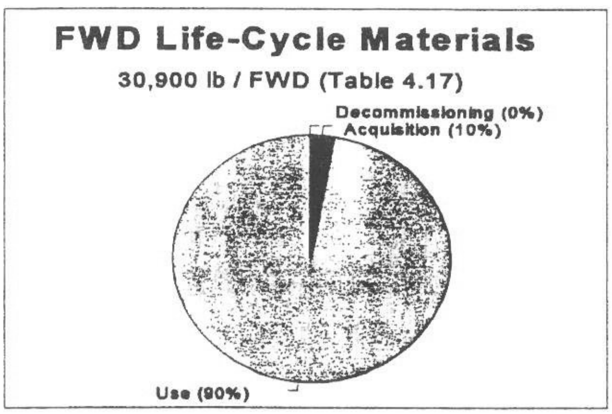


Figure ES4.1. Materials- by stage.

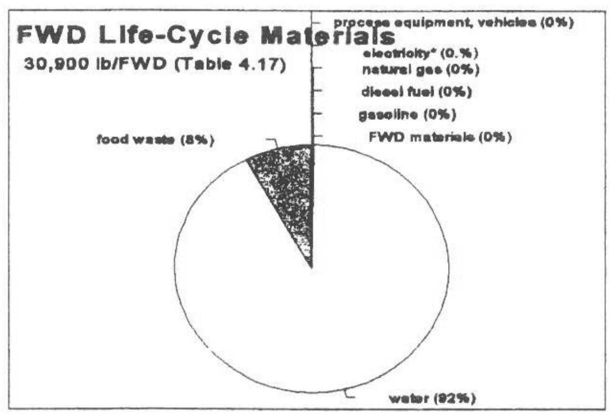


Figure ES4.2. Materials- by category.

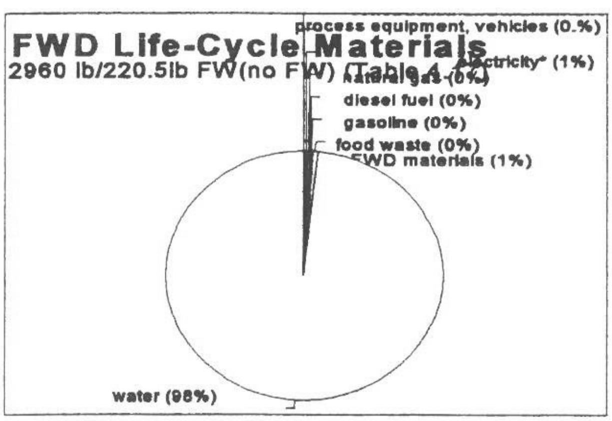


Figure ES4.3. Materials (No FW)- by category.

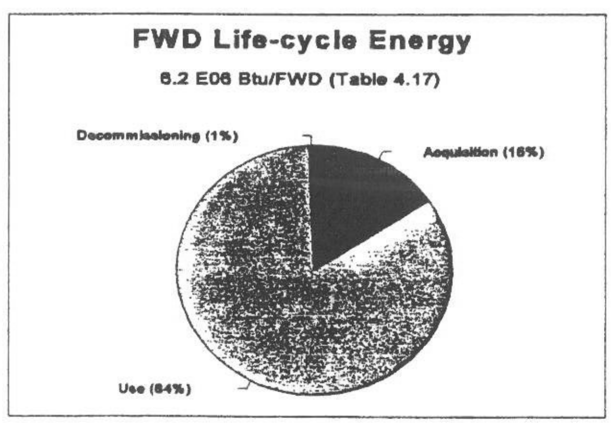


Figure ES4.4. Energy- by stage.

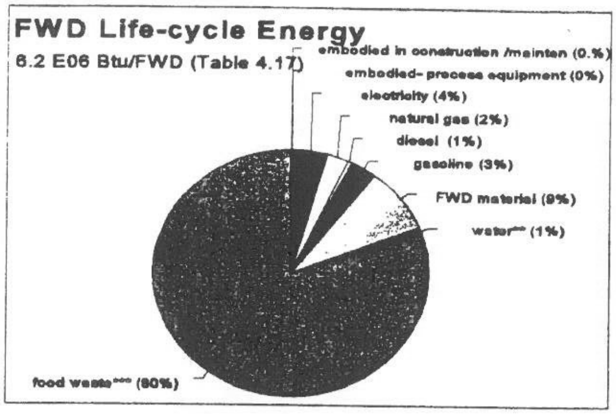


Figure ES4.5. Energy- by category.

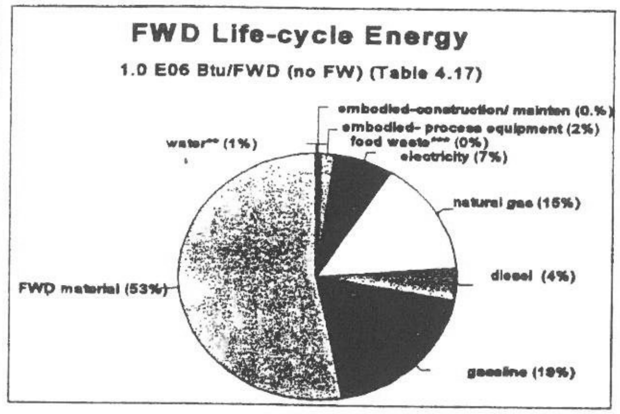


Figure ES4.6. Energy (No FW)- by category.

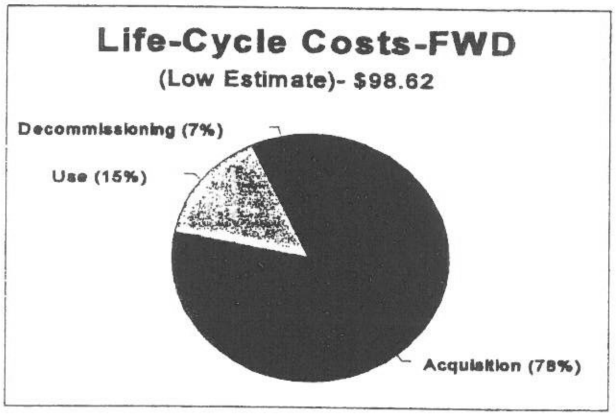


Figure ES4.7. FWD cost by stage- low.

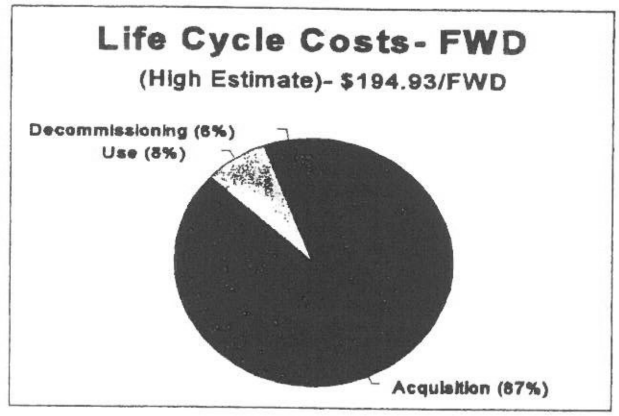


Figure ES4.8. FWD cost by stage- high.

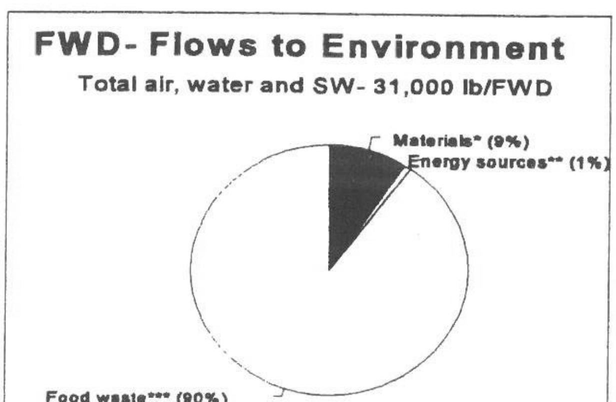


Figure ES4.9. Summary-flows to environment.

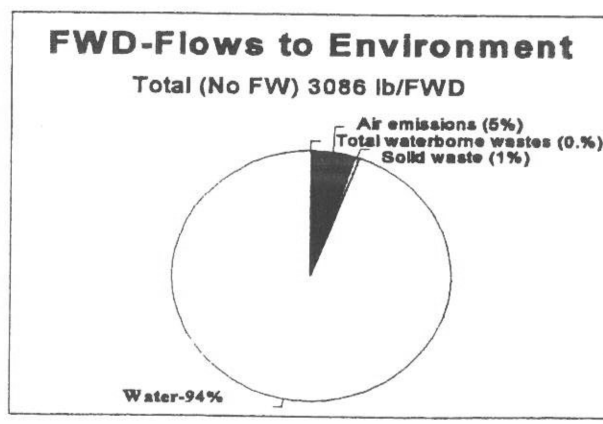


Figure ES4.10. Summary- Flows (No FW).

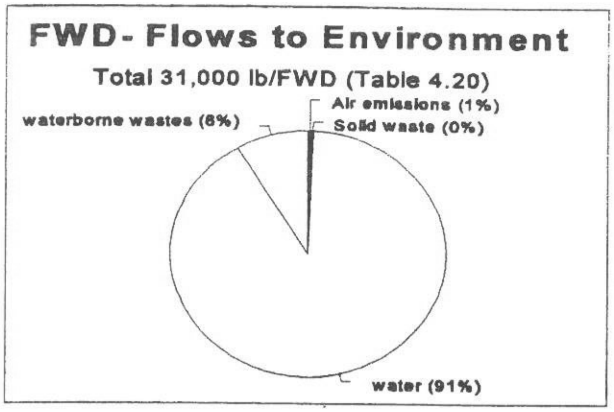


Figure ES4.11. Summary- flows by type.

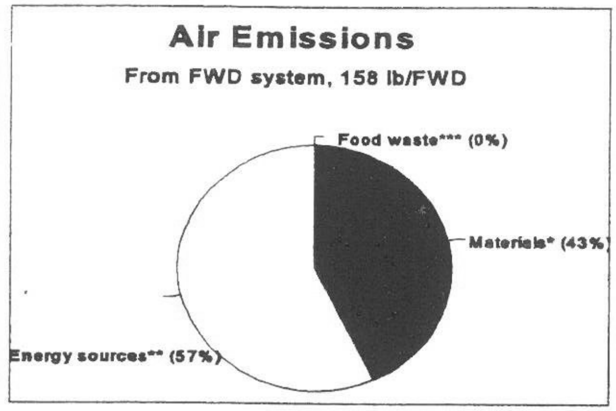


Figure ES4.12. Air emissions by source.

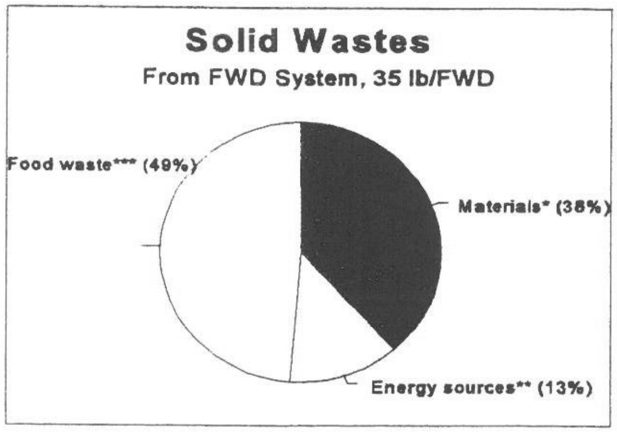


Figure ES4.13. Solid waste by source.

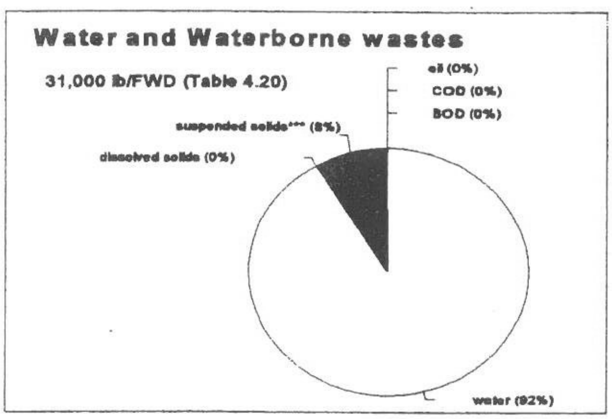


Figure ES4.14. Water/waterborne wastes by type.

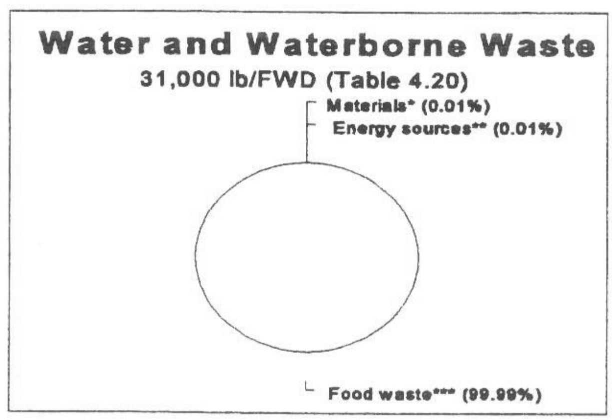


Figure ES4.15. Waterborne wastes by source.

Table ES4.2. (Table 4.20.) Summary of life-cycle emissions from acquisition, use and decommissioning of the FWD.

	Materials*		Energy sources**		Food waste***		Total		Total (No FW)
	lb/FWD	lb/220.5 lb FW	lb/FWD	lb/220.5 lb FW	lb/FWD	lb/220.5 lb FW	lb/FWD	lb/220.5 lb FW	lb/FWD
Air emissions									
particulates	0.16	0.0	0.15	0.0	0.0	0.0	0.31	0.03	0.31
nitrogen oxides	0.17	0.0	0.34	0.0	0.0	0.0	0.50	0.04	0.50
hydrocarbons (other than methane)	0.15	0.0	0.37	0.0	0.0	0.0	0.52	0.05	0.52
sulfur oxides	0.36	0.0	0.35	0.0	0.0	0.0	0.72	0.06	0.72
carbon monoxide	0.69	0.1	0.77	0.1	0.0	0.0	1.46	0.13	1.46
carbon dioxide	65.91	5.9	88.02	7.9	0.0	0.0	153.93	13.78	153.93
aldehydes	NA	NA	0.00	0.0	0.0	0.0	0.00	0.00	0.00
other organics	NA	NA	0.24	0.0	0.0	0.0	0.24	0.02	0.24
ammonia	NA	NA	0.00	0.0	0.0	0.0	0.00	0.00	0.00
lead	NA	NA	0.00	0.0	0.0	0.0	0.00	0.00	0.00
methane	0.00	0.0	0.00	0.0	0.0	0.0	0.00	0.00	0.00
kerosene	NA	NA	0.00	0.0	0.0	0.0	0.00	0.00	0.00
HCl	NA	NA	0.00	0.0	0.0	0.0	0.00	0.00	0.00
Total	67.44	6.04	90.24	8.08	0.0	0.0	157.68	14.11	158
Solid waste	13.57	1.2	4.54	0.4	17.3	1.5	35.37	3.17	18
Waterborne wastes									
water	2744.72	245.6	165.17	14.78	25454.71	2432.42	28364.60	2692.84	2909.20
acid	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00
metal ion	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00
dissolved solids	0.01	0.00	0.14	0.01	0.00	0.00	0.15	0.01	0.15
suspended solids***	0.08	0.01	0.00	0.00	2463.83	66.15	2463.91	66.16	0.08
BOD_5	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
COD	0.04	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.04
phenol	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00

oil	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02
sulfuric acid	NA	NA	0.03	0.00	0.00	0.00	0.03	0.00	0.03
iron	NA	NA	0.01	0.00	0.00	0.00	0.01	0.00	0.01
ammonia	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00
chromium	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00
lead	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00
zinc	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total water and waterborne wastes	0.16	0.01	0.2	0.02	2463.83	66.15	2464	66	0.34
Total	2826	253	260	23	27963	2500	31022	2776	3086

*From materials in FWDs, buildings and maintenance materials, process equipment and vehicles and facility water; Table 4.18.

**Includes embodied and combustion emissions; Table 4.19.

***For FW, food waste solids given under SS and food water under water; Table 4.16.

NA- not available

Conclusions.

1. Land requirements are 0.0072 ft^2 per FWD and 0.0006 ft^2 per 100 kg food waste.

2. Over the life-cycle of the FWD system, 31,000 lb of materials/FWD (2800 lb/100 kg food waste) are required. Water is 92% of the total system materials. Ninety per cent of the materials are required during system use.

3. Over the life-cycle of the FWD system, 6.2×10^6 Btu of energy/FWD (5.5×10^5 Btu/100 kg FW) are required. Eighty per cent is the energy in food waste. Eighty four per cent is attributable to the use of the system.

4. The average cost of the FWD is assumed to be $194.93/FWD ($17.45 per 100 kg FW). Eighty seven per cent of the cost is attributable to system acquisition; eight per cent of the system cost is for system use.

5. There are about 31,000 lb of total flows to the environment for a FWD (2800 lb/100 kg FW). The predominant environmental flow is from water and waterborne wastes, 99% of the flows to the environment, most of which come from food waste. Materials and energy sources are each small (1%) contributions.

6. Energy sources contribute 57% and materials contribute 43% of the life-cycle air emissions (158 lb/FWD); 97% of the air emissions are carbon dioxide.

7. Solid wastes (38 lb/FWD) are a negligible fraction of the total flows to the environment. About half are from landfilled FWD materials, 38% are from solid wastes and construction wastes embodied in materials and 13% are from energy sources.

8. Water is 91% and food waste suspended solids are 9% of the water and waterborne waste flows to the environment; essentially all are from food waste.

9. If food waste and carrier water are subtracted out, 3000 lb of materials and 1×10^6 Btu/FWD are required over the life cycle of a FWD. If food waste and carrier water are subtracted out from flows to the environment, water is 94% and air emissions are 5%. **The materials, energy and flows to the environment from the FWD (minus food waste and carrier water) are the tradeoff for materials, energy and flows to the environment from a MSW collection system.**

10. The percentage of housing units with FWDs has increased slowly since the 1970s and appears to be stable at 40%. It seems likely that the impact of residential FWD use is also stable.

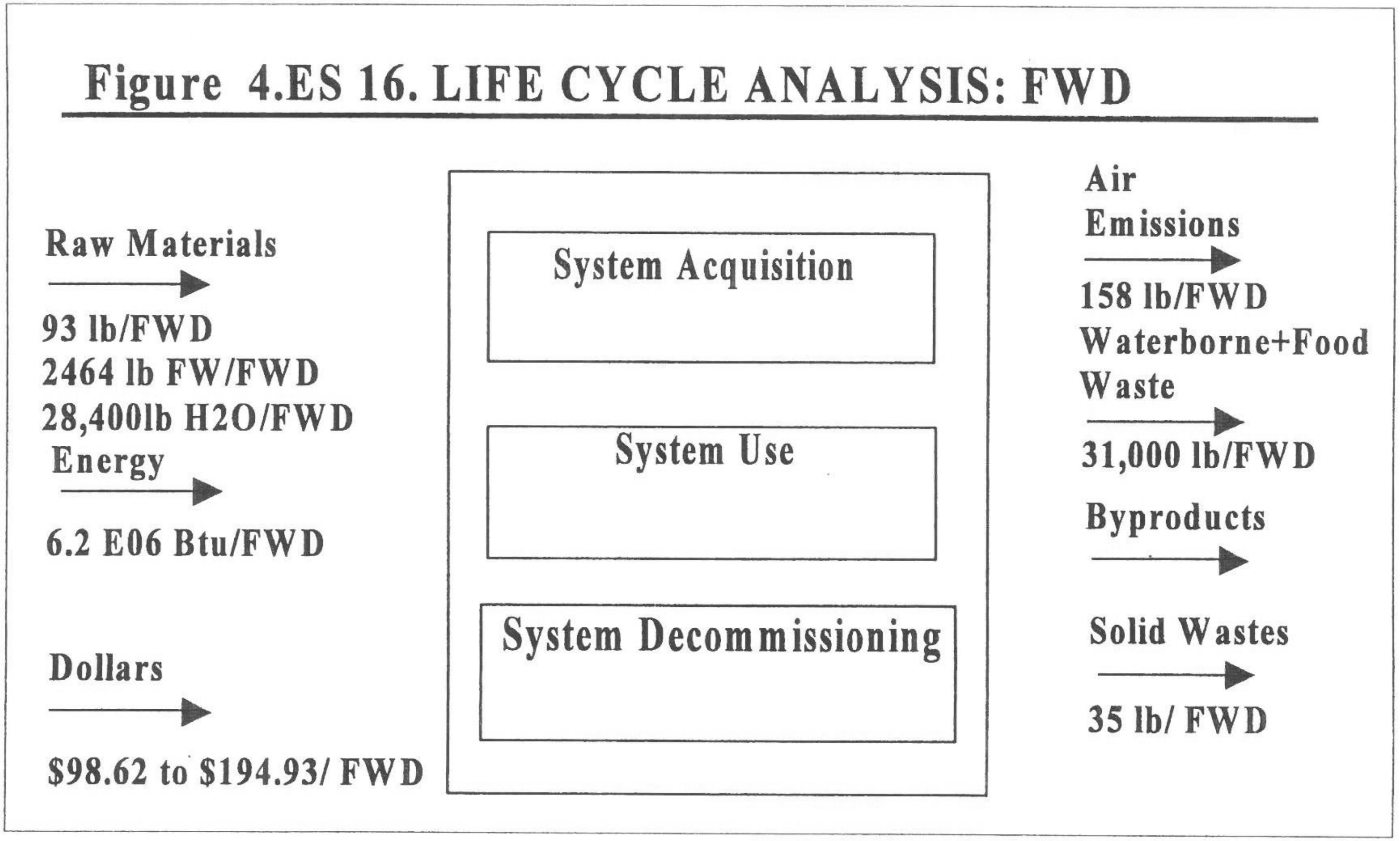


Figure ES4.16. Life Cycle Inventory: FWD.

CHAPTER 5. *ON-SITE SYSTEM EXECUTIVE SUMMARY.*

In Chapter 5, the materials, energy, costs and flows to the environment from the difference in two on-site systems are quantified. One on-site system is designed for and one designed without a FWD; the difference between two on-site systems is attributable to the use of the FWD. Materials, energy, costs and flows to the environment from the acquisition, use and decommissioning the difference in on-site systems are prorated to 100 kg of FWD food waste.

The life-cycle inventory for the OSS in Chapter 5 includes the following facts and assumptions:

* The system designed for the FWD has a 1250 gallon, two-compartment septic tank and a 1000 ft^2 absorption bed.
* The system designed without the FWD has a 1000 gallon, two-compartment septic tank and a 750 ft^2 absorption bed.
* The septic system has a 20 year design life.
* The land requirements are assumed to be the area of the bed plus 50%.
* Means, 1994 is used for costs and installation time.
* A three year pumping interval is assumed.
* Effluent concentrations are from Ketzenberger, 1994 and Laak and Crates, 1977; septage concentrations are from ASCE, 1992.
* Food waste concentrations are from Tables 3.8 and 3.9 of this report; carrier water and the time for FWD operation is from Ketzenberger, 1994.
* Costs for septage removal and haul are from Speedway Sewer Service, 1994.
* An interest rate of 10% and an inflation rate of 3% are assumed.
* Food waste volatile solids in effluent are assumed to be anaerobically decomposed half in the tank and half in the absorption bed.
* It is assumed that there is a 50 mile round trip required for system materials and a 40 mile round trip haul for septage disposal.
* It is assumed that upon decommissioning, the tank is landfilled and absorption bed materials (primarily aggregate) remain on site.
* **The fraction used to prorate parameters to 100 kg of FW is 0.0537, the ratio of 100 kg FW plus associated carrier water (CW) to the total FW + CW through the system over the 20 year design life.**

Summary of materials, energy and costs and flows to the environment for an on-site system. Table ES5.1 (Table 5.19) summarizes life-cycle materials, energy and costs of the difference in on-site systems due to the FWD. Figure ES5.1 (Figure 5.8) shows total materials for the on-site system/FWD. Water is 54% of the materials and construction materials are 43%; food waste is 3% and all others are negligible. Figure ES5.2 (Figure 5.9) shows total system energy for the OSS/FWD. For the OSS and FWD, 38% is energy embodied in materials, food waste energy is 32%, energy in diesel is 22% and all others are under 5%. Figures ES5.3 and ES5.4 (Figures 5.10 and 5.11) show materials and energy by stage; for both over 90% is attributable to the acquisition stage. Figure ES5.5 (Figure 5.12) shows that for the combined OSS and FWD system, 96% of total system materials are attributable to the OSS and 4% to the FWD. Figure ES5.6 (Figure 5.13) shows that for the combined system, 92% of the total system energy is attributable to the OSS and 8% is attributable to the FWD. Figures ES5.7 and ES5.8 (Figures 5.14 and 5.15) show high and low estimates for total system costs, based on high and low estimates for a FWD. The OSS ranges from 74% to 86% of the total system cost.

Table ES5.2 (Table 5.22) summarizes total flows to the environment from materials, energy sources and food waste for the OSS alone, the FWD alone and the total OSS and FWD system. Figures ES5.9 and ES5.10 (Figures 5.16 and 5.17), calculated from Table ES5.2, show

flows to the environment from the FWD plus OSS. Figure ES5.9 shows that 52% of the flows are attributable to food waste, 44% to materials and 4% to energy sources. Figure

ES5.10 shows that 80% of the total flows are water, 10% is solid waste, 6% is septage and about 3% is air emissions. About 38% is from OSS and 62% from the FWD. It is assumed that materials in the bed are decommissioned in place; 3100 lb of materials/100 kg FW remain in the system. Figure ES5.11 summarizes inputs and outputs from the FWD/OSS.

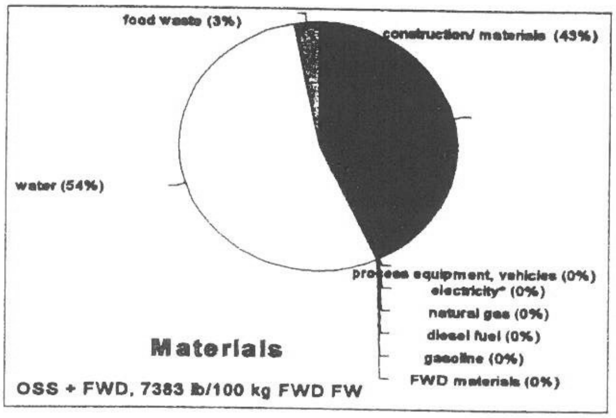


Figure ES5.1.Life-cycle materials-OSS+FWD.

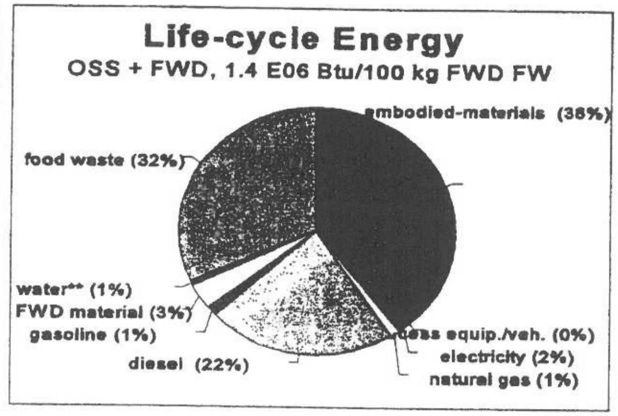


Figure ES5.2.Life-cycle energy-OSS +FWD.

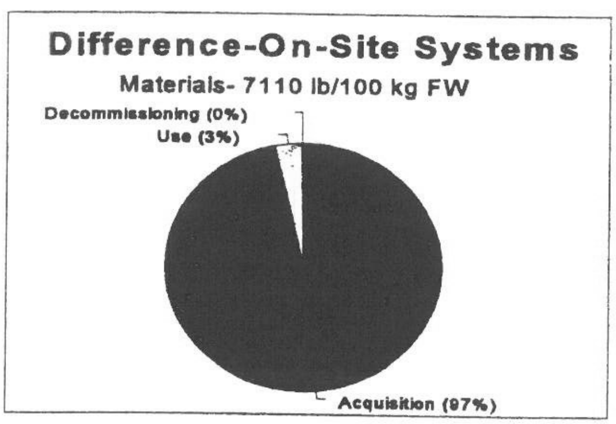


Figure ES5.3. Materials-by stage.

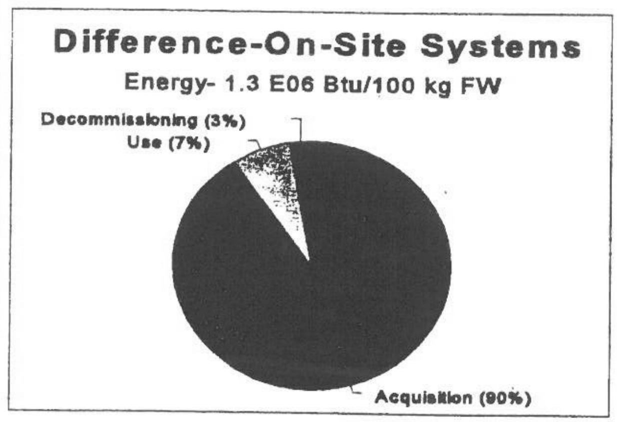


Figure ES5.4. Energy- by stage.

Table ES5.1. (Table 5.19.) Summary of materials, energy and costs of the difference between two on-site systems with and without the FWD.

	Table #	Acquisition	Use	Decommissioning	Total	Per 100 kg FW		FWD (Table 4.17)	Total OSS+FWD	
Land, ft^2	5.5	375	0	0	380.5	20		0.0006	20	
Materials		lb	lb	lb	lb	lb/100 kg	%	lb/100 kg	lb/100 kg	%
construction materials	5.6	5.9e+04	Neg.	Neg.	5.9e+04	3143	44	0.1	3143	43
process equip., vehicles		Neg.	Neg.	Neg.	0.0e+00	0	0	0.1	0	0
electricity*		Neg.	Neg.	Neg.	0.0e+00	0	0	5.0	5	0
natural gas		Neg.	Neg.	Neg.	0.0e+00	0	0	0.5	1	0
diesel fuel		1.9e+02	2.9e+01	1.7e+01	2.4e+02	13	0	0.1	13	0
gasoline		Neg.	Neg.	Neg.	0.0e+00	0	0	0.7	1	0
FWD materials		0.0e+00	0.0e+00	0.0e+00	0.0e+00	0	0	1.5	2	0
water**		2.7e+04	2.9e+02	1.7e+02	2.7e+04	3733	53	265.0	3999	54
food waste		0.0e+00	0.0e+00	0.0e+00	0.0e+00	221	3	0.0	221	3
Total		8.5e+04	3.2e+02	1.9e+02	8.6e+04	7110	100	273.0	7383	100
Energy		Btu	Btu	Btu	Btu	Btu/100 kg	%	Btu/100 kg	Btu/100 kg	%
embod.-mat./ construction energy	5.6	9.8e+06	Neg.	Neg.	9.8e+06	526506	41	308	526814	38
embod.- process equip./veh.		Neg.	Neg.	Neg.	0.0e+00	0	0	1477	1477	0
electricity		Neg.	Neg.	Neg.	0.0e+00	0	0	21668	21668	2
natural gas		Neg.	Neg.	Neg.	0.0e+00	0	0	13126	13126	1
diesel		4.5e+06	6.8e+05	4.0e+05	5.6e+06	302149	24	3717	305866	22
gasoline		Neg.	Neg.	Neg.	0.0e+00	0	0	16780	16780	1
FWD material		0.0e+00	0.0e+00	0.0e+00	0.0e+00	0	0	47197	47197	3
water**		5.6e+04	6.1e+02	3.6e+02	5.7e+04	7840	1	557	8397	1
food waste***		0.0e+00	0.0e+00	0.0e+00	0.0e+00	441000	35	0	441000	32
Total		1.4e+07	6.8e+05	4.0e+05	1.5e+07	1277495	100	104830	1382325	100
Costs-low****		840.40	0.00	67.88	908.27	49.75		8.83	58.58	
Costs-high****		840.40	0.00	67.88	908.27	49.75		17.45	67.20	
electricity, kWh		Neg.	Neg.	Neg.	0	0.00		2		

*Table 2.23.

**Table 2.21; water in construction materials attributed to acquisition: water in energy sources attributed proportionally.

***Assumes 2000 Btu/lb food waste (Tchobanoglous, 1993).

****Acquisition cost is the difference in initial system costs and the difference in land costs between the two systems; there is no difference in operating costs because there is a three year pumping interval for both systems; decommissioning cost is the difference in tank removal for the two systems and the cost to landfill the difference in materials. The cost per 100 kg is the difference in net present value, assuming that decommissioning costs are borrowed today, with a 3% inflation rate and a 10% interest rate, between the two systems per 100 kg.

Neg.- Assumed to be negligible.

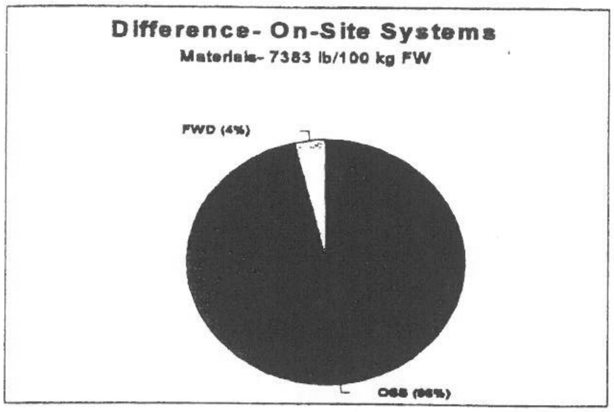


Figure ES5.5. Materials- %OSS and %FWD.

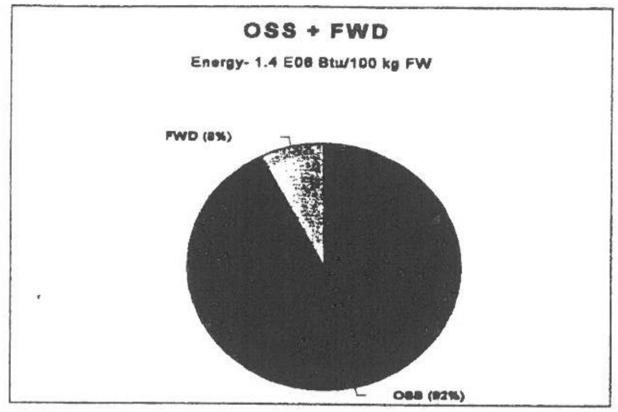


Figure ES5.6. Energy- %OSS and %FWD.

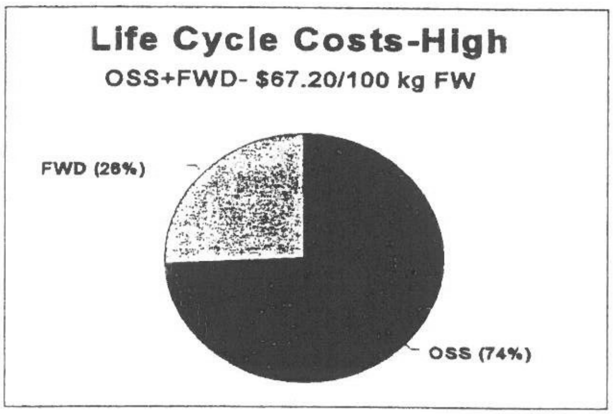


Figure ES5.7. Costs- low.

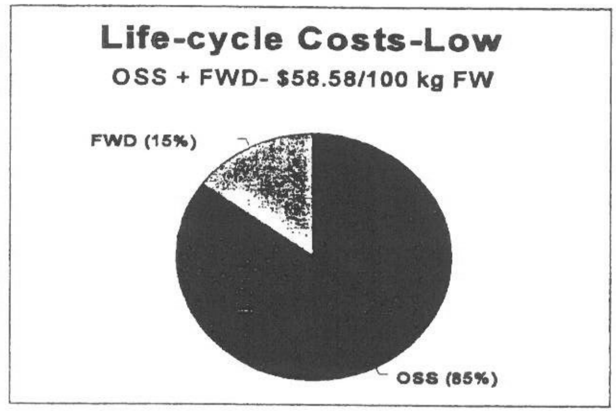


Figure ES5.8. Costs- high.

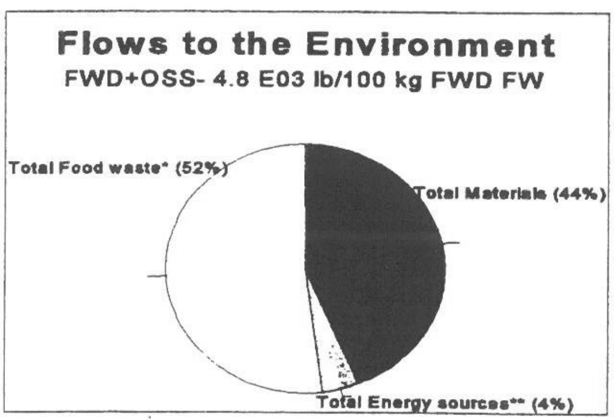


Figure ES5.9. Flows to environment by source.

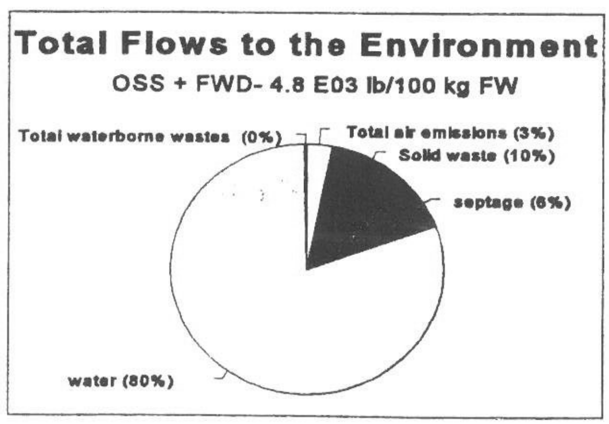


Figure ES5.10. Flows to environment by type.

Table ES5.2. (Table 5.22). Summary of life-cycle emissions from acquisition, use and decommissioning of the difference in on-site systems with and without the FWD.

	OSS Materials**		FWD Materials ****	Total Materials	OSS Energy sources***		FWD Energy sources ****	Total Energy sources	OSS FW*	FWD FW ****	Total FW*	OSS Total		FWD Total	OSS+FWD Total
	lb	lb/100 kg FW	lb/100 kg	lb/100 kg FW	lb	lb/100 kg FW	lb/100 kg FW	lb/100 kg FW	lb/100 kg FW	lb/100 kg FW	lb/100 kg FW	lb	lb/100 kg FW	lb/100 kg FW	lb/100 kg FW
Air emissions															
particulates	3.4e+00	1.8e-01	1.4e-02	2.0e-01	1.0e+00	5.6e-02	1.3e-02	7.0e-02	0.0e+00	0.0e+00	0.0e+00	4.4e+00	2.4e-01	2.8e-02	2.7e-01
NO_x	4.3e+00	2.3e-01	1.5e-02	2.5e-01	7.2e+00	3.9e-01	3.0e-02	4.2e-01	0.0e+00	0.0e+00	0.0e+00	1.1e+01	6.2e-01	4.5e-02	6.6e-01
HC (notCH_4)	3.8e-01	2.0e-02	1.3e-02	3.3e-02	3.4e+00	1.8e-01	3.3e-02	2.2e-01	0.0e+00	0.0e+00	0.0e+00	3.8e+00	2.1e-01	4.7e-02	2.5e-01
sulfur oxides	3.9e+00	2.1e-01	3.2e-02	2.4e-01	1.5e+00	8.0e-02	3.2e-02	1.1e-01	0.0e+00	0.0e+00	0.0e+00	5.4e+00	2.9e-01	6.4e-02	3.6e-01
CO_2	2.1e+00	1.1e-01	6.2e-02	1.7e-01	7.1e+00	3.8e-01	6.9e-02	4.5e-01	0.0e+00	0.0e+00	0.0e+00	9.1e+00	4.9e-01	1.3e-01	6.2e-01
CO	6.1e+02	3.3e+01	5.9e+00	3.9e+01	8.7e+02	4.7e+01	7.9e+00	5.5e+01	3.4e+01	0.0e+00	3.4e+01	1.5e+03	1.1e+02	1.4e+01	1.3e+02
aldehydes	NA	0.0e+00	NA	0.0e+00	2.0e-01	1.1e-02	1.6e-04	1.1e-02	0.0e+00	0.0e+00	0.0e+00	2.0e-01	1.1e-02	1.6e-04	1.1e-02
other organics	NA	0.0e+00	NA	0.0e+00	3.9e+00	2.1e-01	2.1e-02	2.3e-01	0.0e+00	0.0e+00	0.0e+00	3.9e+00	2.1e-01	2.1e-02	2.3e-01
ammonia	NA	0.0e+00	NA	0.0e+00	1.3e-03	6.9e-05	4.7e-06	7.4e-05	0.0e+00	0.0e+00	0.0e+00	1.3e-03	6.9e-05	4.7e-06	7.4e-05
lead	NA	0.0e+00	NA	0.0e+00	3.6e-07	2.0e-08	3.5e-06	3.5e-06	0.0e+00	0.0e+00	0.0e+00	3.6e-07	2.0e-08	3.5e-06	3.5e-06
methane	8.0e-02	4.3e-03	1.8e-04	4.5e-03	1.7e-03	8.9e-05	6.4e-05	1.5e-04	1.5e+01	0.0e+00	1.5e+01	8.2e-02	1.5e+01	2.5e-04	1.5e+01
kerosene	NA	0.0e+00	NA	0.0e+00	4.6e-06	2.5e-07	1.0e-06	1.3e-06	0.0e+00	0.0e+00	0.0e+00	4.6e-06	2.5e-07	1.0e-06	1.3e-06
HCl	NA	0.0e+00	NA	0.0e+00	4.0e-05	2.1e-06	1.4e-07	2.3e-06	0.0e+00	0.0e+00	0.0e+00	4.0e-05	2.1e-06	1.4e-07	2.3e-06
Total air emissions	6.3e+02	3.4e+01	6.0e+00	4.0e+01	9.0e+02	4.8e+01	8.1e+00	5.6e+01	4.9e+01	0.0e+00	4.9e+01	1.5e+03	1.3e+02	1.4e+01	1.4e+02
SW	8.8e+03	4.7e+02	1.2e+00	4.8e+02	2.7e+00	1.5e-01	4.1e-01	5.5e-01	0.0e+00	1.5e+00	1.5e+00	8.8e+03	4.7e+02	3.2e+00	4.8e+02
other-septage	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0e+00	3.1e+02	0.0e+00	3.1e+02	0.0e+00	3.1e+02	0.0e+00	3.1e+02
Waterborne wastes															
water	2.5e+04	1.3e+03	2.5e+02	1.6e+03	2.4e+03	1.3e+02	1.5e+01	1.4e+02	2.1e+03	0.0e+00	2.1e+03	2.7e+04	3.6e+03	2.6e+02	3.8e+03
acid	NA	0.0e+00	NA	0.0e+00	2.8e-07	1.5e-08	1.0e-09	1.6e-08	6.6e-02	0.0e+00	6.6e-02	2.8e-07	6.6e-02	1.0e-09	6.6e-02
metal ion	NA	0.0e+00	NA	0.0e+00	6.0e-03	3.2e-04	2.1e-05	3.4e-04	0.0e+00	0.0e+00	0.0e+00	6.0e-03	3.2e-04	2.1e-05	3.4e-04
DS	0.0e+00	0.0e+00	1.1e-03	1.1e-03	3.4e+00	1.8e-01	1.2e-02	1.9e-01	0.0e+00	0.0e+00	0.0e+00	3.4e+00	1.8e-01	1.3e-02	1.9e-01
SS	1.5e-01	7.8e-03	7.0e-03	1.5e-02	3.1e-03	1.7e-04	1.1e-05	1.8e-04	1.2e+01	0.0e+00	1.2e+01	1.5e-01	1.2e+01	7.1e-03	1.2e+01
BOD_5	6.3e-02	3.4e-03	1.0e-03	4.4e-03	3.3e-03	1.8e-04	1.2e-05	1.9e-04	0.0e+00	0.0e+00	0.0e+00	6.6e-02	3.5e-03	1.1e-03	4.6e-03
COD	0.0e+00	0.0e+00	3.9e-03	3.9e-03	1.6e-02	8.7e-04	5.9e-05	9.3e-04	0.0e+00	0.0e+00	0.0e+00	1.6e-02	8.7e-04	4.0e-03	4.8e-03

phenol	NA	0.0e+00	NA	0.0e+00	1.9e-05	1.0e-06	7.0e-08	1.1e-06	0.0e+00	0.0e+00	0.0e+00	1.9e-05	1.0e-06	7.0e-08	1.1e-06
oil	5.5e-03	2.9e-04	1.3e-03	1.6e-03	4.1e-02	2.2e-03	1.8e-04	2.4e-03	0.0e+00	0.0e+00	0.0e+00	4.6e-02	2.5e-03	1.4e-03	3.9e-03
sulfuric acid	NA	0.0e+00	NA	0.0e+00	1.0e-02	5.5e-04	2.4e-03	3.0e-03	0.0e+00	0.0e+00	0.0e+00	1.0e-02	5.5e-04	2.4e-03	3.0e-03
iron	NA	0.0e+00	NA	0.0e+00	2.7e-03	1.4e-04	6.1e-04	7.5e-04	0.0e+00	0.0e+00	0.0e+00	2.7e-03	1.4e-04	6.1e-04	7.5e-04
ammonia	NA	0.0e+00	NA	0.0e+00	4.6e-04	2.5e-05	1.7e-06	2.7e-05	0.0e+00	0.0e+00	0.0e+00	4.6e-04	2.5e-05	1.7e-06	2.7e-05
chromium	NA	0.0e+00	NA	0.0e+00	1.1e-06	6.0e-08	4.1e-09	6.5e-08	0.0e+00	0.0e+00	0.0e+00	1.1e-06	6.0e-08	4.1e-09	6.5e-08
lead	NA	0.0e+00	NA	0.0e+00	5.0e-07	2.7e-08	1.8e-09	2.8e-08	0.0e+00	0.0e+00	0.0e+00	5.0e-07	2.7e-08	1.8e-09	2.8e-08
zinc	NA	0.0e+00	NA	0.0e+00	7.3e-06	3.9e-07	2.7e-08	4.2e-07	0.0e+00	0.0e+00	0.0e+00	7.3e-06	3.9e-07	2.7e-08	4.2e-07
Total waterborne wastes	2.1e-01	1.1e-02	1.4e-02	2.6e-02	3.5e+00	1.9e-01	1.6e-02	2.0e-01	1.2e+01	0.0e+00	1.2e+01	3.7e+00	1.3e+01	3.0e-02	1.3e+01
Total	3.4e+04	1.8e+03	2.5e+02	2.1e+03	3.3e+03	1.8e+02	2.3e+01	2.0e+02	2.5e+03	1.5e+00	2.5e+03	3.8e+04	4.5e+03	2.8e+02	4.8e+03

*From FW, carrier water and FWD materials; OSS food waste Table 5.17.

**From materials in buildings and maintenance materials, process equipment and vehicles-Table 5.20.

***Includes embodied and combustion emissions-Table 5.21.

****FWD information from Table 4.20.

NA- not available

Conclusions: Following are conclusions from Chapter 5:

1. The land attributable to 100 kg of FW in an OSS is 20 ft^2; 0.0006 ft^2 is attributable to the FWD.

2. There are 7383 lb of materials/100 kg of FW attributable to the difference in OSS, food waste and the FWD; of this total, 4616 lb is attributable to the OSS, 273 to the FWD and 2494 lb to food waste.

3. There is 1.4×10^6 Btu/100 kg FW attributable to the OSS, FWD and food waste; of this 8.3×10^5 Btu/100 kg FW is attributable to the difference in OSS, 4.4×10^5 Btu/100 kg to food waste and 1.0×10^5 Btu/100 kg to the FWD.

4. Assuming an ISE Model 333 ½ HP FWD, the average cost of a FWD($17.45)/ difference in OSS ($49.75) is $67.20/100 kg FW; assuming an industry average for the FWD, the average cost of a FWD ($8.83)/difference in OSS ($49.75) is $58.58/100 kg FW.

5. Assuming that about 3100 lb of aggregate/100 kg FW remains in the bed, the flows to the environment from the FWD/ difference in OSS are 4800 lb/100 kg FW.

6. Water is about 97% of the flows to the environment from the difference in OSS; essentially all of the flows are from system materials. For the total OSS/FWD system, about half of the total flows to the environment are attributable to food waste, 44% to system materials and 4% to energy sources; water is about 87% of the total flows, solid waste is 10%, air emissions are 2% and waterborne wastes are 1% of the flows by type. Sixty per cent of the total flows are attributable to the FWD and 40% to the OSS.

7. The decomposition products from 100 kg of food waste are food and stoichiometric water (67%), carbon dioxide (15%), solids (11%), and methane (7%); none of the energy in methane is recovered in an on-site system.

8. Only one study (Bounds, 1994) was found that audited septic tanks over time (8 years). Approximately 20% of the households had FWDs, which accelerated the scum accumulation rate by about 43% but made little difference in the rate of sludge accumulation (increased sludge accumulation by about 2%). This study found that an average pumping frequency of 12 years was not unreasonably long.

9. Even though FWDs contribute a small fraction of on-site system nitrogen (less than 5%), nitrogen oxidized to nitrate ion moves readily through soils and may reach groundwater. The additional ammonia required to satisfy requirements for biomass production is removed from wastewater; this reduces effluent ammonia ultimately

available to be oxidized to nitrate ion.

10. Research is underway regarding alternative wastewater technologies. Included in the technologies being evaluated for on-site systems are constructed wetlands, recirculating sand and gravel filter systems, mound systems, sand-lined trench systems, effluent spray irrigation system, drip disposal systems for effluent, on-site trickling filter/up-flow filter systems, and peat filters.

11. On-site system regulations and codes have developed as prescriptive standards; these codes were not based on scientific principles, but on empirical relationships and folklore. Approvals for system use have been based on strict compliance with the codes rather than how a system performs. Codes have provided little assurance that environmental or public health goals can be met. Many professionals are calling for performance based standards- technical guidelines for site evaluation, design, construction and operation; regular compliance monitoring and licensing or certification of all service providers (Otis, 1995).

12. It is important that in the future as new standards are developed for sizing septic tanks and absorption beds and regulating septic tank pumping frequencies, these standards make it possible to successfully operate FWDs with on-site systems.

13. Every expert consulted about on-site systems demonstrated a bias against the use of FWDs with on-site systems, regardless of how the on-site system was designed.

14. The use of a FWD has little impact on mass flows of phosphorus in an on-site wastewater system. In an on-site wastewater system phosphorus is sorbed onto soil particles and remains in the absorption bed (Sawhney and Starr, 1977).

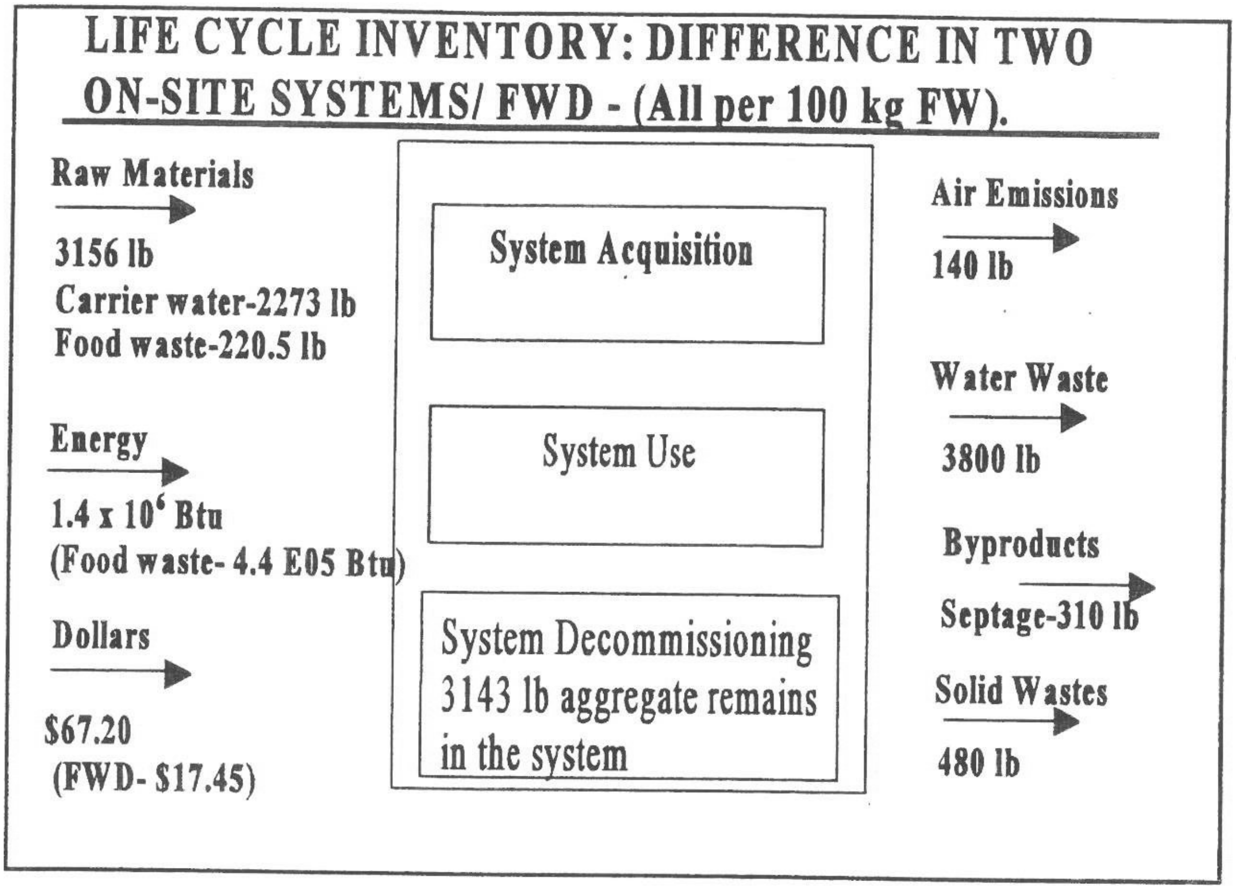


Figure ES5.11. Life cycle inventory: difference in two on-site systems with/without FWD.

Chapter 6. *EXECUTIVE SUMMARY- MUNICIPAL WASTEWATER COLLECTION AND TREATMENT.*

Chapter 6 quantifies the requirements for materials, energy and dollars to acquire, operate and decommission a municipal wastewater collection and treatment system and flows to the environment from materials, energy and food waste passing through the system. The City of Madison (WI) is the system used for the municipal wastewater collection system; Madison Metropolitan Sewerage District (MMSD) is the treatment system used for this project. Materials, energy and costs are specific to the City of Madison and MMSD. All values are prorated to 100 kg of food waste and associated FWD carrier water.

Table ES6.1 (Table 6.98) gives a summary of materials, energy and costs of the municipal wastewater collection and treatment system. Figures ES 6.1 (Figure 6.19), ES 6.2 (Figure 6.20), ES 6.3 (Figure 6.21) and ES 6.4 (Figure 6.22) show system materials and energy by source and by stage. Table ES 6.2 (Table 6.103) gives total flows to the environment from the use of the wastewater collection/ treatment system. Figures ES 6.5 (Figure 6.23) and ES 6.6 (Figure 6.24) show flows to the environment by source and by type.

Following are some of the facts and assumptions used in Chapter 6:

* The wastewater collection system assumes a population of about 260,000 persons and 120,000 housing units, 40% of which have FWDs.

* MMSD provides tertiary treatment for wastewater. The liquid treatment consists of preliminary, primary and biological secondary treatment with denitrification and phosphorus removal and UV disinfection. The solid treatment consists of sludge thickening, stabilization and dewatering, storage and land application.

* The design life of the system is assumed to be 30 years.

* Laterals, collector, and interceptor sewers are assumed to be laid down in trenches with perpendicular sides, bedded in aggregate. The trench height is assumed to be equal to a pipe's outside diameter plus 1.5 feet; the trench width is assumed to be equal to a pipe's outside diameter plus 2 feet. Pre-1970 laterals and collectors were made of vitrified clay; post 1970 they were made of PVC.

* A manhole spacing of 250 feet is assumed. Collector manholes (25,957) are assumed to have an inside diameter of 48 inches, a height of 10 feet, a wall thickness of 5 inches and a base thickness of 8 inches. Interceptor manholes (1200) are assumed to have an inside diameter of 72 inches, a height of 14 feet, a wall thickness of 6 inches and a base thickness of 8 inches.

* Municipal pumping stations, a total of 94, are assumed to be equivalent in size to large diameter manholes with a diameter of 8 feet, a depth of 20 feet, a wall thickness of 8.5 inches and a base thickness of 1 foot.

* MMSD pumping stations are assumed to have all have the dimensions of the recently completed Pump Station #5.

* It is assumed that the area in buildings for the collection system is 13,333 ft^2; the area in buildings for the wastewater treatment plant is 218,393 ft^2.

* The nutrient requirements for biomass produced are ammonia N 12.5% and ortho P 2.5%. The portion of influent TSS that is biodegradable is 80%; the portion of food waste that is biodegradable is 95%. Ninety five percent of organic N is converted to ammonia. Ninety seven percent of the ammonia is oxidized, 95% of the influent organic P is solubilized to ortho P, 96% of the BOD_5 is removed and 92% of the TSS is removed in the aeration basin. For determining the sludge yield due to BOD_5 removal, it was assumed that the yield coefficient is 0.90 lb VSS produced per lb of BOD_5 removed, the decay coefficient is 0.04 per day and the mean cell residence time is 10.5 days. The observed yield is 0.634 lb VSS per lb BOD_5 removed. The sludge production due to nitrification assumes a yield coefficient of 0.25 lb NVSS produced per lb ammonia oxidized and a decay coefficient of 0.05 per day. The percent solids of sludge wasted is 0.24%. In the dissolved air flotation process, there is a 98% solids capture rate; the total N and total P are removed in the same ratio as the solids and the float has 3.6% solids. The solids capture in the gravity belt thickener is 98%; solids are 5.8%.

* It is assumed that the weight of process equipment in the system is 10% of the

weight of pump stations, manholes, MMSD tanks and MMSD buildings.

* Installation energies are calculated based on the volume of excavated material and an average round trip haul of 20 miles.

* The Madison Sewer Utility and the Madison Water Utility residential service charges were assumed to have imbedded all capital and operating costs of the collection and wastewater treatment systems and are used to calculate total costs of 100 kg of food waste based on FWD carrier water.

* It is assumed that system decommissioning includes no significant use of materials, requires 25% of the energy to install the system and that the cost is included in the service charges.

* Food waste parameters, including BOD_5, TSS, N, P and volume requirements are those found in Table 3.8 of this report.

Prorating parameters to 100 kg of food waste, results and discussion of results. The amount of the food waste and carrier water associated with 100 kg (220.5) lb of food waste is 1031 kg + 100 kg or 1131 kg (2494 lb). If 57,428 lb TSS/ day (Table 6.63) and 36.7 MGD of flow go through the system, over the 30 year design life of the system, 6.3×10^8 lb TSS and 3.4×10^{12} lb of water for a total of 3.4×10^{12} lb go through the system. **The portion of total flows and loadings attributable to 2494 lb of FW solids and carrier water is 7.4×10^{-10}; this ratio was used to determine the fraction of the collection system attributable to FW.**

Even though capital costs for MMSD are determined based on a complex set of factors, including volume, BOD, solids, N and P, as given in Table 6.59, the above ratio was also used. **The ratio attributable to 100kg of food waste processed through MMSD is 7.4×10^{-10}, the same as for collection.**

Table ES6.1 gives the summary of materials, energy and costs for the wastewater collection and treatment system. Figures ES6.1, ES6.2, ES6.3 and ES6.4, calculated from Table ES6.1, show the distribution of materials and energy by stage and by source for the wastewater collection and treatment system. Food waste is 9% and water (primarily carrier water) is 91% of the total

Table ES6.1. (Table 6.98). Summary of materials, energy and costs of the WWTP system.

	Table #	Acquisition	Use	Decommissioning	Total	Per 100 kg FW (7)	
Land, ft²	6.2	3540766	0	0	3540766	0.003	
Materials		lb	lb	lb	lb	lb/100 kg	%
construction		1.1e+10	1.4e+06	0.0e+00	1.1e+10	7.9	0
collection	6.33, 6.92	9.9e+09	8.2e+04	Neg.	9.9e+09	7.4	
MMSD	6.33, 6.92	7.3e+08	1.3e+06	Neg.	7.3e+08	0.5	
equipment/vehicles		7.2e+07	0.0e+00	0.0e+00	7.2e+07	0.1	0
collection	6.19	2.5e+06	No Data	Neg.	2.5e+06	0.0	
MMSD	6.32	6.9e+07	No Data	Neg.	6.9e+07	0.1	
electricity(1)		0.0e+00	1.9e+09	0.0e+00	2.0e+09	1.4	0
collection	6.97	No Data	1.0e+08	Neg.	1.0e+08	0.1	
MMSD	6.96	No Data	1.8e+09	Neg.	1.8e+09	1.3	
natural gas		0.0e+00	2.2e+07	0.0e+00	2.2e+07	0.0	0
collection	-	No Data	0.0e+00	Neg.	0.0e+00	0.0	
MMSD	6.96	No Data	2.2e+07	Neg.	2.2e+07	0.0	
diesel fuel(4)		5.4e+07	2.0e+07	1.4e+07	8.7e+07	0.1	0
collection	6.97	5.3e+07	1.0e+07	1.3e+07	7.6e+07	0.1	
MMSD	6.96	1.3e+06	9.3e+06	3.2e+05	1.1e+07	0.0	
gasoline		No Data	2.9e+06	Neg.	2.9e+06	0.0	0
collection	-	No Data	0.0e+00	Neg.	0.0e+00	0.0	
MMSD	6.96	0.0e+00	2.9e+06	0.0e+00	2.9e+06	0.0	
FWD materials		2.0e+06	0.0e+00	0.0e+00	2.0e+06	1.5	0
collection	6.4	2.0e+06	0.0e+00	0.0e+00	2.0e+06	1.5	
MMSD	-	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0	
water(2)(5)		5.5e+09	1.7e+10	6.6e+07	2.3e+10	2286.3	91
collection	6.99, 6.101	4.9e+09	3.3e+09	6.6e+07	8.3e+09	2275.6	
MMSD	6.100, 2, 6.102	6.3e+08	1.4e+10	3.3e+05	1.4e+10	10.7	
FW(3)		0.0e+00	2.7e+08	0.0e+00	2.7e+08	220.5	9
collection	3	0.0e+00	2.7e+08	0.0e+00	2.7e+08	220.5	
MMSD	-	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0	
Total		1.6e+10	1.9e+10	8.0e+07	3.6e+10	2517.7	100
Energy		Btu	Btu(5)	Btu	Btu	Btu/100 kg	%
embodied-construction		6.4e+12	1.3e+12	Neg.	7.7e+12	5707	1

collection	6.58, 6.92	4.6e+12	7.7e+10	Neg.	4.7e+12	3451	
MMSD	6.58, 6.92	1.8e+12	1.3e+12	0.0e+00	3.0e+12	2256.1	
embod.-equipment/veh.		1.4e+12	0.0e+00	0.0e+00	1.4e+12	1021	0
collection	6.58	4.9e+10	No Data	Neg.	4.9e+10	36	
MMSD	6.58	1.3e+12	No Data	Neg.	1.3e+12	984.4	
electricity		0.0e+00	8.2e+12	0.0e+00	8.2e+12	6056	1
collection	6.97	No Data	4.5e+11	Neg.	4.5e+11	337	
MMSD	6.96	No Data	7.7e+12	Neg.	7.7e+12	5719.3	
natural gas		0.0e+00	5.6e+11	0.0e+00	5.6e+11	416	0
collection	-	No Data	0.0e+00	Neg.	0.0e+00	0	
MMSD	6.96	No Data	5.6e+11	Neg.	5.6e+11	415.8	
diesel		1.4e+12	4.5e+11	3.6e+11	2.2e+12	1659	0
collection	6.97	1.4e+12	2.4e+11	3.5e+11	2.0e+12	1460	
MMSD	6.96	4.3e+10	2.1e+11	1.1e+10	2.7e+11	198.4	
gasoline		0.0e+00	7.0e+10	0.0e+00	7.0e+10	52	0
collection	-	No Data	0.0e+00	Neg.	0.0e+00	0	
MMSD	6.96	No Data	7.0e+10	Neg.	7.0e+10	52.0	
FWD material		6.3e+10	0.0e+00	0.0e+00	6.3e+10	47027	9
collection	6.4	6.3e+10	0.0e+00	0.0e+00	6.3e+10	47027	
MMSD	-	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0	
water- emb. energy(2)		1.2e+10	3.6e+10	1.4e+08	4.8e+10	4798	1
collection	2	1.0e+10	7.0e+09	1.4e+08	1.7e+10	4776	
MMSD	2	1.3e+09	2.9e+10	6.9e+05	3.0e+10	22.5	
FW(3)		0.0e+00	5.4e+11	0.0e+00	5.4e+11	441000	87
collection	3	0.0e+00	5.4e+11	0.0e+00	5.4e+11	441000	
MMSD	-	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0	
Total		9.2e+12	1.1e+13	3.6e+11	2.1e+13	507735	100
collection		6.1e+12	1.3e+12	3.5e+11	7.7e+12	498087	
MMSD		3.1e+12	9.8e+12	1.1e+10	1.3e+13	9648	
Costs,$/100 kg(6)	p.103					0.49	
electricity-exportable ,kWh/100 kgFW	6.96	0	210000000	0	210000000	0.2	
(1) For composite U.S. kWh, assumes 2.45 lb of all fuels per average kWh.							
(2)Assumes potable water requirement for MMSD of $40,000/yr and $0.63/100ft3 and 30yr FWD carrier water of 1 liter/c/d and 2.1 Btu/ lb water: no information on water requirements for Madison Water Utility.							
(3)Assumes 2000 Btu/lb food waste (Tchobanoglous, 1993):114468 persons x0.0291 kg/c/dx2.205 lb/kg x365 d/yr x 30 yr.							
(4)Assumes 0.134 ft3/gal and 54 lb/ft3 diesel fuel.							
(5)All embodied water in materials is included in acquisition: water in energy sources is apportioned.							
(6)Includes charges for carrier water and the same amount of wastewater.							
(7)The fraction of materials and energy attributed to 220.5 lb FW and carrier water is the ratio 7.4 E-10 for MMSD and for the collection system.							
Neg.- Assumed to be negligible.							

system materials; all others are less than 1%. The energy in 100 kg of food waste accounts for 87% of the total system energy; the energy embodied in FWD materials is 9%; all others are 1% or less. Forty six percent of the materials are attributable to the acquisition stage and 54% are attributable to the use of the system. Thirty four percent of system energy is attributable to the acquisition stage, 64% to system use and 2% to system decommissioning.

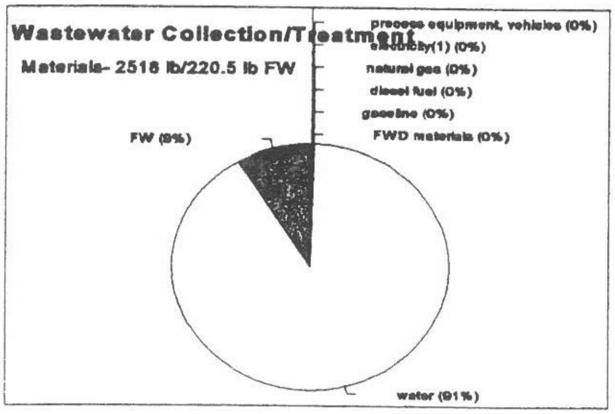


Figure ES6.1. Total material by source.

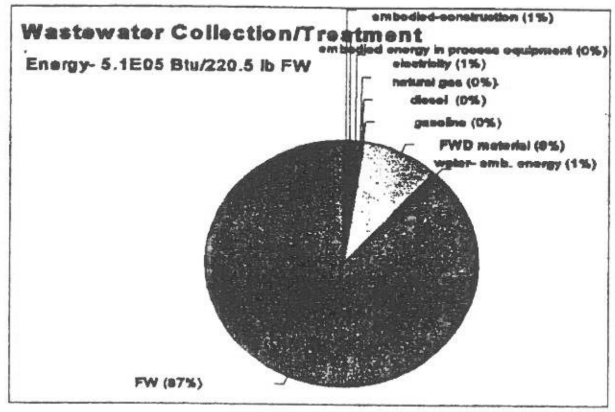


Figure ES 6.2. Total energy by source.

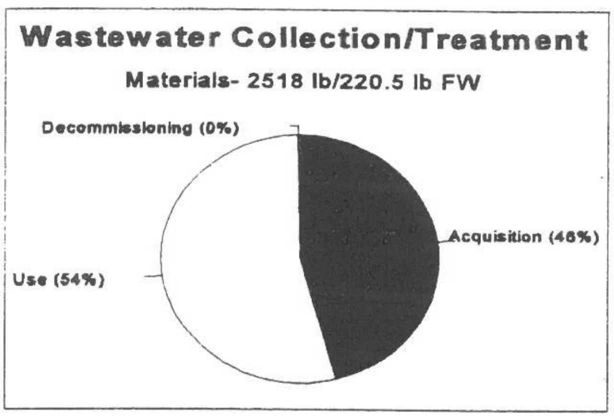


Figure ES 6.3. Materials by stage.

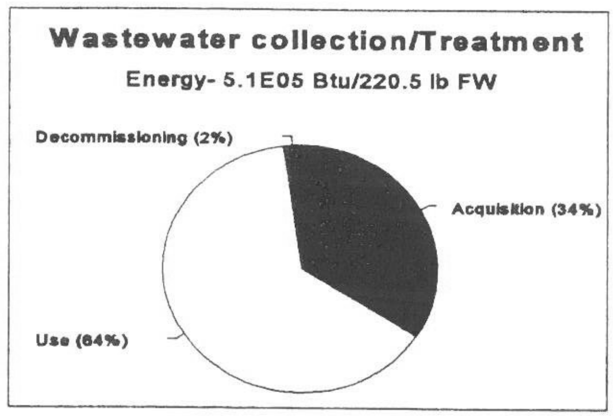
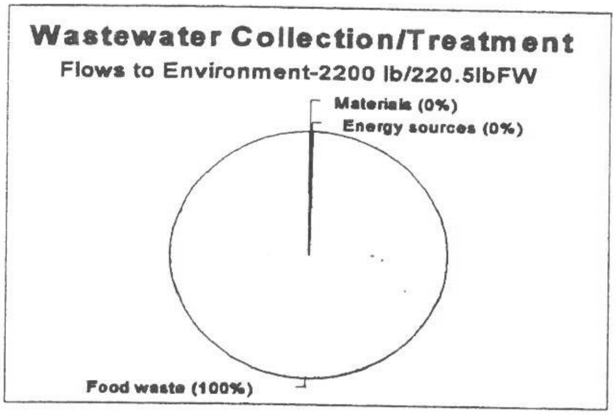


Figure ES 6.4. Energy by stage.

Table ES6.2 gives the summary of flows to the environment from materials, energy sources and food waste for the combined wastewater collection/treatment system. Figures ES6.5 and ES6.6, calculated from Table ES6.2, give flows to the environment by source and by type.



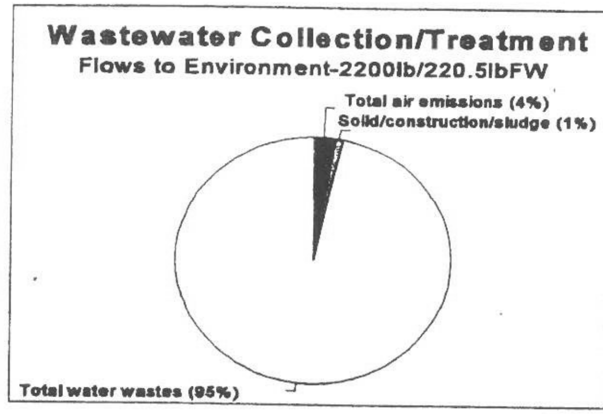


Figure ES6.5. Flows by source. Figure ES6.6. Flows by type.

The largest impact, by weight, of the FWD is from carrier water, the water required to flush food waste through the FWD, (1031 kg). Along with food water, the net food and stoichiometric water, (72 kg), these two flows are essentially the total flows per 100 kg of food waste and are assumed to pass directly through the wastewater treatment facility. From Table 6.91, the 100 kg of food waste going into the wastewater treatment plant requires 11.3 kg of oxygen and 0.2 kg of additional ammonia. About 24 kg of carbon dioxide (all of which is burned), 9 kg of sludge, and 4.8 kg of methane are produced per 100 kg of food waste.

6.1. *Conclusions.*

1. Land requirements for processing 100 kg of food waste through the wastewater collection/ treatment system is 0.003 ft^2, which includes land in buildings and pumping stations and 80 acres for the wastewater treatment facility.

2. Assuming a 30 year design life for system materials, 2518 pounds of system materials are attributable to 100 kg of FWD food waste. Food waste is 9% and water is 91% of the total system materials; about 46% of the system materials are attributed to the acquisition stage and 54% to system use.

Table ES6.2. (Table 6.103). Summary of life-cycle emissions from acquisition, use and decommissioning of the collection system/WWTP system.

	Materials**		Energy sources***		Food waste*		Total	
	lb/30yrs	lb/220.5 lb FW	lb/30yrs	lb/220.5 lb FW	lb/30yrs	lb/220.5 lb FW	lb/30yrs	lb/220.5 lb FW
Air emissions								
particulates	1.1e+06	8.5e-04	1.9e+06	1.4e-03	0.0e+00	0.0e+00	3.0e+06	2.3e-03
NOx (+N_2)	1.6e+06	1.2e-03	6.7e+06	5.0e-03	0.0e+00	0.0e+00	8.4e+06	6.2e-03
HC (not CH_4)	6.4e+05	4.7e-04	3.3e+06	2.5e-03	0.0e+00	0.0e+00	4.0e+06	3.0e-03
SOx	2.3e+06	1.7e-03	8.4e+06	6.2e-03	0.0e+00	0.0e+00	1.1e+07	7.9e-03
CO	4.1e+06	3.1e-03	4.1e+06	3.1e-03	0.0e+00	0.0e+00	8.3e+06	6.1e-03
CO_2****	5.1e+08	3.8e-01	1.3e+09	9.8e-01	0.0e+00	8.2e+01	1.8e+09	8.4e+01
aldehydes	0.0e+00	0.0e+00	7.3e+04	5.4e-05	0.0e+00	0.0e+00	7.3e+04	5.4e-05
other organics	0.0e+00	0.0e+00	1.5e+06	1.1e-03	0.0e+00	0.0e+00	1.5e+06	1.1e-03
NH_3	0.0e+00	0.0e+00	5.5e+02	4.1e-07	0.0e+00	0.0e+00	5.5e+02	4.1e-07
Pb	0.0e+00	0.0e+00	1.5e+01	1.1e-08	0.0e+00	0.0e+00	1.5e+01	1.1e-08
CH_4****	3.3e+04	2.5e-05	7.8e+03	5.8e-06	0.0e+00	0.0e+00	4.1e+04	3.1e-05
kerosene	0.0e+00	0.0e+00	2.8e+02	2.1e-07	0.0e+00	0.0e+00	2.8e+02	2.1e-07
HCl	0.0e+00	0.0e+00	1.7e+01	1.2e-08	0.0e+00	0.0e+00	1.7e+01	1.2e-08
H_2O vapor****	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0e+00	2.4e+01	0.0e+00	2.4e+01
Total air emissions	5.2e+08	3.9e-01	1.3e+09	1.0e+00	0.0e+00	1.1e+02	1.9e+09	1.1e+02
SW/CW	1.7e+09	1.2e+00	1.1e+08	8.1e-02	0.0e+00	1.5e+00	1.8e+09	2.8e+00
Other-sludge	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0e+00	3.4e+02	0.0e+00	3.4e+02
water	5.3e+09	3.9e+00	2.8e+09	2.1e+00	0.0e+00	2.1e+03	8.1e+09	2.1e+03
acid	0.0e+00	0.0e+00	1.2e-01	8.9e-11	0.0e+00	6.6e-02	1.2e-01	6.6e-02
metal ion	0.0e+00	0.0e+00	2.5e+03	1.9e-06	0.0e+00	0.0e+00	2.5e+03	1.9e-06
DS	3.5e+03	2.6e-06	1.4e+06	1.1e-03	0.0e+00	2.5e+00	1.4e+06	2.5e+00
SS	2.9e+05	2.2e-04	1.3e+03	9.9e-07	0.0e+00	2.0e-01	2.9e+05	2.0e-01
BOD_5	1.7e+05	1.3e-04	1.4e+03	1.0e-06	0.0e+00	0.0e+00	1.7e+05	1.3e-04
COD	1.1e+04	8.4e-06	6.9e+03	5.1e-06	0.0e+00	0.0e+00	1.8e+04	1.4e-05
phenol	0.0e+00	0.0e+00	8.2e+00	6.1e-09	0.0e+00	0.0e+00	8.2e+00	6.1e-09
oil	2.6e+04	2.0e-05	2.0e+04	1.5e-05	0.0e+00	0.0e+00	4.6e+04	3.4e-05
H_2SO_4	0.0e+00	0.0e+00	6.6e+05	4.9e-04	0.0e+00	0.0e+00	6.6e+05	4.9e-04
Fe	0.0e+00	0.0e+00	1.6e+05	1.2e-04	0.0e+00	0.0e+00	1.6e+05	1.2e-04
NH_3	0.0e+00	0.0e+00	2.0e+02	1.5e-07	0.0e+00	0.0e+00	2.0e+02	1.5e-07
Cr	0.0e+00	0.0e+00	4.8e-01	3.5e-10	0.0e+00	0.0e+00	4.8e-01	3.5e-10
Pb	0.0e+00	0.0e+00	2.1e-01	1.6e-10	0.0e+00	0.0e+00	2.1e-01	1.6e-10
Zn	0.0e+00	0.0e+00	3.1e+00	2.3e-09	0.0e+00	0.0e+00	3.1e+00	2.3e-09
Total water wastes	5.3e+09	3.9e+00	2.8e+09	2.1e+00	0.0e+00	2.1e+03	8.1e+09	2.1e+03
Total	7.5e+09	5.5e+00	4.3e+09	3.2e+00	0.0e+00	2.2e+03	1.2e+10	2.2e+03

*Includes food waste (assumes that FW is 70% water and 30% solids), stoichiometric water and carrier water.

**From materials in buildings and maintenance materials, process equipment and vehicles.

***Includes precombustion and combustion emissions for fuels and electricity.

****It is assumed that all CH_4 produced in digesters from food waste is burned to CO_2 and H_2O.

*****Sludge is 5.8% solids.

NA- not available

3. Over 90% of the system materials are in the collection system; aggregate makes up 87% of the collection system by weight.

4. Assuming a 30 year design life for system materials, 5.1 E 05 Btu is attributable to 100 kg of FWD food waste. The energy in food waste represents about 87% of the total system energy; 34% of the system energy is required for system acquisition, 64% for system use and 2% for system decommissioning.

5. Energy embodied in system materials makes up 85% of the total system energy; excavation and haul energy is 15%.

6. FWD wastewater parameters (Table 3.8), which were measured in the 1970's, are likely to overestimate FWD contributions to wastewater treatment facilities today. Yet, using MMSD as a model, it appears that contributions from the 40% of households assumed to have FWDs, make a small contribution to flows (about 0.1%); and contributions to each of the loadings is under 10% (Table 6.60).

7. Table 6.76 which gives secondary effluent for the present system and calculated hypothetical systems if no or all households had a FWD, respectively, suggests that ammonia nitrogen, nitrate nitrogen, total phosphorus and ortho phosphorus loadings in effluent are lower in the hypothetical system in which all households use FWDs than for the present system or for the system assuming no households had a FWD. In the carbon limited wastewater treatment system, food waste carbon uptakes nitrogen and phosphorus, is converted into biomass and removed from the system as sludge.

8. There are 2200 lb of total materials flowing to the environment from the acquisition, use and decommissioning of a FWD/ POTW system. Essentially all of the flows by source are from food waste (carrier water + food waste). Flows to the environment by type are 95% water wastes; air emissions and solid wastes are 5% of the total.

9. By weight, carbon dioxide (24.2 kg) is the largest flow to the environment from food waste dry solids passing through the wastewater treatment plant. Sludge (9.0 kg) is the second largest flow. Methane (4.8 kg) is the third largest flow to the environment; all others are 1% or less. If it is assumed that all the methane is combusted for energy recovery, there are no methane emissions; carnon dioxide emissions increase to 82 lb and there are 24 lb of water vapor.

10. The U.S. government in promulgating the Part 503 Sludge Rule (CFR Title 40, Parts 257, 403 and 503) emphasizes the beneficial use of sludge by defining acceptable management practices and setting limits for pollutants and pathogens.

11. Municipal sewage sludge is a source of N and P in crop production and when used at agronomic rates for N and P, can usually supply crop requirements for many other

nutrients,as well, with the possible exception of potassium (National Research Council, 1996).

12. Public concerns about real or perceived risks create business risks and militate against agricultural use of sludge and reclaimed water despite the federal or state regulatory safeguards (Krauss and Page, 1997).

13. Residential water conservation may involve dual water systems, both potable and nonpotable systems. Nonpotable water could be used for waste disposal, both human and food. FWDs could be redesigned to use potable water for flushing FW into the FWD and nonpotable water for grinding and flushing FW to the household wastewater system. Risks to human health, costs and benefits would need to be evaluated carefully.

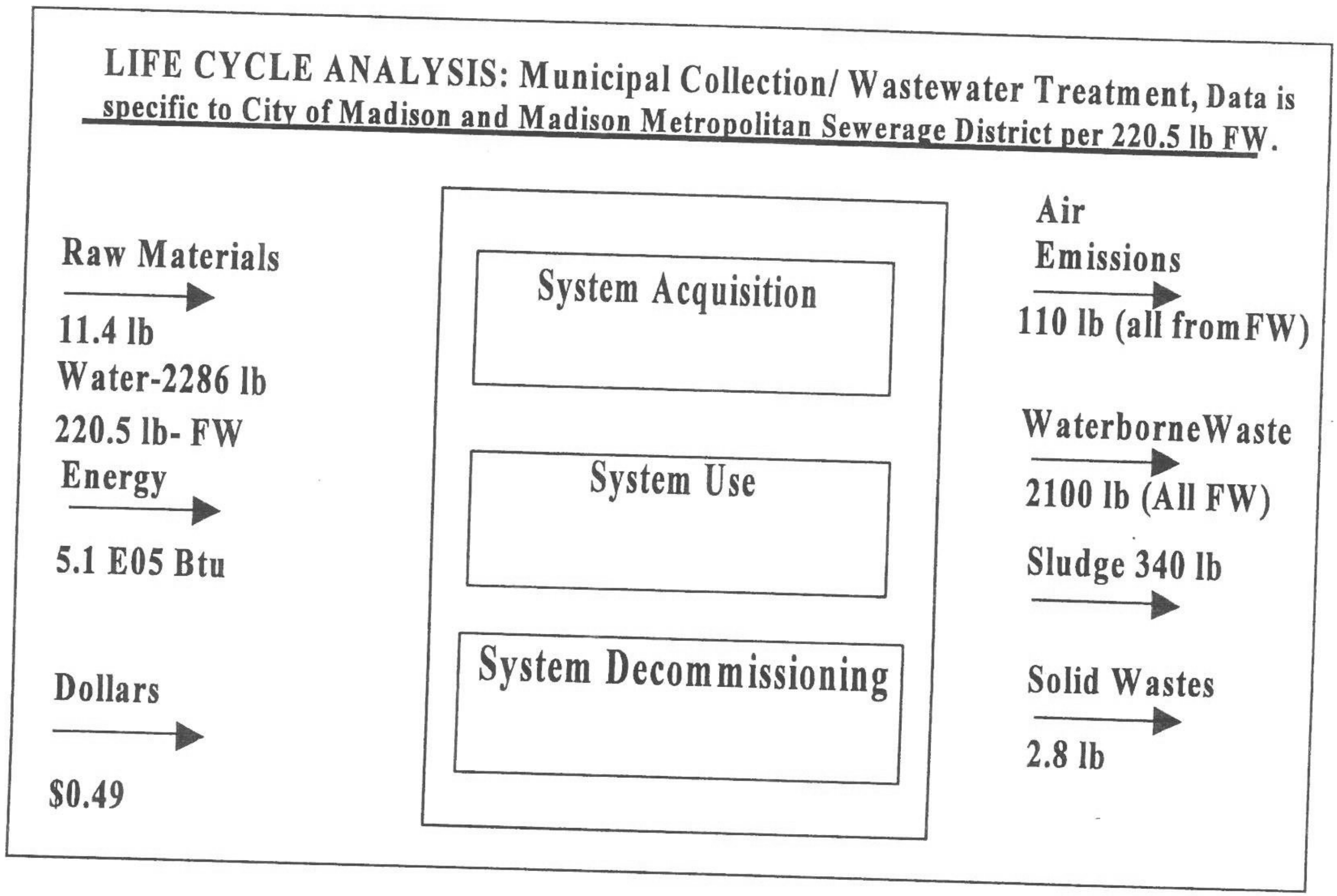


Figure ES6.7. Life cycle inventory: municipal collection/wastewater treatment.

Chapter 7. *EXECUTIVE SUMMARY- MSW COLLECTION.*

Chapter 7 quantifies the requirements for materials, energy and dollars to acquire, operate and decommission a MSW collection system and flows to the environment from materials, energy and food waste passing through the system. The City of Madison (WI) is the collection system used for this project; tonnages, construction materials, and costs are specific to this system. National data, based on ongoing research at Research Triangle Institute, N.C., is used for collection parameters for vehicles, mileage, and water requirements. National MSW generation, recovery and discard rates are used. All values are prorated to 100 kg of food waste. All parameters are multiplied by the fraction, 5.758×10^{-8}, which is 220.5 lb of food waste divided by the total amount of MSW through the system over the 15 year design period, 3.83×10^{9} lb MSW.

Following are assumptions and facts used for the inventory of the MSW collection system:

* Weekly collection is assumed for a city of 191,000 population, 72535 houses and 3815 commercial sites.
* A system design life of 15 years is assumed for the collection system to correspond to the life of the landfill; buildings in the collection system are assumed to have a design life of 30 years.
* MSW collection loads are hauled directly to the landfill.
* MSW (and food waste) is stored in the kitchen in a HDPE kitchen and transferred to a 90 gallon HDPE wheeled cart outside the house for MSW collection.
* Building requirements for the City of Madison for MSW collection functions are 100,000 ft^2 in area.
* It is assumed that the land requirements are double the building requirements and the land is fenced.
* The diesel fuel required to collect MSW is 0.9 gallons per 1000 lb of MSW.
* Twenty kWh of electricity are required per ton of MSW.
* Ten gallons of water are required for collection facilities per ton of MSW.
* Collection costs are $89.82/ton MSW (Dreckmann, 1997).
* It is assumed that the energy to decommission the system is 25% of that for excavation and hauling.

Summary of materials, energy and costs required for the municipal collection system.

Table ES7.1 gives a summary of total materials, energy and costs of a MSW collection system. Figures ES7.1 through ES7.4 are calculated from Table ES7.1. Figure ES7.1 shows materials by type.

Table ES7.1 (Table 7.18). Summary of materials, energy and costs of the municipal collection system.

	Acquisition	Use	Decommissioning	Total	Per 220.5 lb FW	
Land, ft^2	200000	0	0	200000	0.01	
Materials	lb	lb	lb	lb	lb	%
construction materials/ containers	46524858	308925	Neg.	46833783	2.70	6
vehicles	2933548	0	Neg.	2933548	0.17	0
electricity(1)	No Data	93717859	Neg.	93717859	5.40	11
natural gas(5)	No Data	No Data	Neg.	0	0.00	0
diesel fuel(4)	78385	24937790	2915	25019089	1.44	3
gasoline	No Data	No Data	Neg.	0	0.00	0
FWD materials	No Data	No Data	Neg.	0	0.00	0
water(2)	134277409	534374691	29145	668681245	38.50	80
FW(3)	0	0	0	0	0.00	0
Total	183814201	653339264	32060	837185524	48.21	100
Energy	Btu	Btu(5)	Btu	Btu	Btu	%
embodied- materials	326486876793	3178527470	Neg.	329665404264	18983	24
embodied- vehicles	35208082381	0	Neg.	35208082381	2027	3
electricity	No Data	405903458403	Neg.	405903458403	23373	30
natural gas	No Data	No Data	Neg.	0	0	0
diesel	1841558236	585879520147	230194780	587951273163	33856	43
gasoline	No Data	No Data	Neg.	0	0	0
FWD material	0	0	0	0	0	0
water- embodied energy(2)	281982559	1122186851	61205	1404230614	81	0
FW(3)	0	0	0	0	0	0
Total	363818499970	996083692870	230255984	1.360132e+12	78320	100
electricity- kWh(7)	No Data	38292779	Neg.	38292779	2	
Costs(6)$	0	0	0	0	9.90	

(1) Table 2.23.
(2)All water embodied in materials in acquisition; assumes water of 10 gal/ton MSW from RTI and 2.1 Btu/ lb water.
(3)Assumes 2000 Btu/lb food waste (Tchobanoglous, 1993)and FW is 8.0% of MSW.
(4)Assumes 0.134 ft^3/gal and 54 lb/ft^3 diesel fuel and 1.7x10^{5}Btu/gal.
(5)No information is available on natural gas consumed in collection facilities.
(6)Assume $89.82/T for MSW collection (Dreckmann, 1997).
(7)Assumes 1.75 kWh/lb methane (Taylor, 1992 as reported in Franklin Associates Ltd., 1994).
Neg.- Assumed to be negligible.

There are 48 lb of materials attributable to 100 kg of food waste. Water is 80%, the fuels required to generate electricity 11%, construction materials 6% and diesel 3% of the materials attributable to 100 kg of food waste passing through the MSW collection system. There are 7.8 x 10^4 Btu of energy attributable to 100 kg of food waste. Diesel fuel is 43%, the fuels required to generate electricity are 30% and energy embodied in materials is 24% of the energy attributable to 100 kg food waste passing through the MSW collection system. Figures ES7.3 and ES7.4 give materials and energy by stage. Seventy eight per cent of the total materials are required for system use; 22% for system acquisition. Seventy three per cent of the total system energy is required for system use; 27% for system acquisition.

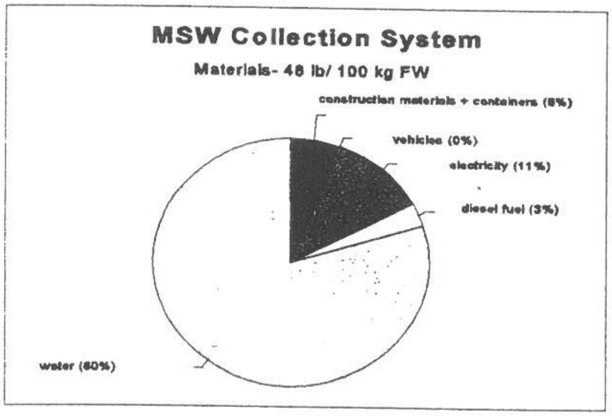


Figure ES7.1. Total materials by type.

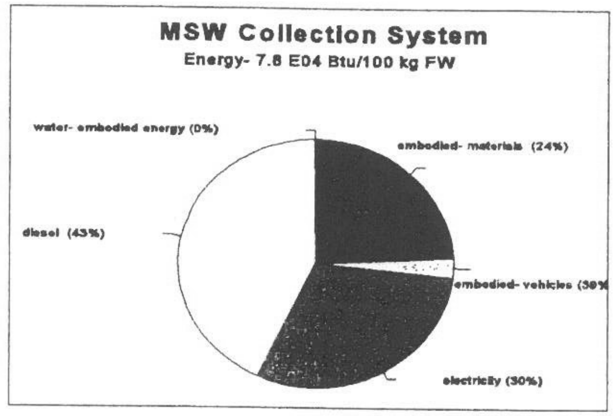


Figure ES7.2. Total energy by type.

Flows to the environment from MSW collection. Table ES7.2 summarizes flows to the environment from all sources. Figures ES7.5 and ES7.6 are calculated from Table ES7.2 and show flows to the environment by type and by source. Waterborne wastes make up 78% of the flows to the environment by type air emissions are 20%. Energy sources contribute 63%, materials contribute 18%, and facility water contributes 19% of the flows to the environment.

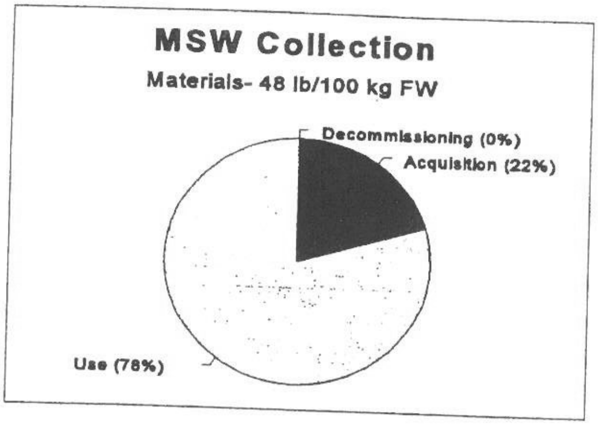


Figure ES7.3. Materials by stage.

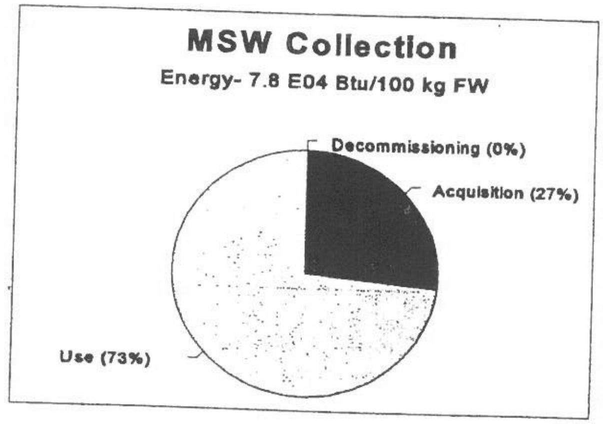


Figure ES7.4. Energy by stage.

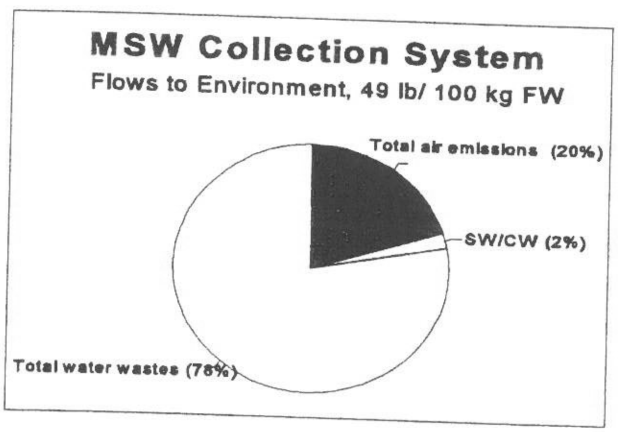


Figure ES7.5. Flows by type.

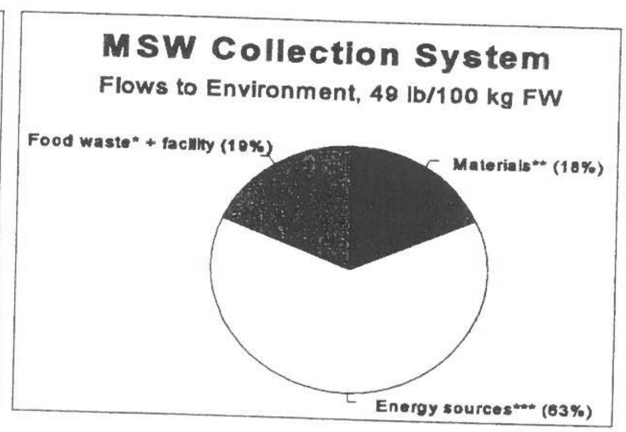


Figure ES7.6. Flows by source.

Conclusions. Following are conclusions for the MSW collection system.

1. There are 0.01 ft^2 of MSW collection system land attributable to 100 kg of food waste.

2. There are 48 lb of materials attributable to 100 kg of food waste passing through the MSW collection system. Eighty per cent of the materials is water; 11% fuels required to generate electricity; 6% construction materials and 3% diesel fuel . Seventy eight per cent is attributed to the use of the system; 22% to system acquisition.

3. There are 7.8 x 10^4 Btu of energy attributable to 100 kg of food waste passing through the MSW collection system. Forty three per cent of the energy is in diesel fuel, 30% is

in electricity and 24% is embodied in materials. Seventy three per cent of the energy is attributed to system use, 27% to system acquisition.

4. The cost attributable to 100 kg of food waste passing through the system is $9.90.

5. There are 49 lb of flows to the environment attributable to 100 kg of food waste; 78% is water, 19% is carbon dioxide, 2% is solid and construction waste and 1% is other air emissions.

6. Projecting 1990 to 1993 changes in MSW forward over the system design life, food waste discarded to MSW decreases from 0.29 to 0.28 lb/c/d. Because other materials (particularly paper and yard waste) are being removed from MSW, food waste will increase from 8.7% to 12.5% of MSW discarded.

7. Implied in 40CFR Part 243 is that if food waste were removed from MSW, there would be no minimum once per week requirements for MSW collection.

8. Removing food waste from MSW removes readily putrescible material and potentially makes it possible to store MSW longer between collections.

Table ES7.2 (Table 7.21). Summary of life-cycle emissions from acquisition, use and decommissioning of the MSW collection facility.

	Materials**		Energy sources***		Food waste* + facility		Total	
	lb/15yrs	lb/220.5 lb FW	lb/15yrs	lb/220.5 lb FW	lb/15yrs	lb/220.5 lb FW	lb/15yrs	lb/220.5 lb FW
Air emissions								
particulates	68701	0.00	211118	0.01			279820	0.02
NOx (+N2)	130911	0.01	1023324	0.06			1154234	0.07
HC (not CH4)	26520	0.00	449960	0.03			476480	0.03
SOx	340848	0.02	687861	0.04			1028709	0.06
CO	131524	0.01	826848	0.05			958372	0.06
CO2	13080088	0.75	154076182	8.87			167156270	9.63
aldehydes	NA		20553	0.00			20553	0.00
other organics	NA		404622	0.02			404622	0.02
NH3	NA		139	0.00			139	0.00
Pb	NA		0	0.00			0	0.00
CH4	2037	0.00	556	0.00			2592	0.00
kerosene	NA		20	0.00			20	0.00
HCl	NA		4	0.00			4	0.00
Water vapor-FW								
Total air emissions	13780629	0.79	157701186	9.08			171481815	9.87
SW/CW	9116104	0.52	7675411	0.44			16791516	0.97
Ash								
Water wastes								
water	133493555	7.69	375093239	21.60	160094451	9.22	668681245	38.50
acid	NA		0	0.00			0	0.00
metal ion	NA		642	0.00			642	0.00
DS	201	0.00	364162	0.02			364363	0.02
SS	19757	0.00	339	0.00			20096	0.00
BOD	77447	0.00	357	0.00			77804	0.00
COD	512	0.00	1748	0.00			2260	0.00
phenol	NA		2	0.00			2	0.00
oil	844	0.00	4483	0.00			5327	0.00
H2SO4	NA		45874	0.00			45874	0.00
Fe	NA		11385	0.00			11385	0.00
NH3	NA		50	0.00			50	0.00
Cr	NA		0	0.00			0	0.00
Pb	NA		0	0.00			0	0.00
Zn	NA		1	0.00			1	0.00
Total water wastes	133592317	8	375522281	22	160094451	9.22	669209048	38.53
Total	156489049	9	540898878	31.15	160094451	9.22	857482379	49

*Assumes that no FW is included; water required in maintaining facility (10 gal/ton MSW) is included.

**From materials in buildings and maintenance materials, process equipment and vehicles; Table 7.20.

***Includes embodied and combustion emissions for fuels and electricity; Table 7.19.

NA- not available

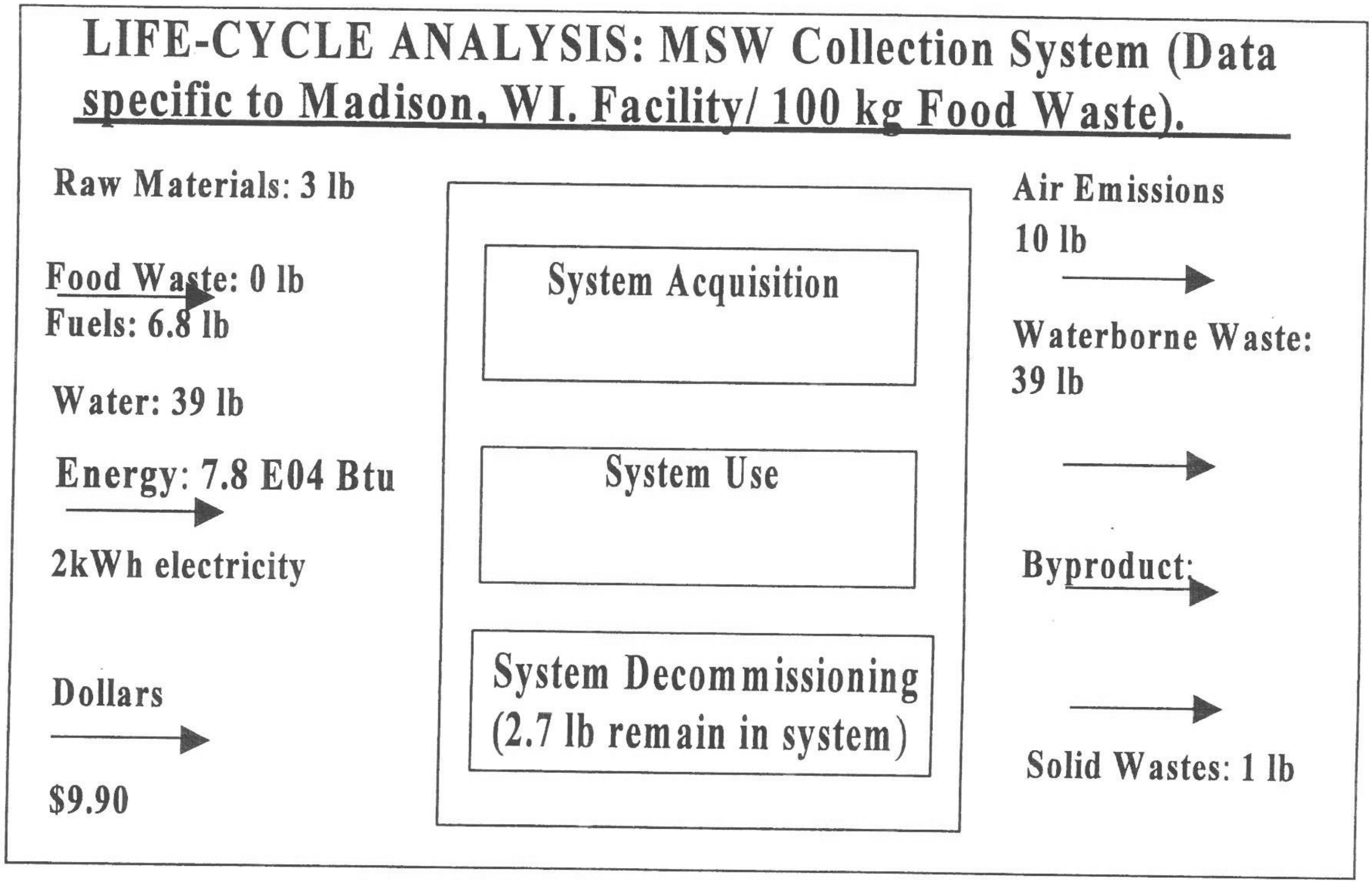


Figure ES7.7. Life-cycle inventory: MSW Collection System.

Chapter 7. ***EXECUTIVE SUMMARY- LANDFILL.***

Chapter 7 quantifies the requirements for materials, energy and dollars to acquire, operate and decommission a landfill system. It quantifies flows to the environment from the materials, energy and the processing of food waste through the landfill. The Dane County Landfill is the system used for this project and tonnages of MSW, construction materials, vehicles, process equipment and costs are specific to this landfill. All materials, energy requirements and costs are prorated to 100 kg of food waste inputs to the landfill.

Table ES7.3 gives a summary of the materials, energy and costs of the landfill. Included in assumptions made for this project are the following:

* The design life of the landfill addition is 15 years; there are 30 years of post-closure care provided for, but no landfill reclamation is included.
* The landfill will receive 3,533,160,000 lb of MSW, about 350 ton/day, over its design life of 15 years.
* The cost information is based on a 30 acre addition to the Dane County Landfill, designed to last for 15 years.
* The land area fenced area is 70 acres.
* The liner is 4 feet of clay, an HDPE flexible membrane liner with a geotextile; the final cover system includes a 2 foot clay liner, and a HDPE geocomposite.
* The landfill has a leachate collection system and discharges leachate to the Madison Metropolitan Sewerage District for treatment.
* The landfill has a gas collection system with power generation equipment; the system parasitic load is 10% of the electricity generated.
* It is assumed that 95% of food waste solids are decomposable and 84% of the decomposable solids decompose in the landfill; residuals remain in the landfill.
* It is assumed that carbon dioxide and methane go to the landfill gas collection system. Of the landfill gas generated, it is assumed that 66% is collected and 33% is vented to the atmosphere.
* It is assumed that food water goes into the leachate collection system; all leachate is captured in the leachate collection system.
* There are two buildings required for the landfill with a total area of 14144 ft^2.
* Diesel fuel is the primary energy source for landfill construction and operation.
* It is assumed that 0.7 gallons per 1000 pounds of MSW is required for construction and operation of the landfill.

Summary of materials, energy and costs required for the landfill system. Table ES7.3 gives the summary of materials, energy and costs of the landfill system. Figure ES7.8 shows the system materials; landfill materials are almost half (48%), food waste is 43%, water is 9% and all other materials are negligible. Figure ES7.9 shows total system energy; food waste makes up about 89% of the total system energy; diesel makes up 6%, methane makes up 3%; all other contributions are small. Figure ES7.10 shows total system materials by stage. Eighty eight per cent of system materials are attributable to system acquisition; 12% are attributable to system use. Figure ES7.11 shows total system energy by stage; 30% is attributable to system acquisition; 70% is attributable to system use.

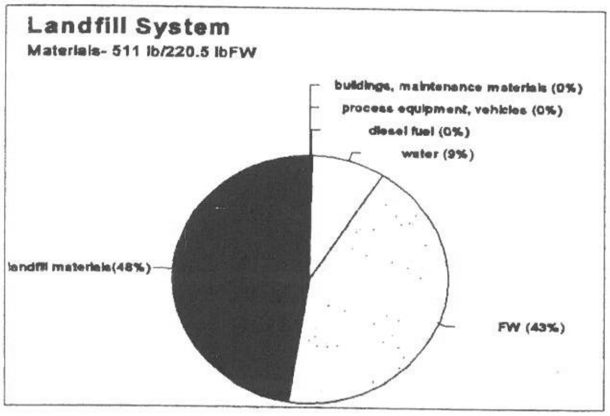


Figure ES7.8. Total materials by type.

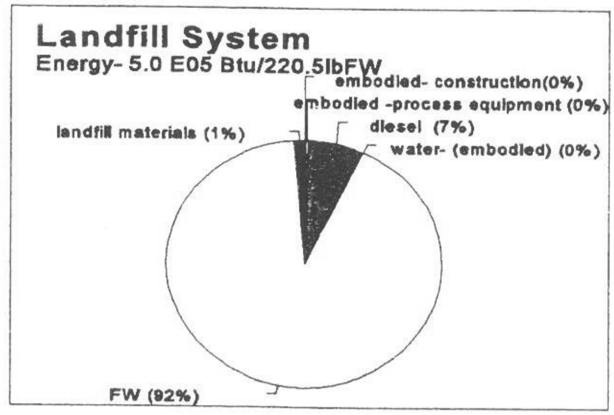


Figure ES7.9. Total energy by type.

Table ES7.3 (Table 7.43). Summary of materials, energy and costs of the landfill system.

	Acquisition	Use	Decommissioning	Total	Per 220.5 lb FW	
Land, ft^2	3049200	0	0	3049200	0.19	
Materials	lb	lb	lb	lb	lb	%
buildings, fencing, maintenance materials	4.3e+06	4.4e+04	Neg.	4.3e+06	0.3	0
process equipment, vehicles	1.4e+06	No Data	Neg.	1.4e+06	0.1	0
electricity	No Data	No Data	Neg.	0.0e+00	0.0	0
natural gas(1)	No Data	9.4e+06	Neg.	9.4e+06	0.6	0
diesel fuel(4)	1.3e+07	8.9e+06	1.2e+04	2.2e+07	1.4	0
gasoline	No Data	No Data	Neg.	0.0e+00	0.0	0
FWD materials	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0	0
water(2)	4.4e+08	2.7e+08	1.2e+05	7.1e+08	44.3	9
FW(3)	0.0e+00	2.8e+08	0.0e+00	2.8e+08	220.5	43
landfill materials(5)	3.9e+09	0.0e+00	0.0e+00	3.9e+09	243.4	48
Total	4.4e+09	5.7e+08	1.3e+05	4.9e+09	510.5	100
Energy	Btu	Btu(5)	Btu	Btu	Btu	%
embodied - construction/ maintenance materials	1.1e+10	4.5e+08	Neg.	1.1e+10	709	0
embodied- process equipment / vehicles	2.6e+10	No Data	Neg.	2.6e+10	1635	0
electricity	No Data	No Data	Neg.	0.0e+00	0	0
natural gas	No Data	2.5e+11	Neg.	2.5e+11	15299	3
diesel	3.0e+11	2.1e+11	2.1e+09	5.1e+11	31877	6
gasoline	No Data	No Data	Neg.	0.0e+00	0	0
FWD material	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0	0
water- embodied energy(2)	9.3e+08	5.6e+08	2.5e+05	1.5e+09	93	0
FW(3)	0.0e+00	5.7e+11	0.0e+00	5.7e+11	441000	89
landfill materials	9.5e+10	0.0e+00	0.0e+00	9.5e+10	5919	1
Total	4.3e+11	1.0e+12	2.1e+09	1.5e+12	496531	100
Costs(6)$/ton	0.0e+00	0.0e+00	0.0e+00	3.4e+01	3.75	
Exportable Electricity- kWh(7)	0.0e+00	0.0e+00	0.0e+00	0.0e+00	-16	

(1) Facility electricity generated from burning landfill gas in industrial boiler; and Table 2.22.

(2)Water requirements of 10 gal/ton MSW from RTI and 2.1 Btu/ lb water.

(3)Assumes 2000 Btu/lb food waste (Tchobanoglous, 1993)and FW is 8.0% of MSW.

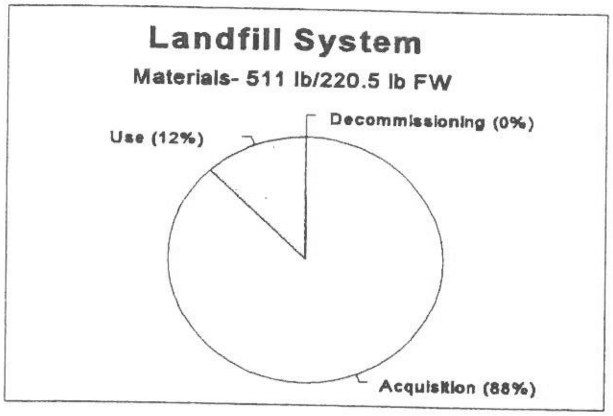
(4)Assumes 0.134 ft^3/gal and 54 lb/ft^3 diesel fuel; decommissioning is 25% of diesel fuel to excavate for buildings.

(5)No information is available on the embodied energy in soil; included is embodied energy for aggregate and plastic liners; all soil included in acquisition.

(6)Average landfill costs of $34/ton.

(7)There is 15 lb of methane generated per 100 kg FW, 1.75 kWh generated per lb of methane recovered (Taylor, 1992 as reported in Franklin Assoc. Ltd, 1994), 66% recovered and 10% parasitic load.

Neg.- Assumed to be negligible.



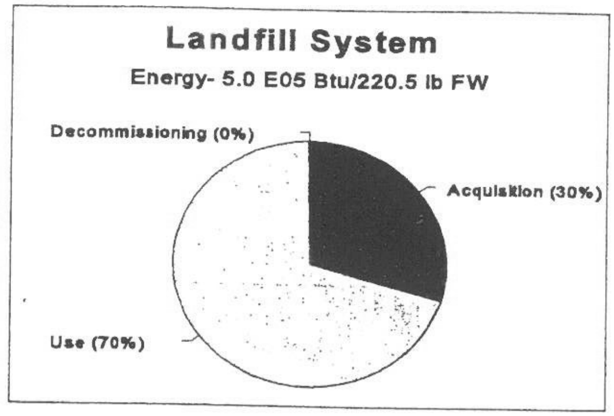
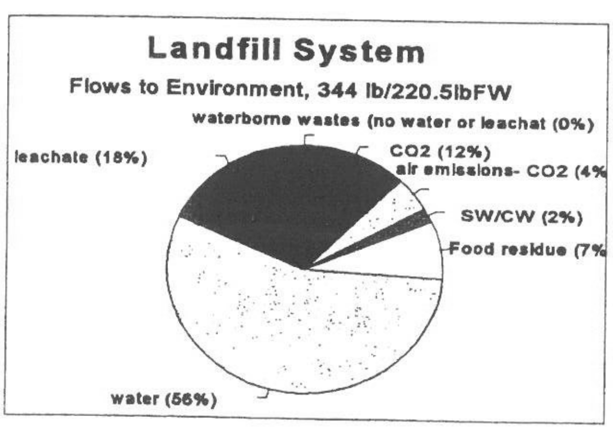


Figure ES7.10. Materials by stage.

Figure ES7.11. Energy by stage.

Flows to the environment from MSW disposal in a landfill. Table ES7.4 is a summary of life-cycle emissions from the acquisition, use and decommissioning of a landfill; data is specific to the Dane County Landfill. Figure ES7.12 shows flows to the environment by type. Water makes up 56% of the flows, leachate makes up 18%, carbon dioxide makes up 12% and food residue makes up 7%. Figure ES7.13 shows flows to the environment by source. Food waste makes up 86%; materials make up 8% and energy sources make up 7% of the flows to the environment by source. Figure ES7.14 gives an inventory overview for the landfill system.



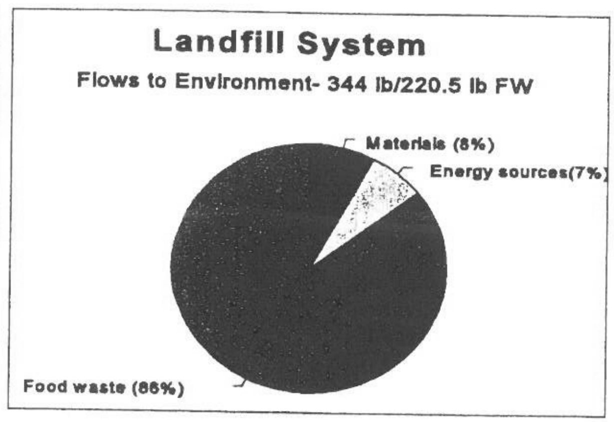


Figure ES7.12. Flows by type.

Figure ES7.13. Flows by source.

Conclusions. Following are conclusions from the landfill section of this chapter:

1. The land attributable to 100 kg of food waste is 0.19 ft^2.

2. There are 511 lb of materials attributable to 100 kg of food waste. Forty eight per cent are landfill soil materials; 43% are food waste; 9% is water. Eighty eight per cent are attributable to system acquisition (daily cover is attributed to system acquisition).

3. The energy attributable to 100 kg of food waste is 5.0×10^4 Btu. Eighty nine per cent is attributable to food waste. Seventy per cent is attributable to the use of the system.

4. The life-cycle cost is $3.75 per 100 kg of food waste.

5. There are 384 lb of flows to the environment attributable to 100 kg of food waste; 56% is water; 18% is leachate; 12% is carbon dioxide and 7% is food residues. There are 243 lb of landfill soil materials that remain in the system.

6. The use of the FWD has little to no impact on the design size of a landfill.

7. Putrescible waste, such as food waste, is a food source and breeding ground for disease vectors such as rodents, birds, flies and mosquitos in landfilled materials which creates the requirement for costly daily soil or alternative cover material to be applied at the end of each operating day (EPA 530-R-93-017).

8. Landfills will continue to play a central role in any waste disposal strategy. In the future the typical landfill will become larger and more regional, reflecting a reduction in the number of disposal sites and economies of scale.

9. Incentives to promote the removal of paper and yard waste from landfills, while at the same time promoting the development of landfill gas-to-energy projects, seems like public policy at cross-purposes.

Table ES7.4 (Table 7.47). Summary of life-cycle emissions from acquisition, use and decommissioning of the landfill.

	Materials**		Energy sources***		Food waste*		Total		Total minus difference in emissions
	lb/15yrs	lb/220.5 lb FW	lb/15yrs	lb/220.5 lb FW	lb/15yrs	lb/220.5 lb FW	lb/15yrs	lb/220.5 lb FW	lb/15yrs
Air emissions									
particulates	45702	0	96616	0		0.00	142318	0.01	-0.01
NOx (+N2)	63675	0	689755	0		0.00	753429	0.05	0.01
HC (not CH4)	11799	0	631606	0		0.00	643405	0.04	0.18
SOx	97241	0	156751	0		0.00	253992	0.02	-0.09
CO	63012	0	654977	0		0.00	717989	0.04	0.03
CO2*****	7985666	0	110050729	7	44112936	61.67	162149330	69.04	71.01
aldehydes	NA	0	17754	0		0.00	17754	0.00	0.00
other organics	NA	0	350536	0		0.00	350536	0.02	0.02
NH3	NA	0	117	0	0	0	117	0.00	0.00
Pb	NA	0	0	0		0.00	0	0.00	0.00
CH4*****	1253	0	861	0	19225217.736	4.99	19227332	4.99	4.99
kerosene	NA	0	1	0		0.00	1	0.00	0.00
HCl	NA	0	4	0		0.00	4	0.00	0.00
Water vapor-FW*****	0	0	0	0	0	22.40	0	22.40	24.33
Total air	8268346	0.52	112649706	7.03	63338153.264	49.28	184256206	96.60	100.47
Solid/construction waste	105893200	7	284520	0	0	0.00	106177720	6.63	5.04
Food residue	0	0.00	0	0.00	32234947	25.08	32234947	25.08	25.08
Water and waterborne wastes									
water	314004720	20	247409600	15	335560803.57	155.36	896975123	190.40	190.40
acid	NA	0	0	0	0	0	0	0.00	0.00
metal ion	NA	0	540	0	0	0	540	0.00	0.00
DS	28	0	307848	0	0	0	307877	0.02	0.02

SS	4053	0	285	0	0	0	4338	0.00	0.00
BOD_5	10706	0	300	0	0	0	11007	0.00	0.00
COD	72	0	1471	0	0	0	1543	0.00	0.00
phenol	NA	0	2	0	0	0	2	0.00	0.00
oil	57	0	4105	0	0	0	4163	0.00	0.00
H_2SO_4	NA	0	1151	0	0	0	1151	0.00	0.00
Fe	NA	0	300	0	0	0	300	0.00	-0.01
NH_3	NA	0	42	0	0	0.00	42	0.00	0.00
Cr	NA	0	0	0	0	0	0	0.00	0.00
Pb	NA	0	0	0	0	0	0	0.00	0.00
Zn	NA	0	1	0	0	0	1	0.00	0.00
leachate****	NA	0	NA	0	1002565394	63	1002565394	62.57	62.57
Total water	314019638	20	247725645	15	335560804	218.00	897306086	190.42	253
Total	428181183	27	360659871	22.51	431133904	332.14	1219974958	381	384

*FW products plus facility water; Table 7.37.

**From materials in buildings and maintenance materials, process equipment and vehicles; Table 7.44.

***Includes embodied and combustion emissions for fuels and electricity; Table 7.45.

****1200 gal/acre 100 ft day x 1 acre/43,560 ft^2 x 27 ft^3/yd^3 x 1 yd^3/1200 lb x 3.533 x 10^9 lb x 365 days x 15 years x 0.134 ft^3/gal x 62.4 lb/ft^3.

*****Assumed that 2/3 of landfill methane generated was captured and burned; remainder of methane offgassed to atmosphere is given as CH4; CO2 and H2O vapor produced are added to CO2 and H2O vapor entries. Water vapor for 15 years not calculated.

NA- not available

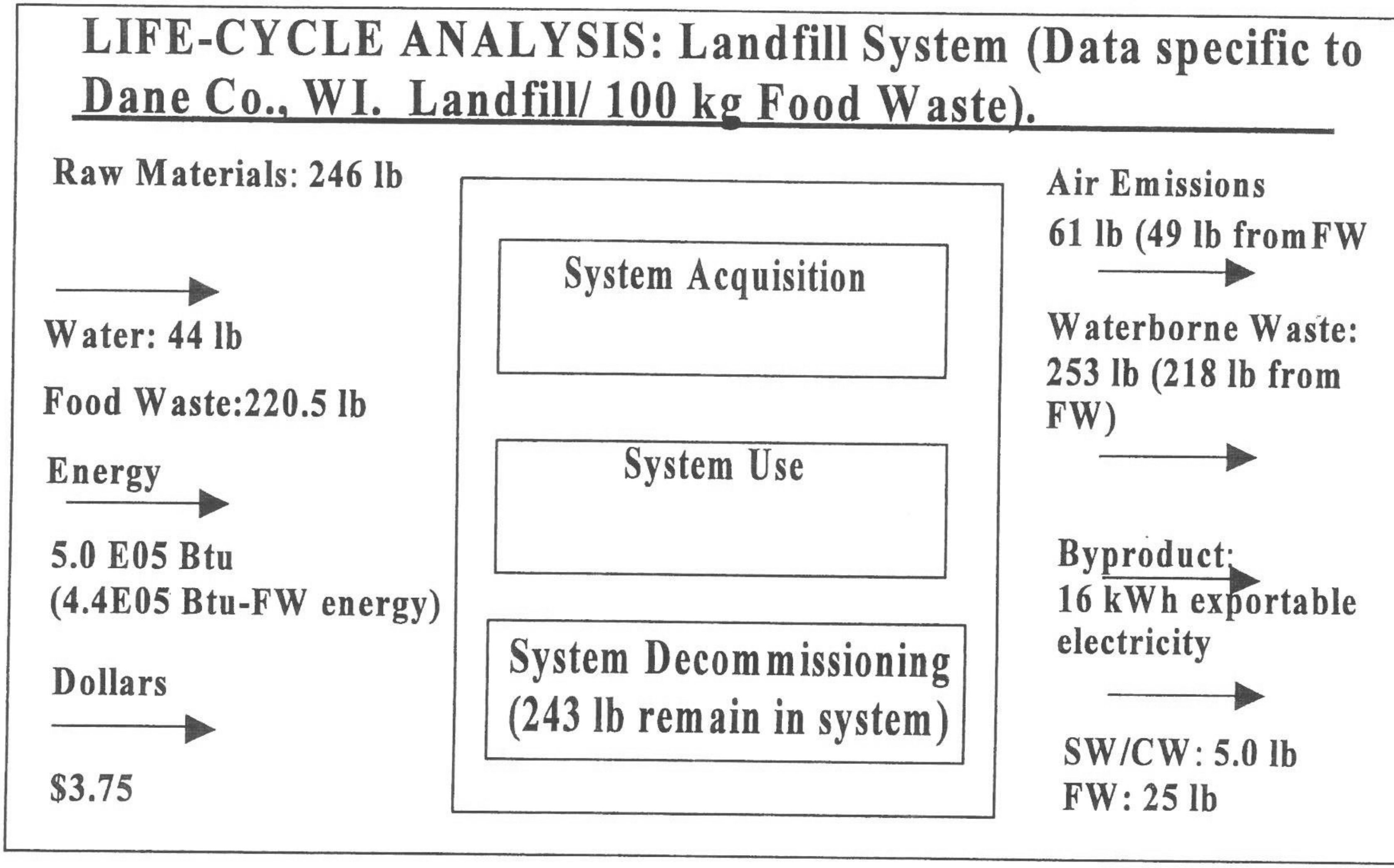


Figure ES7.14. Life-cycle inventory: landfill system.

CHAPTER 8. *COMPOST SYSTEM EXECUTIVE SUMMARY.*

Impacts to the environment from processing food waste through a compost facility are inventoried in Chapter 8. The facility chosen for this project is Columbia County, WI. Composting Facility. Its design capacity of 80 TPD is 62% of the U.S. average design capacity of 130 TPD; its capital cost of $2,500,000 is 51% of the U.S. average capital cost of $6.9 million and its tip fee of $33/ ton for compost is 75% of the U.S. average of $44/ton. Data for MSW inputs to the facility is based on 1990 U.S.E.P.A. data. All materials, energy and cost data are specific to Columbia County Composting Facility.

Materials, energy, costs and flows to the environment from the acquisition, use and decommissioning of the Columbia Co. Compost Facility are quantified and prorated to 100 kg (220.5 lb) of food waste. ***The ratio of 100 kg food waste to the total weight of MSW through the system over its 15 year design life is 2.88 x 10^{-7}.***

The life-cycle inventory for the compost facility includes the following facts and assumptions:

* The facility operates at a capacity of 70 TPD.
* The design life of the facility is 15 years.
* Composting operations are housed in 63,500 ft^2 of buildings with 27,700 ft^2 of additional concrete pads for windrows; the site is 64 acres, entirely fenced.
* In-vessel composting process equipment includes two process trains, which each include a steel digestive drum, trommel screen and a conveyor.
* Food waste inputs are 8.0% of the MSW inputs to the system.
* MSW is 20% moisture; cheese factory waste water is added to make 50% moisture.
* Food waste is 30% dry solids; 95% degradable solids and 5% ash; 95% of the degradable solids degrade in the compost system and 5% remain as compost.
* Compost is 50% dry solids and 50% moisture.
* It is assumed that 83% of the decomposition occurs in the in-vessel composter

and 17% occurs during the windrow curing which follows.

* It is assumed that there is no leachate from the process.
* It is assumed that no materials are consumed during the decommissioning of the system; the energy required for decommissioning is 25% of the energy for installation and the cost of decommissioning is 25% of the capital cost of the system.

Summary. Table ES8.1 (Table 8.17) gives the summary of materials, energy and costs required to acquire, use and decommission the Columbia Co. Compost Facility, both the total for the 15 year design life of the system and also per 220.5 lb of food waste. Figures ES8.1 through ES8.5 (Figures 8.13 to 8.17) are calculated from Table ES8.1. Figures ES8.1 and ES8.2 show the distribution of total materials and total energy in the compost system, respectively. Figure ES8.1 shows that about 84% of the materials required over the life of the system is food waste; water is 10% and each of the other types, is less than 5%. Figure ES8.2 shows that about 87% of the total system energy is in food waste and 8% is in the fuels to generate electricity.

Figures ES8.3, ES8.4, and ES8.5 show total system materials, energy and costs by stage. About 78% of the materials are attributable to the use of the system; about 22% are attributable to system acquisition. Over 81% of the system energy is attributable to the use of the compost system; about 19% is attributable to the acquisition stage. Materials and energy required for decommissioning are negligible. Over 86% of the cost of the system is required to use the system; about 11% is required for system acquisition.

Table ES8.2 (Table 8.20) summarizes total flows consumed over the design life of the system from materials, energy sources and food waste. Figures ES8.6 and ES8.7 (Figures 8.18 and

8.19) are calculated from Table ES8.2. Figure ES8.6 shows flows to the environment by

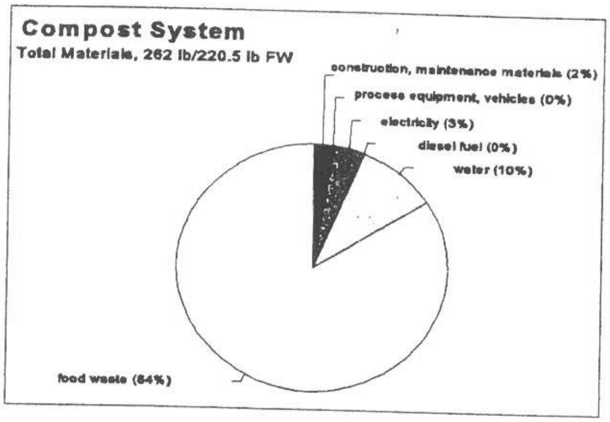


Figure ES8.1. Total system materials.

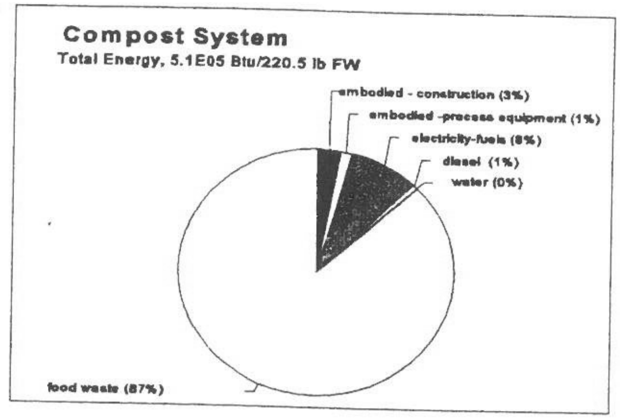


Figure ES8.2. Total system energy.

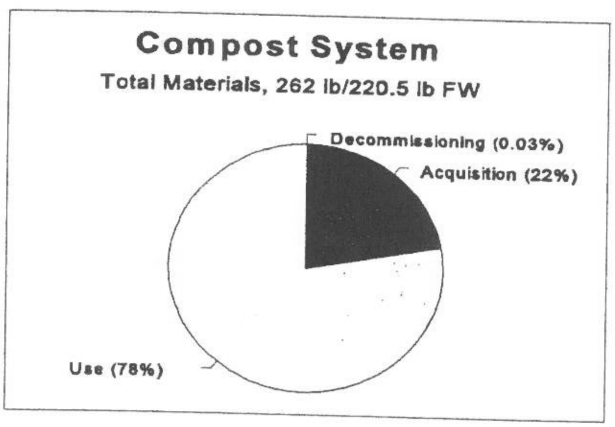


Figure ES8.3. Materials by stage.

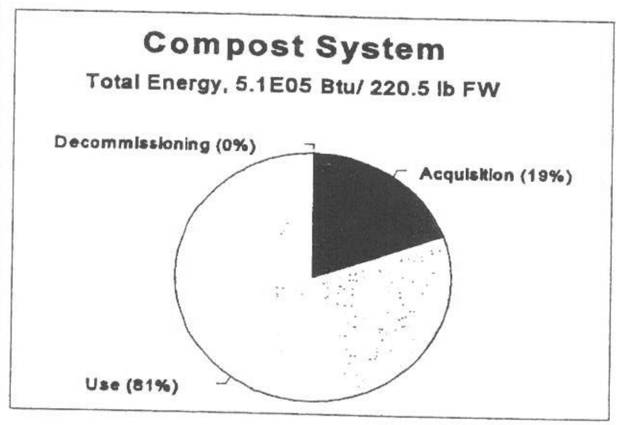


Figure ES8.4. Energy by stage.

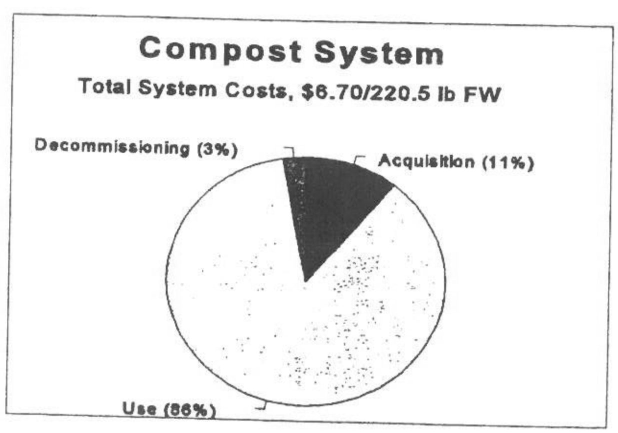


Figure ES8.5. Costs by stage.

Table ES8.1. (Table 8.17.) Summary of materials, energy and costs of the compost system.

	Table #	Acquisition	Use	Decommissioning	Total	Per 220.5 lb FW	
Land, ft^2	8	2787840	0	0	2787840	0.80	
Materials		lb	lb	lb	lb	lb	%
construction, maintenance materials	8.4, 8.5, 8.14	20155899	196168	Neg.	20352066	5.9	2
process equipment, vehicles	8.6, 8.7	1262800	No Data	Neg.	1262800	0.4	0
electricity(1)	8	No Data	33075000	Neg.	33075000	9.5	4
natural gas	-	No Data	No Data	Neg.	0	0.0	0
diesel fuel	8.9, 8.15	45429	482041	5314	532784	0.2	0
gasoline	-	No Data	No Data	Neg.	0	0.0	0
FWD materials	-	0	0	0	0	0.0	0
water(2)	8.13, 8.18, 8.19	21242127	50514904	53136	71810168	25.5	10
food waste	8	0	66869435	0	66869435	220.5	84
Total (5)		42706255	151137548	58450	193902253	261.9	100
Energy		Btu	Btu	Btu	Btu	Btu	
embodied-construction/ maintenance materials	8.4, 8.5, 8.14	44385450292	2023695098	Neg.	46409145390	13351	3
embodied-process equipment/vehicles	8.6, 8.7	24245760000	No Data	Neg.	24245760000	6975	1
electricity-fuels	8	No Data	142735500000	Neg.	14273550000 0	41061	8
natural gas	-	No Data	No Data	Neg.	0	0	0
diesel	8.9, 8.15	888311098	11324899337	124836560	12338046995	3549	1
gasoline	-	No Data	No Data	Neg.	0	0	0
FWD material	-	0	0	0	0	0	0
water(2)	-2	44608467	106081299	111586	150801352	43	0
food waste(3)	-3	0	133738870080	0	13373887008 0	441000	87
Total		69564129858	289929045813	124948146	35961812381 8	505979	100
electricity-kWh	8	0	13500000	0	13500000	4	
Costs, $	8	2500000	20167496	625000	23292496	6.70	

(1)Table 2.23.

(2)Facility water of 25 gal water/day, all embodied water in diesel and electricity and 2.1 Btu/ lb water;all materials' water attributed to acquisition.

(3)2000 Btu/lb food waste (Tchobanoglous, 1993).

(4)0.134 ft^3 /gal and 54 lb/ft^3 diesel fuel.

(5)Does not include oxygen which reacts with food waste.

Neg.- Assumed to be negligible.

type; air emissions are 81%, compost is 12%, water and waterborne wastes are 6% and solid and construction wastes are 1% of the total. Figure ES8.7 shows flows to the environment by source; 91% are attributable to food wastes, 7% to energy sources and 2% to materials.

Table ES8.2. (Table 8.20) Summary of life-cycle emissions from acquisition, use and decommissioning of the Columbia Co. Compost Facility.

	Materials**		Energy sources***		Food waste*		Total	
	lb/15 yrs	lb/220.5 lb FW	lb/15 yrs	lb/220.5 lb FW	lb/15 yrs	lb/220.5 lb FW	lb/15 yrs	lb/220.5 lb FW
Air emissions								
particulates	9044	0.00	38237	0.01		0.00	47280	0.01
nitrogen oxides	13972	0.00	112233	0.03		0.00	126205	0.04
HC (not methane)	13138	0.00	39517	0.01		0.00	52655	0.02
sulfur oxides	22048	0.00	190963	0.05		0.00	213012	0.06
CO	61903	0.01	46402	0.01		0.00	108306	0.03
CO_2	6722057	1.09	24045678	6.92	25843903	85.22	56611639	94.07
aldehydes	NA	0.00	466	0.00		0.00	466	0.00
other organics	NA	0.00	8644	0.00		0.00	8644	0.00
ammonia	NA	0.00	4	0.00		0.00	4	0.00
lead	NA	0.00	0	0.00		0.00	0	0.00
methane	309	0.00	139	0.00		0.00	448	0.00
kerosene	NA	0.00	7	0.00		0.00	7	0.00
HCl	NA	0.00	0	0.00		0.00	0	0.00
Water vapor-FW	NA	0	NA	0	49541318	163.36	49541318	163.36
Total air emissions	6842472	1.11	24482290	7.04	75385221	248.58	106709982	257.59
Solid/ construction waste	3237741	0.88	2611567	0.75	0	0.00	5849308	1.68
Compost	0	0.00	0	0.00	11948772	39.40	11948772	39.40
Water and waterborne wastes								
water	20787834	4.60	49877840	14.35	1144494	0.33	71810168	20.66
acid	NA	0.00	0	0.00	0	0.00	0	0.00
metal ion	NA	0.00	20	0.00	0	0.00	20	0.00
dissolved solids	128	0.00	11560	0.00	0	0.00	11688	0.00
suspended solids	4459	0.00	11	0.00	0	0.00	4470	0.00
BOD	1352	0.00	11	0.00	0	0.00	1363	0.00
COD	325	0.00	55	0.00	0	0.00	380	0.00
phenol	NA	0.00	0	0.00	0	0.00	0	0.00
oil	443	0.00	172	0.00	0	0.00	614	0.00
sulfuric acid	NA	0.00	15818	0.00	0	0.00	15818	0.00
iron	NA	0.00	3921	0.00	0	0.00	3921	0.00
ammonia	NA	0.00	2	0.00	0	0.00	2	0.00
chromium	NA	0.00	0	0.00	0	0.00	0	0.00
lead	NA	0.00	0	0.00	0	0.00	0	0.00
zinc	NA	0.00	0	0.00	0	0.00	0	0.00
Total water wastes	20794540	5	49909409	14	1144494	0.33	71848443	20.67
Total	30874752	7	77003266	22	88478487	288.3	196356506	319

*Table 8.13; plus 25 gal water used in the facility/day.

**From materials in buildings and maintenance materials, process equipment and vehicles; Table 8.19.

***Includes embodied and combustion emissions for fuels and electricity; Table 8.18.

NA- not available

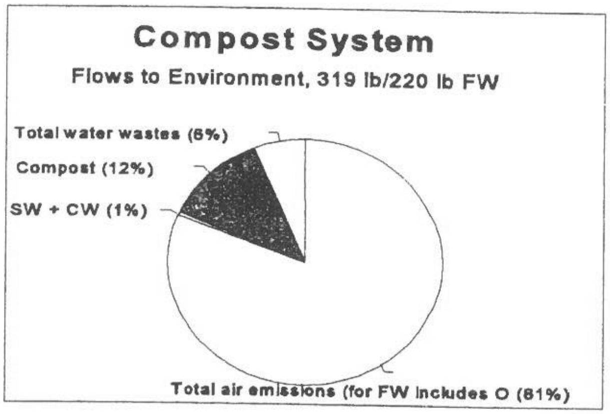


Figure ES8.6. Flows by type.

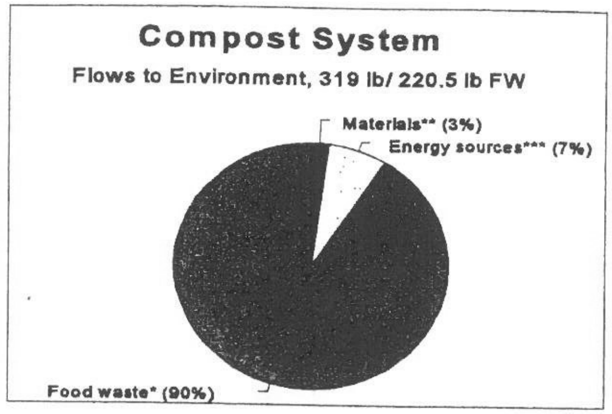


Figure ES8.7. Flows by source.

Conclusions. Following are conclusions from Chapter 8.

1. **There are 262 lb of materials attributable to 100 kg of food waste over the life of the compost system.** About 78% of the materials used are attributable to the use of the system; about 22% are required during the acquisition of the system. Eighty four per cent of the materials are food waste; 10% water, 4% fuels used to generate electricity and construction materials 2%

2. **There are 5.1 x 10^5 Btu of energy per 100 kg of food waste required over the life of the system.** Eighty one per cent of the energy is attributable to the use of the system and about 19% is attributable to system acquisition. Energy required for decommissioning is negligible. Eighty seven per cent of the energy is food waste energy; 8% is attributable to the fuels in electricity, and 3% is embodied in system materials.

3. **It costs $6.70 per 100 kg to compost food waste.** Eighty six per cent of the cost of the system is attributable to system use; 11% to system acquisition and 3% to system decommissioning.

4. There **are 319 lb of air emissions, water and waterborne wastes, solid and construction waste and compost flows to the environment per 100 kg food waste from the compost system over its design life.** Air emissions are 81%, water and waterborne wastes are 6%, solid and construction waste are 1% and compost is 12% of the total flows to the environment by type. Food wastes contribute about 90%, energy sources contribute 7% and materials contribute about 3% of the total flows to the environment by source.

5. MSW composting as a technology is at a crossroads; facilities have problems with

compost quality and markets for compost, odor problems and cost competitiveness.

6. The market value of compost does not recover processing costs.

7. Even though there is active, on-going compost research, compost science is in its infancy for MSW composting in the U.S.. It is a relatively low-technology solid waste management option; in practice, unit processes are poorly characterized.

8. Composting technology trends include increasing controls on the compost process, odor management and product quality, all of which will require increased processing costs.

9. No energy recovery is possible in aerobic composting. Composting results in the destruction of ½ of the energy value in wastes (Dean, 1995).

10. Food waste water (at 70%) supplements the water requirements for MSW (at 25%), which has an overall moisture deficiency. A moisture content of about 50% is required for composting.

11. The composting process, by volume, results in 1/3 of the material going to a landfill, 1/3 of the material going to CO_2 and 1/3 of material becoming compost (Casey, 1996). For food waste none goes to a landfill, 14% becomes compost and 86% goes to the atmosphere (30% is CO_2 and 57% is water).

12. Food waste in input material changes the regulations which apply to composting (not including home composting), including increasing the engineered containment structures and leachate collection, requiring a plan of operation report submittal and approval, monitoring and reporting (WDNR Proposed Composting Rule (s. NR 502.12) dated 2/20/96).

13. As NPK fertilizer, compost is seldom worth the energy to spread it, although it can improve poor soils (Dean, 1995).

14. Because food waste is mixed with toxic metals and organics present in MSW, the resulting compost product is more contaminated than if it were produced from just source separated food waste.

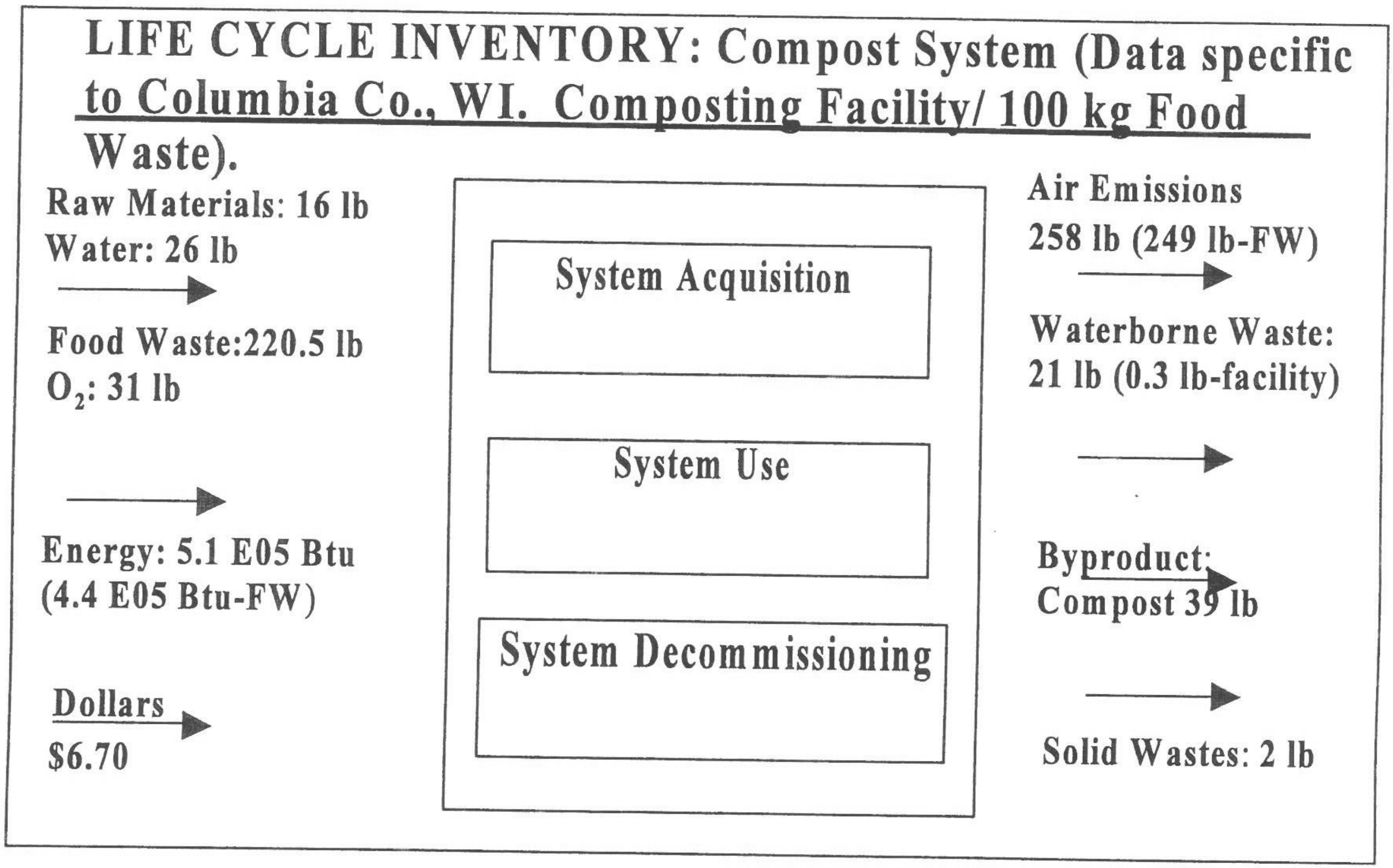


Figure ES8.8. Life Cycle Analysis: Compost System

CHAPTER 9. *WASTE-TO-ENERGY EXECUTIVE SUMMARY.*

In Chapter 9, impacts to the environment from processing food waste through a waste-to-energy facility are inventoried. The facility chosen is Hennepin County, MN. Energy Resources Corp. (HERC). When compared to U.S. waste-to-energy facilities, the HERC, which is a mass-burn, waterwall system with dry scrubber/fabric filter for air pollution control, is typical in terms of technology chosen, above average in design capacity, and near the low end of the range for capital costs. Data for MSW inputs to the facility are based on 1990 USEPA data. All materials, energy and cost data are specific to the HERC.

Materials, energy, costs and flows to the environment from the acquisition, use and decommissioning of the HERC are prorated to 100kg of food waste. For the HERC which processes 1000 tons/day with an 85% availability for 20 years, **220.5 lb represents the fraction, 1.78×10^{-8}, of the total MSW processed over the design life of the system.** Each parameter will be multiplied by this fraction to determine the quantity attributable to 100 kg of food waste.

Table ES9.1 gives a summary of the life-cycle flows for the WTE system (specifically for the HERC). Because some of the information requested of the HERC was considered proprietary and unavailable to this project, information gaps were filled from other sources, primarily the Minnesota Pollution Control Agency's files, as well as private sources.

Following are assumptions and facts about the HERC:

* The facility, which has a design capacity of 1200 TPD operates at a capacity of

1000 TPD and an availability of 85%.

* The design life of the facility is 20 years.
* The facility is on a 500,000 ft^2 site with about 15,220 ft^2 of auxilliary buildings; there are two process trains of boilers, turbines etc..
* The gross power output is 38 MW and 700 kWh/ton processed; the net power output is 33 MW and 540 kWh/ton processed.
* Air pollution control is assumed to include lime injection, thermal DeNOX and activated carbon injection for mercury control.
* It is assumed that 25.70 % of the MSW becomes ash and that 12% of the ash is fly ash and 88% is bottom ash.
* Food waste is 70% water and 30% dry solids; 95% of the dry solids are combustible solids and 5% are ash solids.
* MSW inputs to the system are assumed to have the composition of the 1990 U.S.E.P.A. MSW stream and 8.0% food waste.
* It is assumed that combustion products, except for ash, are air emissions.
* It is assumed that no materials are consumed during decommissioning; the energy required for decommissioning is 25% of the energy required for construction; the cost of decommissioning is 25% of the capital cost of the facility.

Summary of materials, energy and costs and flows to the environment for the WTE system.

The total cost per 100 kg of food waste is:

$4.90 (capital cost) + $4.26 (operating cost) + $1.23 (decommissioning) = $10.39 or $94.28/ton. This agrees with a realistic estimate for tipping fees of $100/ton MSW (Ham, 1996). At $100/ ton, the cost to combust 220.5 lb of FWD food waste is:

$100/ton x 1 ton/2000 lb x 220.5 lb = $11.03/100 kg FW

Table ES9.1 (Table 9.27) gives a summary of materials, embodied energy and costs of a waste-to-energy system over its design life and prorated to 220.5 lb of food waste. Figures ES9.1 (Figure 9.18), ES9.2 (Table 9.19), ES9.3 (Table 9.20), ES9.4 (Table 9.21) and ES9.5

(Table 9.22) show total materials and energy by type and by stage and by total system costs. Food waste makes up 76% of system materials, water contributes 13%, and diesel and the MSW required to generate system electricity contribute 1% and 8%. Food waste is 68% of the total system energy, electricity fuels contribute 15%, natural gas 9% and diesel 7%. Over 96% of the total system materials and 98% of total system energy are attributable to the operation of the system. Acquisition requires about half, use about 40% and decommissioning about 12% of total system costs.

Flows to the environment from waste-to-energy. Table ES9.2 (Table 9.31) summarizes flows to the environment from all sources. Figures ES9.6 (Figure 9.23) and ES9.7 (Figure 9.24) show flows to the environment by type and by source. Air emissions make up about 91% of total system emissions; water wastes are about 8% of the flows to the environment by type. Food wastes make up 88%, materials 1% and energy sources 11% by source.

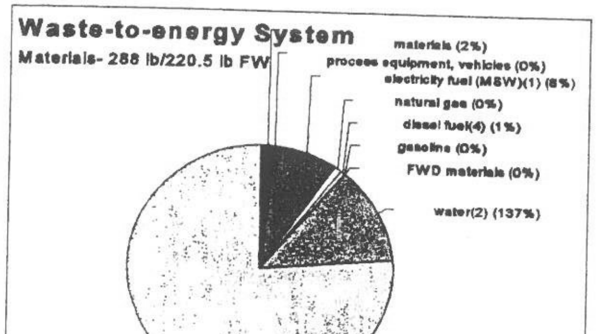


Figure ES9.1. Total materials by source.

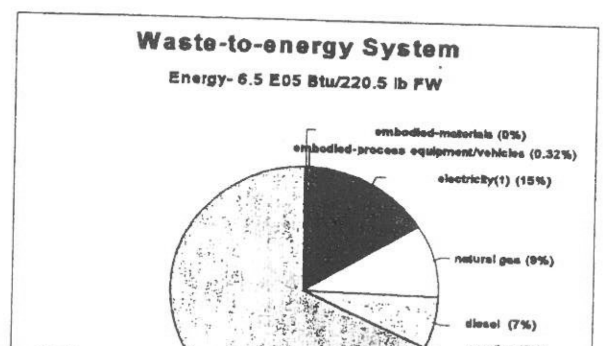


Figure ES9.2. Total energy by source.

Table ES9.1. (Table 9.28). Summary of materials, energy and costs of the W-T-E system.

	Table #	Acquisition	Use	Decommissioning	Total	Per 220.5 lb FW	
Land, ft2	9.4	500000	0	0	500000	0.01	
Materials		lb	lb	lb	lb	lb	%
materials	9.9,9.20, 9.21	7.8e+07	2.0e+08	0.0e+00	2.8e+08	5.0	2
process equipment, vehicles	9.10-9.12	6.6e+06	0.0e+00	0.0e+00	6.6e+06	0.1	0
electricity fuel (MSW)(1)		0.0e+00	1.2e+09	0.0e+00	1.2e+09	22.1	8
natural gas	9.21	0.0e+00	1.3e+08	0.0e+00	1.3e+08	2.4	1
diesel fuel(4)	9.14,9.24	1.1e+05	1.1e+08	2.7e+04	1.1e+08	1.9	1
gasoline	-	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0	0
FWD materials	-	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0	0
water(2)	9.28,9.29	1.1e+08	1.9e+09	2.7e+05	2.1e+09	36.5	13
FW(3)	9.17	0.0e+00	1.0e+09	0.0e+00	1.0e+09	220.5	76
Total		1.9e+08	4.6e+09	3.0e+05	4.8e+09	288.4	100
Energy		Btu	Btu(5)	Btu	Btu	Btu	%
embodied-materials	9.9,9.20, 9.21	1.3e+11	6.5e+08	0.0e+00	1.3e+11	2289	0
embodied-process equipment/vehicles	9.10-9.12	1.2e+11	0.0e+00	0.0e+00	1.2e+11	2068	0
electricity(1)	-	0.0e+00	5.6e+12	0.0e+00	5.6e+12	99225	15
natural gas	2.22	0.0e+00	3.5e+12	0.0e+00	3.5e+12	61347	9
diesel	2.22	2.5e+09	2.4e+12	6.3e+08	2.4e+12	43108	7
gasoline	-	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0	0
FWD material	-	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0	0
water- embodied energy(2)		2.3e+08	4.1e+09	5.7e+05	4.3e+09	77	0
FW(3)		0.0e+00	2.0e+12	0.0e+00	2.0e+12	441000	68
Total		2.5e+11	1.3e+13	6.3e+08	1.4e+13	649113	100
Costs(6)	9.26	2.8e+08	2.4e+08	6.9e+07	5.9e+08	10.39	
Electricity-exportable from FW		0.0e+00	0.0e+00	0.0e+00	0.0e+00	0	
Electricity- exportable from MSW(7)		0.0e+00	3.4e+09	0.0e+00	3.4e+09	54	

(1) Fraction MSW required to provide 10% parasitic load (10% of total MSW burned over the design life of the

(2)Water from materials attributed to acquisition; make-up water-0.0364 lb/lb MSW from Table 9.12; 2.1 Btu/ lb water.

(3)There are 2000 Btu/lb food waste (Tchobanoglous, 1993)and FW is 8.0% of MSW (Chapter 7, Table 7.10).

(4)Assumes 0.134 ft3/gal and 54 lb/ft3 diesel fuel.

(5)No information is available on the embodied energy in lime, ammonia or activated carbon or for the quantity of auxilliary natural gas consumed.

(6)From NREL/TP-431-4988C.

(7)Exportable electricity (540 kWh/ton) from total MSW burned minus 10% parasitic load attributable to 100 kg FW.

Neg.- assumed to be negligible.

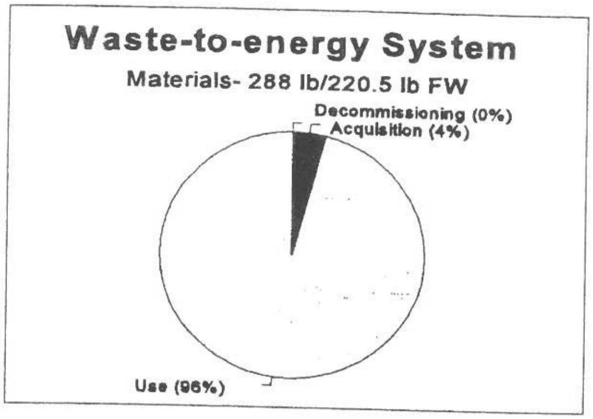


Figure ES9.3. Materials by stage.

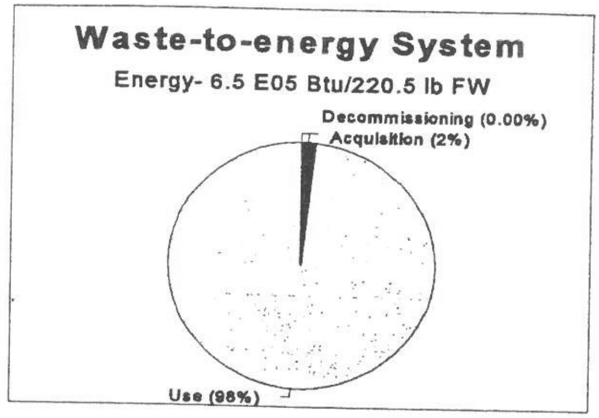


Figure ES9.4. Energy by stage.

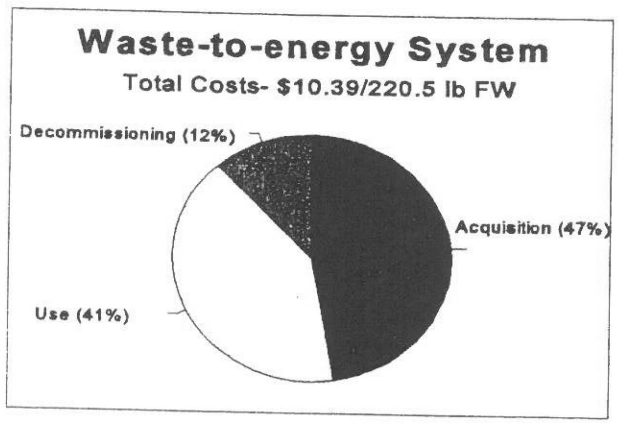


Figure ES9.5. Total system costs.

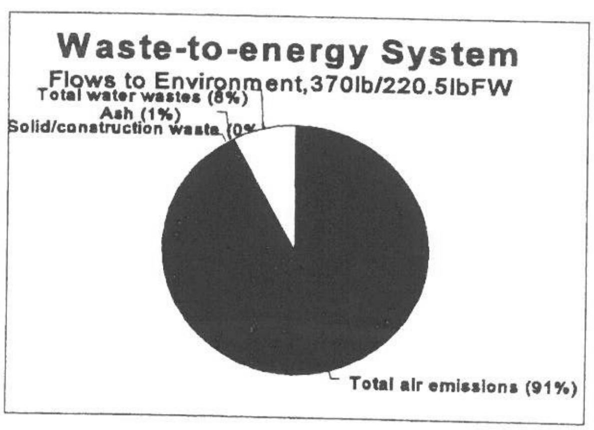


Figure ES9.6. Flows by type.

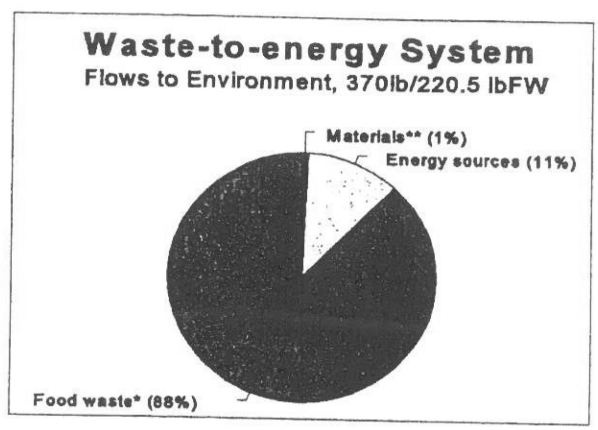


Figure ES9.7. Flows by source.

Conclusions. Following are conclusions from the WTE chapter:

1. The land attributable to 100 kg of food waste is 0.01 ft^2.

2. There are 288 lb of materials attributable to 100 kg of food waste. Water makes up 13% of the materials, 76% is food waste, 1% is diesel and 8% is the MSW required to generate system electricity. Nearly all of the materials (96%) are attributable to the use of the system.

3. There are 6.5 x 10^5 Btu of energy attributable to 100 kg of food waste. Seven per cent is diesel, 68% is food waste and 9% is natural gas. Virtually all (98%) of the energy is attributable to the use of the system.

4. There are 370 lb of flows to the environment attributable to 100 kg of food waste. Air emissions contribute 91%, water and waterborne wastes contribute 8% and ash contributes 1% by type. By source, energy sources contribute 11%, food waste contributes 88% of the total, and the contribution from materials is 1%.

5. The cost to acquire, to use and to decommission the system per 100 kg food waste is \$4.90, \$4.26 and \$1.23, respectively, for a total cost of \$10.39 per 100 kg of food waste or \$94.28 per ton.

6. When energy losses are taken into account, burning food waste in a municipal waste combustor yields no net exportable energy.

7. The use of FWDs has a small but positive effect in removing moisture from a municipality's MSW stream.

8. The fuel value of MSW almost doubled since 1960, but may be dropping in the future. Recycling programs, instituted in the '90s, are removing paper and yard waste which will lower the fuel value of MSW; however, the plastics' content of MSW discarded continues to increase which increases the fuel value of MSW.

9. Communities in which waste-to-energy facilities are located have high recycling goals. If diverting FWD food waste to wastewater treatment facilities was defined as recycling, food waste diversion through FWD could count as recycling.

Table ES9.2. (Table 9.31) Summary of life-cycle emissions from acquisition, use and decommissioning of the W-T-E facility.

	Materials**		Energy sources***		Food waste*		Total	
	lb/20yrs	lb/100kg FW	lb/20yrs	lb/100kg FW	lb/20yrs	lb/100kg FW	lb/20yrs	lb/100kg FW
Air emissions								
particulates	3.5e+04	6.2e-04	4.9e+05	8.8e-03		0.0e+00	5.3e+05	9.4e-03
NOx (+N_2)	5.6e+04	9.9e-04	3.7e+06	6.6e-02		2.7e+00	3.8e+06	2.8e+00
HC (not CH_4)	4.9e+04	8.7e-04	6.0e+06	1.1e-01		0.0e+00	6.1e+06	1.1e-01
SO_x	8.7e+04	1.5e-03	9.9e+05	1.8e-02		0.0e+00	1.1e+06	1.9e-02
CO	3.4e+05	6.0e-03	3.3e+06	5.9e-02		0.0e+00	3.7e+06	6.5e-02
CO_2	3.4e+07	6.0e-01	8.2e+08	1.5e+01		1.2e+02	8.6e+08	1.3e+02
aldehydes	NA	0.0e+00	8.7e+04	1.5e-03		0.0e+00	8.7e+04	1.5e-03
other organics	NA	0.0e+00	1.7e+06	3.0e-02		0.0e+00	1.7e+06	3.0e-02
NH_3	NA	0.0e+00	5.7e+02	1.0e-05		0.0e+00	5.7e+02	1.0e-05
Pb	NA	0.0e+00	1.6e-01	2.9e-09		0.0e+00	1.6e-01	2.9e-09
CH_4	1.5e+03	2.7e-05	1.1e+04	1.9e-04		0.0e+00	1.2e+04	2.2e-04
kerosene	NA	0.0e+00	4.2e+00	7.4e-08		0.0e+00	4.2e+00	7.4e-08
HCl	NA	0.0e+00	1.8e+01	3.1e-07		0.0e+00	1.8e+01	3.1e-07
Water vapor-FW	NA	0.0e+00	NA	0.0e+00		2.0e+02	0.0e+00	2.0e+02
Total air emissions	3.4e+07	6.1e-01	8.4e+08	1.5e+01		3.2e+02	8.7e+08	3.4e+02
SW/CW	1.7e+07	3.0e-01	2.0e+06	3.6e-02		0.0e+00	1.9e+07	3.4e-01
Ash	NA	0.0e+00	NA	0.0e+00		3.3e+00	0.0e+00	3.3e+00
Water/waterborne wastes								
water	1.1e+08	1.9e+00	1.5e+09	2.7e+01		0.0e+00	1.6e+09	2.9e+01
acid	NA	0.0e+00	1.2e-01	2.2e-09		0.0e+00	1.2e-01	2.2e-09
metal ion	NA	0.0e+00	2.6e+03	4.7e-05		0.0e+00	2.6e+03	4.7e-05
DS	3.5e+01	6.3e-07	1.5e+06	2.7e-02		0.0e+00	1.5e+06	2.7e-02
SS	2.0e+04	3.5e-04	1.4e+03	2.5e-05		0.0e+00	2.1e+04	3.8e-04
BOD_5	3.4e+02	6.1e-06	1.5e+03	2.6e-05		0.0e+00	1.8e+03	3.2e-05
COD	8.5e+01	1.5e-06	7.2e+03	1.3e-04		0.0e+00	7.3e+03	1.3e-04
phenol	NA	0.0e+00	8.5e+00	1.5e-07		0.0e+00	8.5e+00	1.5e-07
oil	2.0e+03	3.6e-05	2.4e+04	4.2e-04		0.0e+00	2.6e+04	4.6e-04
H_2SO_4	NA	0.0e+00	9.3e+03	1.7e-04		0.0e+00	9.3e+03	1.7e-04
Fe	NA	0.0e+00	2.4e+03	4.3e-05		0.0e+00	2.4e+03	4.3e-05
NH_3	NA	0.0e+00	2.1e+02	3.7e-06		0.0e+00	2.1e+02	3.7e-06
Cr	NA	0.0e+00	5.0e-01	8.9e-09		0.0e+00	5.0e-01	8.9e-09
Pb	NA	0.0e+00	2.2e-01	3.9e-09		0.0e+00	2.2e-01	3.9e-09
Zn	NA	0.0e+00	3.2e+00	5.7e-08		0.0e+00	3.2e+00	5.7e-08
Total water wastes	1.1e+08	1.9e+00	1.5e+09	2.7e+01		0.0e+00	1.6e+09	2.9e+01
Total	1.6e+08	2.8e+00	2.3e+09	4.2e+01		3.2e+02	2.5e+09	3.7e+02

*Assumes that FW is 8.0% of MSW, 30% solids, solids are 5% ash; plus makeup water of 0.0364 lb per lb of MSW. (0.0364 lb H2O/lb MSW x 220.5 lb = 8.0 lb H2O). Table 9.17.

**From materials in buildings and maintenance materials, process equipment and vehicles; Table 9.29.

***Includes embodied and combustion emissions for fuels and electricity; Table 9.28.

NA- not available

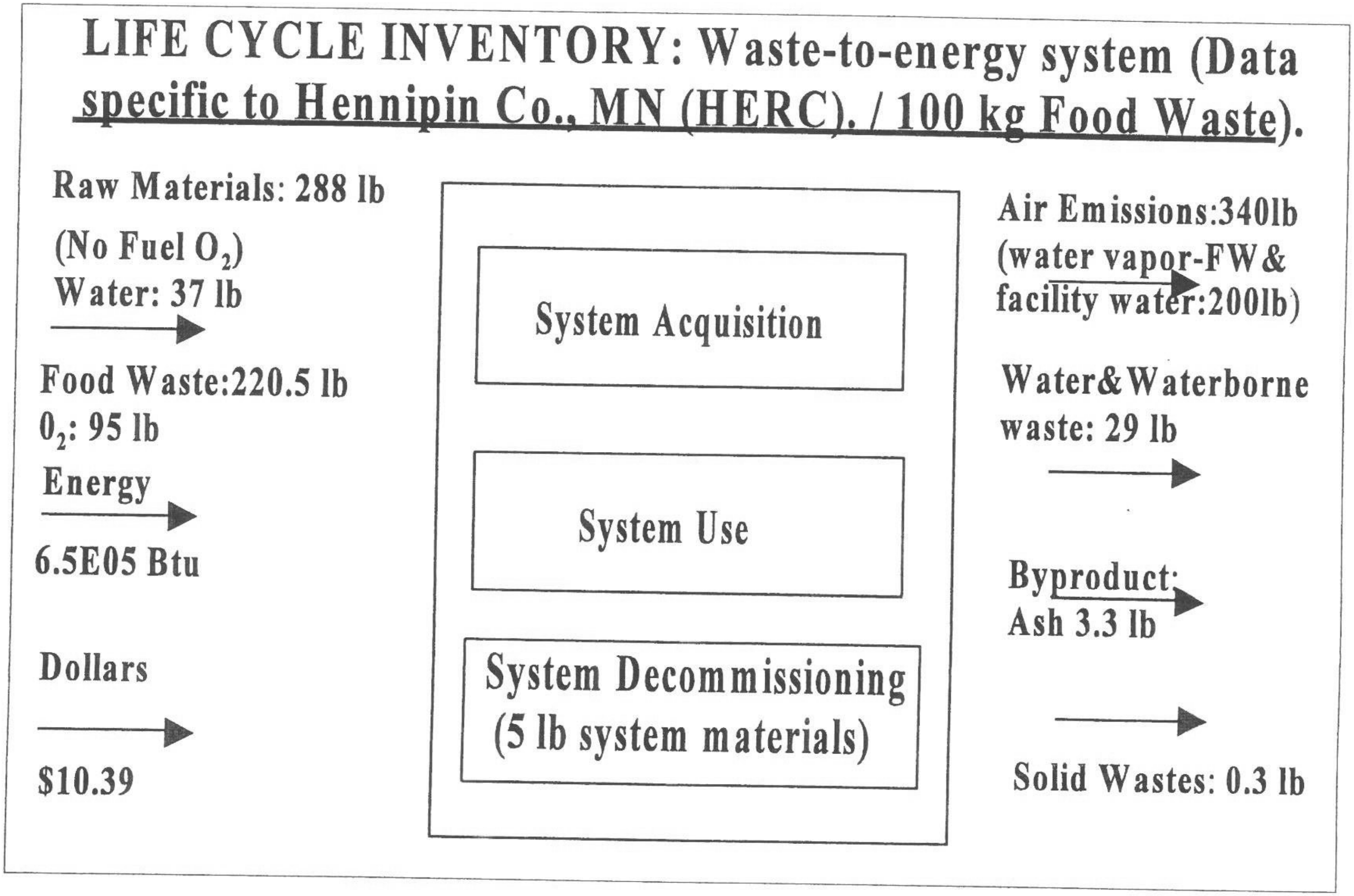


Figure ES9.8. Life-cycle inventory for WTE system.

CHAPTER 10. FOOD WASTE MANAGEMENT PROJECT: LIFE-CYCLE COMPARISON OF FIVE SYSTEMS CURRENTLY USED TO MANAGE FOOD WASTE.

10.1. ***Overall project objectives.*** The overall project goal was to develop a life-cycle inventory methodology and to use to this methodology to quantify total system materials, energy, costs and flows to the environment from acquiring, using and decommissioning typical examples of five systems currently used to manage food. The five systems include two wastewater management systems, a rural conventional on-site wastewater management system (OSS) and a municipal wastewater treatment plant (POTW), and three MSW systems, municipal collection of MSW followed by a landfill, a compost facility and a waste-to-energy facility. The specific facilities inventoried for the project, MMSD, City of Madison MSW collection system, the Dane County, WI. Landfill, the Columbia County, WI. Compost Facility and the Hennepin County, MN. Energy Resource Facility (HERC), were chosen for a number of reasons. Technologies used at these facilities are representative of current state-of-the-art practices; facilities are neither unusually small or large, they have stable operating histories and are meeting present laws and regulations; and there was locally and publicly available data on materials, energy and costs required for this inventory. The HERC is privately owned, but information on system mass flows, energy and costs, available in federal reports, the Minnesota Pollution Control Agency files and the engineering literature, made it possible to complete the inventory. For the on-site system, the difference between two conventional on-site systems (one designed for and one without a FWD) was inventoried. The life-cycle inventory for each system includes land, total system materials, total system energy, total system costs and total flows to the environment (air emissions, waterborne wastes and solid wastes) from materials, energy sources and food waste.

10.2. ***Current status and assumptions for food waste.*** Food waste currently goes through FWDs (also kitchen sinks and dishwashers) into wastewater systems and into MSW management systems. Figure 3.18 shows that about half goes to MSW (41% to landfill, 10% to WTE and a negligible amount to compost) and half goes to wastewater systems (37% to POTWs and 12% to OSS). FWDs contribute about one-third of the food waste going to wastewater systems.

Food waste is assumed to be 70% water and 30% solids. It is assumed that 95% of food waste solids are decomposable and 5% are inert. It is assumed that all of the decomposable food waste solids decompose in wastewater systems; 84% of the decomposable food waste solids decompose in a landfill and 16% remain as landfill residues; 95% of the decomposable food waste solids decompose in a compost facility and 5% remain undecomposed as compost; and all decomposable food waste solids are decomposed in a WTE facility leaving 5% ash.

10.3. ***Prorating all inventory parameters to 100 kg of food waste inputs.*** All inventory parameters are expressed per 100 kg of food waste to place data on a normalized basis for comparison. For the four municipal systems, it is assumed that the use of the FWD has no impact on system size. The current design of MMSD is set by Wisconsin Administrative Code NR 110(4) which increases POTW design requirements when there are FWDs in a service area; so, the current design already assumes the impact of FWDs. As indicated in Chapter 6, if all households had FWDs, the design flow would increase 0.1%; the assumption that the impact of the use of the FWD is negligible is reasonable. Whether all or not households have a FWD has a negligible impact on the average daily per capita weight of MSW discarded, as indicated in Figure A3.36. For the OSS, it was assumed that the use of a FWD required a redesign of the system (based on information in Ketzenberger, 1994). The 100 kg of food waste is an accounting tool that makes it possible to compare the total materials, energy and costs (attributable to 100 kg of food waste inputs) for the five systems.

Table 3.8 gives values used for FWD total solids and associated carrier water used throughout the project- 0.0291 kg total solids/person/day and associated carrier water of 1 liter/person/ day. For wastewater systems, 100 kg of food waste is associated with 1031 kg of FWD carrier water. For the POTW system, the ratio of 100 kg (220.5 lb) plus 1031 kg (2273 lb) divided by the total solids and water through the system over its design life was used to determine the fraction of materials, energy and costs attributable to 100 kg of food waste. For the on-site system, the difference between the two systems is all attributable to food waste and the fraction used was 100 kg plus associated carrier water of 1031 kg divided by the sum of the total food waste and associated carrier water through the system over its design life. For the FWD; the ratio used was the sum of 100 kg plus 1031 kg divided by the sum of the total food waste and associated carrier water through the FWD over its 12 year design life. For each of the MSW systems, the fraction attributable to 100 kg of food waste was 100 kg of food waste divided by the total MSW through a system over its design life.

Table 10.1 gives the design life and ratios used to prorate inventory parameters to 100 kg of food waste for each system. For all municipal systems and especially the POTW system, 100 kg of food waste and associated carrier water is a small fraction of the total system. Ratios for MSW systems are two orders of magnitude larger than the ratio for the POTW system; but 100 kg of food waste (and food waste is 8% of MSW) is a still a small fraction of the total MSW through each system. For the FWD and on-site systems, where the entire system is attributable to food waste, ratios are about eight orders of magnitude larger than the ratio for the POTW system.

Table 10.1. System design life and ratios used to prorate inventory parameters to 100 kg FW.

	System design life	System ratio
FWD	12	8.9e-02
OSS	20	5.4e-02
POTW	30	7.4e-10
MSW Collection System	15	5.8e-08
Compost System	15	2.9e-07
WTE System	20	1.8e-08
Landfill system	15	6.2e-08

10.4. *Comparison of land, materials, energy and costs for the five systems.* Table 10.2 gives a direct comparison of materials, energy and costs for each technology. Because the FWD is a household wastewater collection system device that diverts food waste to wastewater systems, FWD parameters are added to the OSS and POTW systems to assess the total impact of the FWD on these systems. Because the FWD is a wastewater collection system device, to be able to make a comparison between wastewater and MSW systems, MSW collection system parameters are added to equivalent parameters for the three MSW systems. Food waste is attributed to the treatment/disposal system. Because the diversion of

Table 10.2. Comparison of materials, energy and costs of five systems used to manage food waste.

Neg.-negligible; NI-no information; NA-not applicable	FWD	OSS	FWD+ OSS	POTW	POTW+ FWD	MSW Collection	Compost	Compost + Collection	W-T-E	WTE+ Collection	Landfill	Landfill+ Collection
	Table 4.17	Table 5.19		Table 6.103		Table 7.18	Table 8.17		Table 9.27		Table 7.43	
Land, ft²	ft²/100kg	ft²/100kg	ft²/100kg	ft²/100kg	ft²/100kg	ft²/100kg	ft²/100kg	ft²/100kg	ft²/100kg	ft²/100kg	ft²/100kg	ft²/100kg
	0.0006	20.43	20.43	0.003	0.003	0.01	0.80	0.81	0.01	0.02	0.19	0.20
Materials	lb/100kg	lb/100kg	lb/100kg	lb/100kg	lb/100kg	lb/100kg	lb/100kg	lb/100kg	lb/100kg	lb/100kg	lb/100kg	lb/100kg
construction and landfill materials	0.1	3143.2	3143.3	7.9	8.0	2.7	5.9	8.6	5.0	7.7	243.7	246.4
process equipment, vehicles	0.1	Neg.	0.1	0.1	0.1	0.2	0.4	0.5	0.1	0.3	0.1	0.3
electricity	1.4	Neg.	1.4	1.4	2.8	5.4	9.5	14.9	22.1	27.4	0.0	5.4
natural gas	0.5	Neg.	0.5	0.0	0.5	NI	0.0	0.0	2.4	2.4	0.6	0.6
diesel fuel	0.1	12.9	13.0	0.1	0.2	1.4	0.2	1.6	1.9	3.3	1.4	2.8
gasoline	0.7	Neg.	0.7	0.0	0.7	NI	0.0	0.0	0.0	0.0	0.0	0.0
FWD materials	1.5	0.0	1.5	0.0	1.5	NA	0.0	0.0	0.0	0.0	0.0	0.0
water	260.4	3733.4	3993.8	2286.3	2546.7	38.5	25.5	64.0	36.5	75.0	44.3	82.8
food waste	0.0	220.5	220.5	220.5	220.5	0.0	220.5	220.5	220.5	220.5	220.5	220.5
Total	264.9	7109.9	7374.8	2516.2	2781.1	48.2	261.9	310.1	288.4	336.6	510.5	558.7
Total minus FW and CW	264.9	4616.2	4881.1	22.5	287.4	48.2	41.4	89.6	67.9	116.1	290.0	338.2
Energy	Btu/100kg	Btu/100kg	Btu/100kg	Btu/100kg	Btu/100kg	Btu/100kg	Btu/100kg	Btu/100kg	Btu/100kg	Btu/100kg	Btu/100kg	Btu/100kg
embodied materials	308	526506	526814	5707	6014	18983	13351	32334	2289	21272	6628	25611
embodied-process equip./vehicles	1477	Neg.	1477	1021	2498	2027	6975	9002	2068	4095	1635	3662
electricity	6177	Neg.	6177	6056	12233	23373	41061	64434	99225	122598	NI	23373
natural gas	13126	Neg.	13126	416	13542	NI	NI	NI	61347	61347	15299	15299
diesel	3717	302149	305866	1659	5376	33856	3549	37405	43108	76963	31877	65733
gasoline	16780	NI	16780	52	16832	NI	NI	NI	NI	NI	NI	NI
FWD material	47197	0	47197	0	47197	NA	NA	NA	NA	NA	NA	NA
water	547	7840	8387	4798	5345	81	43	124	77	158	93	174
Total	89329	836495	925824	19708	109037	78320	64979	143299	208113	286433	55531	133851
Total minus exportable FW energy*	89329	836495	925824	-43585	45744	78320	64979	143299	208113	286433	1792	80112
Costs-$	17.45	49.75	67.20	0.49	17.94	9.90	6.70	16.60	10.39	20.30	3.75	13.65
Exportable electricity** kWh	0	0	0	19	19	0	0	0	0	0	16	16

* Exportable energy for POTW = 63,293 Btu/100 kg FW; for Landfill = 53739 Btu/100 kg FW.

**Exportable electricity based on methane combustion and 1.75 kWh/lb methane; exportable FW energy- subtract 3412 Btu per exportable kWh.

food waste through FWDs to municipal wastewater systems is an important option evaluated for this project, each inventory parameter is compared to the equivalent parameter for the POTW/FWD system in Table 10.3, which facilitates a rapid comparison of system parameters.

Table 10.3. Comparing systems to POTW/FWD system.

Parameter	OSS/FWD	POTW/FWD	Compost/Collection	WTE/Collection	Landfill/Collection
Total Land	**6245**	**1.0**	**249**	**6.2**	**61.7**
Materials					
construction materials	391.8	1.0	1.1	1.0	0.4
process equipment, vehicles	0.6	1.0	4.1	2.2	2.0
electricity (lb of fuels)	0.5	1.0	5.3	9.7	1.9
natural gas	1.0	1.0	0.0	4.5	1.1
diesel fuel	64.8	1.0	8.0	16.5	13.9
gasoline	1.0	1.0	0.0	0.0	0.0
FWD materials	1.0	1.0	0.0	0.0	0.0
water	1.6	1.0	0.0	0.0	0.0
food waste	1.0	1.0	1.0	1.0	1.0
Total Materials	**2.7**	**1.0**	**0.1**	**0.1**	**0.2**
Total minus FW and Carrier Water	**17.0**	**1.0**	**0.3**	**0.2**	**0.4**
Energy					
embodied- materials	87.6	1.0	5.4	3.5	3.3
embodied-process equip./vehicles	0.6	1.0	3.6	1.6	1.5
electricity-fuels	0.5	1.0	5.3	10.0	1.9
natural gas	1.0	1.0	0.0	4.5	1.1
diesel	56.9	1.0	7.0	14.3	12.2
gasoline	1.0	1.0	0.0	0.0	0.0
FWD material	1.0	1.0	0.0	0.0	0.0
water	1.6	1.0	0.0	0.0	0.0
Total	**8.5**	**1.0**	**1.3**	**2.6**	**1.2**
Total minus exportable FW energy	**20.2**	**1.0**	**3.1**	**6.3**	**1.8**
Exportable electricity, kWh	0	1.0	0	0	0.8
Total Costs	**3.7**	**1.0**	**0.9**	**1.1**	**0.8**

Table 10.4 compares materials and energy parameters by the percent each subcategory contributes to total materials or energy. Table 10.5 compares the five systems by the per cent of materials and energy contributed by each stage; zeros indicate a contribution less than 0.5%. Table 10.6 compares the five systems by ratios of materials (each material parameter per 100 kg FW to 100 kg) and by ratios of energy (each energy parameter per 100

Table 10.4. Comparing percentage of materials, and energy in subcategories.

	FWD (no FW)	OSS	POTW	MSW Collection (noFW)	Compost	WTE	Landfill
Materials-lb/100kg	265	7110	2518	48	262	288	510
	%	%	%	%	%	%	%
construction materials	0	44	0	6	2	2	48
process equipment, vehicles	0	0	0	0	0	0	0
electricity	1	0	0	11	4	8	0
natural gas	0	0	0	0	0	1	0
diesel fuel	0	0	0	3	0	1	0
gasoline	0	0	0	0	0	0	0
FWD materials	1	0	0	0	0	0	0
water	98	53	91	80	10	13	9
food waste	0	3	9	0	84	76	43
Total	100	100	100	100	100	100	100
Energy-Btu/100 kg	89329	836495	66735	78320	64979	208113	55531
	%	%	%	%	%	%	%
embodied- materials	0	63	9	24	21	1	12
embodied-process equip./vehicles	2	0	2	3	11	1	3
electricity	7	0	9	30	63	48	0
natural gas	15	0	1	0	0	29	28
diesel	4	36	2	43	5	21	57
gasoline	19	0	0	0	0	0	0
FWD material-embodied energy	53	0	70	0	0	0	0
water-embodied energy	1	1	7	0	0	0	0
Total	100	100	100	100	100	100	100

kg FW to the energy in 100 kg (441000 Btu/100 kg) of FW). This comparison makes it possible to rapidly identify the two or three most important materials or energy parameters for each system. Table 10.7 gives the percentage contributed by the FWD (or MSW collection system) and the percentage contributed by the treatment/disposal system for land, total materials, total energy and total cost. Total land, materials, energy and costs are compared for the five systems. Table 10.8 gives total materials and energy for each system with and without the contribution of food waste and carrier water.

Table 10.5. Comparing systems by stage.

	Acquisition	Use	Decommissioning	Total
Total materials required	%	%	%	%
OSS	97	3	0	100
POTW	46	54	0	100
Compost	22	78	0	100
WTE	4	96	0	100
Landfill*	88	12	0	100
Total energy required	%	%	%	%
OSS	93	4	3	100
POTW	44	54	2	100
Compost	31	69	0	100
WTE	2	98	0	100
Landfill*	30	70	0	100

*Daily cover attributed to acquisition stage.

Table 10.6. Ratios of parameter weights per 100 kg FW to 100 kg FW and parameter energy per 100 kg FW to energy in 100 kg FW (441,000 Btu).

	FWD/OSS	FWD/POTW	MSW Collection/Compost	MSW Collection/WTE	MSW Collection/Landfill
Materials					
construction	14.3	0.0	0.0	0.0	1.1
process equip., vehicles	0.0	0.0	0.0	0.0	0.0
electricity	0.0	0.0	0.1	0.1	0.0
natural gas	0.0	0.0	0.0	0.0	0.0
diesel fuel	0.1	0.0	0.0	0.0	0.0
gasoline	0.0	0.0	0.0	0.0	0.0
FWD materials	0.0	0.0	0.0	0.0	0.0
water	18.1	11.6	0.3	0.3	0.4
food waste	1.0	1.0	1.0	1.0	1.0
Total	33.4	12.6	1.4	1.5	2.5
Energy					
embodied- materials	1.2	0.0	0.1	0.0	0.1
embod.-process equip./ vehicles	0.0	0.0	0.0	0.0	0.0
electricity	0.0	0.0	0.1	0.3	0.1
natural gas	0.0	0.0	0.0	0.1	0.0
diesel	0.7	0.0	0.1	0.2	0.1
gasoline	0.0	0.0	0.0	0.0	0.0
FWD material	0.1	0.1	0.0	0.0	0.0
water	0.0	0.0	0.0	0.0	0.0
Total (minus exportable FW energy)	2.1	0.1	0.3	0.7	0.2

Table 10.7. Comparing systems by the percent contributed by the FWD (or MSW collection system) to the percent contributed by the system.

	land	total materials	total energy	total costs
FWD/OSS	%	%	%	%
FWD	0	4	10	26
OSS	100	96	90	74
FWD/POTW				
FWD	20	10	82	97
POTW	80	90	18	3
MSW Collection/Compost				
MSW Collection	1	16	55	60
Compost	99	84	45	40
MSW Collection/WTE				
MSW Collection	56	14	27	49
WTE	44	86	73	51
MSW Collection/Landfill				
MSW Collection	6	9	59	73
Landfill	94	91	41	27

Table 10.8. System materials and energy minus food waste and carrier water.

	Materials		Energy	
	With FW and CW	Without FW and CW	Total	Total minus exportable FW energy
FWD+OSS	7375	4881	925824	925824
POTW+FWD	2781	287	109037	45744
Compost+Collection	310	90	143299	143299
WTE+Collection	337	116	286433	286433
Landfill+Collection	559	338	133851	80112

10.4.1. *Total land requirements*. As shown below, land requirements per 100 kg FW range over three orders of magnitude. Arranged lowest to highest the five systems are

1. FWD/POTW (0.003 ft^2 per 100 kg FW)
2. MSW Collection/WTE (0.02 ft^2 per 100 kg FW)
3. MSW Collection/Landfill (0.20 ft^2 per 100 kg FW)
4. MSW Collection/Compost (0.81 ft^2 per 100 kg FW)
5. FWD/OSS (20 ft^2 per 100 kg FW)

There is a large difference in land requirements between rural and municipal systems. The rural FWD/OSS has over 6000 times the land requirements of the FWD/POTW system, the least land consumptive system. Land requirements of the FWD are negligible. Essentially all of the land requirements of the FWD/OSS are contributed by the OSS absorption bed. The MSW Collection/Compost system is the most land consumptive of the MSW systems, requiring almost 250 times as much land as the FWD/POTW system, and almost all (99%) of the land requirements are contributed by the compost system. The MSW Collection/Landfill system requires over 60 times the land of the FWD/POTW system. The MSW Collection/ WTE system is the least land consumptive of the MSW systems, requiring about six times the land of the FWD/POTW system.

10.4.2. ***Total system materials.*** Total system materials per 100 kg vary over one order of magnitude as indicated below. Total system materials minus food waste and carrier water arranged lowest to highest for the five systems are

1. MSW Collection/Compost (90 lb per100 kg FW)
2. MSW Collection/WTE (120 lb per100 kg FW)
3. FWD/POTW (290 lb per100 kg FW)
4. MSW Collection/Landfill (340 lb per100 kg FW)
5. FWD/OSS (4900 lb per100 kg FW)

The FWD/OSS requires 17 times the materials of the FWD/POTW, 96% are contributed by the OSS and most are the extra aggregate in the absorption bed and concrete in the tank required for the larger OSS. The FWD/OSS requires over 30 times the weight of the 100 kg of food waste in total system materials.

Including food waste and carrier water, wastewater systems require about an order of magnitude more life-cycle materials per 100 kg of food waste then MSW systems. The difference is primarily attributable to the carrier water associated with food waste. If the weights of food waste and carrier water are subtracted from the totals for each system, to one significant digit, the materials' requirements of the FWD/POTW system are similar to the MSW Collection/Landfill, the MSW Collection/Compost system and the MSW Collection/WTE system and are an order of magnitude lower than the FWD/OSS system.

As indicated in Table 10.4, construction materials are significant for the rural FWD/OSS because 100 kg of food waste represents a comparatively high fraction of the total material through the system and for the MSW Collection/Landfill because of soil daily cover quantities. Process equipment and vehicles are negligible for all systems. Fuel weights are a negligible percentage for wastewater systems and for the MSW/Landfill. For the MSW Collection/WTE system, fuels represent about 10% of the total life-cycle materials; for the MSW Collection/ Compost system they represent about 5%. Food waste and carrier water contribute almost all the life-cycle materials for the FWD/POTW but only about 1/3 for the FWD/OSS. Food waste contributes about 70% of the total system materials for the MSW Collection/Compost system, 66% for the MSW Collection/ WTE system, and 39% for the MSW Collection/ Landfill system.

10.4.3. *Total energy requirements.* Total system energy requirements (minus exportable FW energy) vary over an order of magnitude. Total system energy minus exportable FW energy arranged lowest to highest are given below:

1.	FWD/POTW	(46,000 Btu per 100 kg FW)
2.	MSW Collection/Landfill	(80,000 Btu per 100 kg FW)
3.	MSW Collection/Compost	(140,000 Btu per 100 kg FW)
4.	MSW Collection/WTE	(290,000 Btu per 100 kg FW)
5.	FWD/OSS	(930,000 Btu per 100 kg FW)

The FWD/ POTW system has the lowest and the FWD/OSS system the highest life-cycle energy requirements. Exportable energy from burning digester gas and landfill gas lowers the life-cycle energy requirements for the FWD/POTW and MSW Collection/Landfill system, respectively. The 100 kg of food waste is a large fraction of materials through the FWD/OSS over its design life, which contributes to the total system energy requirements.

As indicated in Table 10.4, energy embodied in construction materials is highest for the FWD/OSS. Process equipment and vehicles contribute less than 10% of the total life-cycle energy for all systems but the MSW Collection/Compost system. Fuels and electricity represent about 98% of the total life-cycle energy for the MSW Collection/WTE system, 85% for the MSW Collection/Landfill system, and 68% for the MSW Collection/Compost system. Energy embodied in FWD materials make up most of the life-cycle energy for the FWD/POTW system. The four municipal systems are from about three times to 20 times lower than the rural FWD/OSS.

10.4.4. ***Total system costs.*** Total system costs vary by a factor of about 5. Total system costs arranged lowest to highest are given below:

1.	MSW Collection/Landfill	($13.65 per 100 kg FW)
2.	MSW Collection/Compost	($16.60 per 100 kg FW)
3.	FWD/POTW	($17.94 per 100 kg FW)

4. MSW Collection/WTE ($20.30 per 100 kg FW)
5. FWD/OSS ($67.20 per 100 kg FW)

The system with the highest cost per 100 kg food waste, the FWD/OSS, is about 5 times the cost per 100 kg food waste of the least cost system, the MSW Collection/Landfill system. The four municipal systems are reasonably similar in cost per 100 kg FW. For the MSW/POTW most of the total cost is due to the FWD and is paid by the homeowner; the cost of processing the 100 kg of food waste through the POTW is less than 50 cents.

10.5. ***Comparison of flows to the environment for the five systems.*** Table 10.9 compares flows to the environment (air emissions, water, waterborne wastes, solid and construction waste and byproducts (septage, sludge, compost, ash and landfill residues) for the five food waste management systems. Table 10.10 compares inventory parameters for each system to the FWD/POTW system. Table 10.11 compares the weight of each parameter per 100 kg to 100 kg for the five systems. Table 10.12 shows a comparison of emissions' parameters per 100 kg to the 100 kg of FW. Table 10.13 compares systems by percent of flows (air emissions, solid and construction waste, water, waterborne wastes, byproducts and total flows) contributed by the FWD (MSW Collection system) and the percent contributed by the disposal system.

Table 10.9. Summary of life-cycle emissions from acquisition, use and decommissioning of five engineered systems for the management of food waste.

	FWD	OSS	FWD+ OSS	POTW	POTW+ FWD	MSW Collection	Compost System	Collection +Compost	WTE System	Collection +WTE	Landfill System	Collection +Landfill
Air emissions	lb/100kg	lb/100kg	lb/100kg	lb/100kg	lb/100kg	lb/100kg	lb/100kg	lb/100kg	lb/100kg	lb/100kg	lb/100kg	lb/100kg
particulates	2.8e-02	2.4e-01	2.7e-01	1.8e-03	3.0e-02	1.6e-02	1.4e-02	3.0e-02	9.4e-03	2.5e-02	-1.2e-02	3.8e-03
nitrogen oxides	4.5e-02	6.2e-01	6.6e-01	5.1e-03	5.0e-02	6.6e-02	3.6e-02	1.0e-01	2.8e+00	2.8e+00	7.8e-03	7.4e-02
HC (not methane)	4.7e-02	2.1e-01	2.5e-01	2.6e-03	4.9e-02	2.7e-02	1.5e-02	4.3e-02	1.1e-01	1.4e-01	1.8e-01	2.1e-01
sulfur oxides	6.4e-02	2.9e-01	3.6e-01	5.7e-03	7.0e-02	5.9e-02	6.1e-02	1.2e-01	1.9e-02	7.8e-02	-8.9e-02	-3.0e-02
carbon monoxide	1.3e-01	4.9e-01	6.2e-01	5.8e-03	1.4e-01	5.5e-02	3.1e-02	8.6e-02	6.5e-02	1.2e-01	3.3e-02	8.8e-02
carbon dioxide	1.4e+01	1.1e+02	1.3e+02	8.4e+01	9.7e+01	9.6e+00	9.4e+01	1.0e+02	1.3e+02	1.4e+02	7.1e+01	8.1e+01
aldehydes	1.6e-04	1.1e-02	1.1e-02	5.4e-05	2.1e-04	1.2e-03	1.3e-04	1.3e-03	1.5e-03	2.7e-03	1.1e-03	2.3e-03
other organics	2.1e-02	2.1e-01	2.3e-01	1.1e-03	2.2e-02	2.3e-02	2.5e-03	2.6e-02	3.0e-02	5.4e-02	2.2e-02	4.5e-02
ammonia	4.7e-06	6.9e-05	7.4e-05	3.9e-07	5.1e-06	8.0e-06	1.3e-06	9.3e-06	1.0e-05	1.8e-05	6.5e-06	1.5e-05
lead	3.5e-06	2.0e-08	3.5e-06	1.1e-08	3.5e-06	2.3e-09	3.5e-10	2.6e-09	2.9e-09	5.1e-09	1.8e-09	4.1e-09
methane	2.5e-04	1.5e+01	1.5e+01	2.9e-05	2.8e-04	1.5e-04	1.3e-04	2.8e-04	2.2e-04	3.7e-04	5.0e+00	5.0e+00
kerosene	1.0e-06	2.5e-07	1.3e-06	1.3e-07	1.2e-06	1.1e-06	1.9e-06	3.1e-06	7.4e-08	1.2e-06	-4.1e-06	-2.9e-06
HCl	1.4e-07	2.1e-06	2.3e-06	1.2e-08	1.5e-07	2.5e-07	3.8e-08	2.8e-07	3.1e-07	5.6e-07	2.0e-07	4.5e-07
Water vapor-FW	0.0e+00	0.0e+00	0.0e+00	2.4e+01	2.4e+01	0.0e+00	1.6e+02	1.6e+02	2.0e+02	2.0e+02	2.4e+01	2.4e+01
Total air emissions	1.4e+01	1.3e+02	1.4e+02	1.1e+02	1.2e+02	9.9e+00	2.6e+02	2.7e+02	3.4e+02	3.5e+02	1.0e+02	1.1e+02
SW/CE	1.6e+00	4.7e+02	4.8e+02	2.8e+00	4.4e+00	9.7e-01	1.7e+00	2.7e+00	3.4e-01	1.3e+00	5.0e+00	6.0e+00
*Other	0.0e+00	3.1e+02	3.1e+02	3.4e+02	3.4e+02	0.0e+00	3.9e+01	3.9e+01	3.3e+00	3.3e+00	2.5e+01	2.5e+01
Water/waterborne wastes												
water	2.6e+02	3.6e+03	3.8e+03	2.1e+03	2.3e+03	3.9e+01	2.1e+01	5.9e+01	2.9e+01	6.7e+01	1.9e+02	2.3e+02
acid	1.0e-09	6.6e-02	6.6e-02	6.6e-02	6.6e-02	1.7e-09	2.7e-10	2.0e-09	2.2e-09	4.0e-09	1.4e-09	3.2e-09
metal ion	2.1e-05	3.2e-04	3.4e-04	1.8e-06	2.3e-05	3.7e-05	5.8e-06	4.3e-05	4.7e-05	8.4e-05	3.0e-05	6.7e-05
dissolved solids	1.3e-02	1.8e-01	1.9e-01	2.5e+00	2.5e+00	2.1e-02	3.4e-03	2.4e-02	2.7e-02	4.8e-02	1.8e-02	3.9e-02
suspended solids	7.1e-03	1.2e+01	1.2e+01	2.0e-01	2.1e-01	1.2e-03	1.3e-03	2.4e-03	3.8e-04	1.5e-03	2.5e-02	2.7e-02
BOD	1.1e-03	3.5e-03	4.6e-03	1.3e-04	1.2e-03	4.5e-03	3.9e-04	4.9e-03	3.2e-05	4.5e-03	1.3e-02	1.8e-02
COD	4.0e-03	8.7e-04	4.8e-03	1.3e-05	4.0e-03	1.3e-04	1.1e-04	2.4e-04	1.3e-04	2.6e-04	2.5e-02	2.5e-02

phenol	7.0e-08	1.0e-06	1.1e-06	5.8e-09	7.6e-08	1.2e-07	1.9e-08	1.4e-07	1.5e-07	2.7e-07	9.7e-08	2.2e-07
oil	1.4e-03	2.5e-03	3.9e-03	3.3e-05	1.5e-03	3.1e-04	1.8e-04	4.8e-04	4.6e-04	7.7e-04	4.2e-04	7.3e-04
sulfuric acid	2.4e-03	5.5e-04	3.0e-03	3.1e-04	2.7e-03	2.6e-03	4.6e-03	7.2e-03	1.7e-04	2.8e-03	-9.6e-03	-6.9e-03
iron	6.1e-04	1.4e-04	7.5e-04	7.6e-05	6.8e-04	6.6e-04	1.1e-03	1.8e-03	4.3e-05	7.0e-04	1.0e-02	1.1e-02
ammonia+NO_3	1.7e-06	2.5e-05	2.7e-05	1.4e-07	1.8e-06	2.9e-06	4.5e-07	3.3e-06	3.7e-06	6.5e-06	2.5e-03	2.5e-03
chromium	4.1e-09	6.0e-08	6.5e-08	3.4e-10	4.4e-09	7.0e-09	1.1e-09	8.1e-09	8.9e-09	1.6e-08	5.7e-09	1.3e-08
lead	1.8e-09	2.7e-08	2.8e-08	1.5e-10	2.0e-09	3.1e-09	4.8e-10	3.6e-09	3.9e-09	7.0e-09	2.5e-09	5.6e-09
zinc	2.7e-08	3.9e-07	4.2e-07	2.2e-09	2.9e-08	4.5e-08	7.1e-09	5.2e-08	5.7e-08	1.0e-07	3.7e-08	8.2e-08
Total water wastes	3.0e-02	1.3e+01	1.3e+01	2.8e+00	2.8e+00	3.0e-02	1.1e-02	4.1e-02	2.8e-02	5.9e-02	8.5e-02	1.2e-01
Total	2.8e+02	4.5e+03	4.8e+03	2.5e+03	2.8e+03	4.9e+01	3.2e+02	3.7e+02	3.7e+02	4.2e+02	3.2e+02	3.7e+02

*Septage(OSS)/sludge(POTW)/compost(compost)/ash(WTE)/food residues(landfill).

10.5.1. ***Total air emissions.*** Total air emissions range from a low of 110 lb/100 kg for the MSW Collection/Landfill system to a high of about 350 lb/100 kg for the MSW Collection/ WTE system, as shown below.

1.	MSW Collection/Landfill	(110 lb per 100 kg FW)
2.	FWD/POTW	(120 lb per 100 kg FW)
3.	FWD/OSS	(140 lb per 100 kg FW)
4.	MSW Collection/Compost	(270 lb per 100 kg FW)
5.	MSW Collection/WTE	(350 lb per 100 kg FW)

Food waste carbon dioxide, water vapor and methane are the largest air emissions by type. For the MSW Collection/WTE system, 41% of the total emissions is CO_2; 58% is water vapor. The MSW Collection/Compost system has the second highest air emissions, 61% of which is water vapor; 39% is carbon dioxide. For the FWD/OSS, FWD/POTW and MSW Collection/ Landfill systems, carbon dioxide represents over 70% of the total air emissions.

Because it was assumed that all methane produced in the FWD/POTW system was burned for energy recovery, methane emissions from food waste were reduced to zero and emissions of CO_2 and water vapor were increased. For the MSW Collection/Landfill system, it was assumed that 2/3 of the methane emissions were captured and burned and 1/3 were air emissions from the landfill. It was assumed that all FWD/OSS methane emissions were air emissions. In Table 10.10, because systems are compared to the FWD/POTW, methane emissions for the FWD/OSS and MSW Collection/Landfill stand out for being very high. All other air emissions make relatively small contributions to the total. Food waste contributions to air emissions are the major contributions. Contributions from materials are negligible and from energy sources are small.

Table 10.10. Comparing inventory parameters for each system to the POTW/FWD system.					
Parameter	FWD/OSS	FWD/POTW	MSW Collection/Compost	MSW Collection/WTE	MSW Collection/Landfill**
Air emissions					
particulates	9.0	1.0	1.0	0.9	0.1
nitrogen oxides	13.2	1.0	2.1	56.9	1.5
HC (not methane)	5.1	1.0	0.9	2.8	4.3
sulfur oxides	5.1	1.0	1.7	1.1	-0.4
carbon monoxide	4.6	1.0	0.6	0.9	0.6
carbon dioxide	1.3	1.0	1.1	1.5	0.8
aldehydes	50.6	1.0	6.2	12.9	10.8
other organics	10.2	1.0	1.1	2.4	2.0
ammonia	14.6	1.0	1.8	3.6	2.9
lead	1.0	1.0	0.0	0.0	0.0
methane	54797.0	1.0	1.0	1.3	18008.0
kerosene	1.1	1.0	2.6	1.0	-2.5
HCl	15.0	1.0	1.9	3.7	3.0
Water vapor-FW	0.0	1.0	6.9	8.4	1.0
Total air emissions	1.2	1.0	2.2	2.8	0.9
SW/CW	108.5	1.0	0.6	0.3	1.4
Other*	0.9	1.0	0.1	0.0	0.1
Water/ waterborne wastes					
water	1.6	1.0	0.0	0.0	0.1
acid	1.0	1.0	0.0	0.0	0.0
metal ion	14.8	1.0	1.9	3.6	2.9
dissolved solids	0.1	1.0	0.0	0.0	0.0
suspended solids	58.9	1.0	0.0	0.0	0.1
BOD_5	3.9	1.0	4.1	3.8	15.0
COD	1.2	1.0	0.1	0.1	6.4
phenol	14.5	1.0	1.8	3.5	2.8
oil	2.7	1.0	0.3	0.5	0.5
sulfuric acid	1.1	1.0	2.6	1.0	-2.5
iron	1.1	1.0	2.6	1.0	15.9
ammonia+NO_3	14.5	1.0	1.8	3.6	1374.4
chromium	14.6	1.0	1.8	3.6	2.9
lead	14.4	1.0	1.8	3.5	2.8
zinc	14.4	1.0	1.8	3.5	2.8
Total water wastes	4.5	1.0	0.0	0.0	0.0
Total	1.7	1.0	0.1	0.1	0.1
*Compost/ash/food residues/septage					
**Corrected for emissions off-sets.					

Table 10.11. Comparing ratios for each system (parameter weights per 100 kg divided by 100 kg).

	FWD/OSS	FWD/POTW	MSW Collection/Compost	MSW Collection/WTE	MSW Collection/Landfill
Air emissions					
particulates	0.00	0.00	0.00	0.00	0.00
nitrogen oxides	0.00	0.00	0.00	0.01	0.00
HC (not methane)	0.00	0.00	0.00	0.00	0.00
sulfur oxides	0.00	0.00	0.00	0.00	0.00
carbon monoxide	0.00	0.00	0.00	0.00	0.00
carbon dioxide	0.58	0.44	0.47	0.64	0.37
aldehydes	0.00	0.00	0.00	0.00	0.00
other organics	0.00	0.00	0.00	0.00	0.00
ammonia	0.00	0.00	0.00	0.00	0.00
lead	0.00	0.00	0.00	0.00	0.00
methane	0.07	0.00	0.00	0.00	0.02
kerosene	0.00	0.00	0.00	0.00	0.00
HCl	0.00	0.00	0.00	0.00	0.00
Water vapor-FW	0.00	0.11	0.74	0.91	0.11
Total air emissions	**0.66**	**0.55**	**1.21**	**1.57**	**0.50**
SW/CW	**2.16**	**0.02**	**0.01**	**0.01**	**0.03**
***Other**	**1.40**	**1.55**	**0.18**	**0.02**	**0.11**
Water/waterborne wastes					
water	**17.44**	**10.58**	**0.27**	**0.30**	**1.04**
acid	0.00	0.00	0.00	0.00	0.00
metal ion	0.00	0.00	0.00	0.00	0.00
dissolved solids	0.00	0.01	0.00	0.00	0.00
suspended solids	0.00	0.00	0.00	0.00	0.00
BOD_5	0.00	0.00	0.00	0.00	0.00
COD	0.00	0.00	0.00	0.00	0.00
phenol	0.00	0.00	0.00	0.00	0.00
oil	0.00	0.00	0.00	0.00	0.00
sulfuric acid	0.00	0.00	0.00	0.00	0.00
iron	0.00	0.00	0.00	0.00	0.00
ammonia+NO_3	0.00	0.00	0.00	0.00	0.00
chromium	0.00	0.00	0.00	0.00	0.00
lead	0.00	0.00	0.00	0.00	0.00
zinc	0.00	0.00	0.00	0.00	0.00
Total waterborne wastes	**0.06**	**0.01**	**0.00**	**0.00**	**0.00**
Total	**21.71**	**12.72**	**1.67**	**1.89**	**1.68**

*Septage(OSS)/sludge(POTW)/compost(compost)/ash(WTE)/food residues(landfill).

Table 10.12. Comparing systems by the percent contributed by the FWD (or MSW collection system) to the percent contributed by the system.

	Total Air Emissions	Total Solid and Construction Waste	Total Water	Total Waterborne Wastes	Total Flows	Total Byproducts*
FWD/OSS	%	%	%	%	%	%
FWD	10	0	7	0	6	0
OSS	90	100	93	100	94	100
FWD/POTW						
FWD	12	37	11	1	10	0
POTW	88	63	89	99	90	100
MSW Collection/Compost						
MSW Collection	4	36	65	73	13	0
Compost	96	64	35	27	87	100
MSW Collection/WTE						
MSW Collection	3	74	57	52	12	0
WTE	97	26	43	48	88	100
MSW Collection/Landfill						
MSW Collection	9	16	17	26	13	0
Landfill	91	84	83	74	87	100

Below, greenhouse gas (carbon dioxide and methane) flows to the environment are compared for the five systems and arranged from lowest to highest. To compensate for higher greenhouse gas impact, methane weights are multiplied by four and added to the weight of carbon dioxide. It is assumed that all methane is burned to carbon dioxide in the FWD/POTW system, 2/3 is captured and burned in the MSW Collection/Landfill system, and none is captured in the FWD/OSS. The lowest three are essentially equivalent.

1. FWD/POTW (97 lb per 100 kg FW)
2. MSW Collection/Landfill (100 lb per 100 kg FW)
3. MSW Collection/Compost (100 lb per 100 kg FW)
4. MSW Collection/WTE (140 lb per 100 kg FW)
5. FWD/OSS (190 lb per 100 kg FW)

Acid gases are arranged from lowest to highest below. Included are oxides of nitrogen and sulfur. The MSW Collection/Landfill value is less than 0.05 lb per 100 kg.

1.	MSW Collection/Landfill	(0.0 lb per 100 kg FW)
2.	FWD/POTW	(0.1 lb per 100 kg FW)
3.	MSW Collection/Compost	(0.2 lb per 100 kg FW)
4.	FWD/OSS	(1.0 lb per 100 kg FW)
5.	MSW Collection/WTE	(2.9 lb per 100 kg FW)

10.5.2. ***Total solid and construction waste.*** Solid and construction wastes per 100 kg of food waste range over 2 orders of magnitude with the MSW Collection/WTE system the lowest and the FWD/OSS the highest and with the exception of the FWD/OSS at 10% is generally a small contribution (0.1 to 2%) to the total flows to the environment. The systems are arranged from lowest to highest below:

1.	MSW Collection/WTE	(1.0 per 100 kg FW)
2.	MSW Collection/Compost	(2.7 lb per 100 kg FW)
3.	FWD/POTW	(4.4 lb per 100 kg FW)
4.	MSW Collection/Landfill	(6.0 lb per 100 kg FW)
5.	FWD/OSS	(480 lb per 100 kg FW)

The four municipal systems are similar and several orders of magnitude lower than the rural system.

10.5.3. ***Total byproducts.*** Total byproducts are the food waste disposal process residues; including septage (FWD/OSS), sludge (FWD/POTW), compost (MSW Collection/Compost), ash (MSW Collection/WTE) and landfill residues (MSW Collection/Landfill). The wastewater residues and compost include water; ash and landfill residues do not. The wastewater residues are two orders of magnitude larger than the MSW Collection/WTE system ash residues and one order of magnitude higher than the MSW Collection/Compost and the MSW Collection/ Landfill residues, as shown below.

1.	MSW Collection/WTE	(3.3 lb per 100 kg)
2.	MSW Collection/Landfill	(25 lb per 100 kg)
3.	MSW Collection/Compost	(39 lb per 100 kg)
4.	FWD/OSS	(310 lb per 100 kg)
5.	FWD/POTW	(340 lb per 100 kg)

The byproducts from the FWD/OSS are about the same as the weight of those from the FWD/POTW residues. The wastewater system generates 1.4 (FWD/OSS) times and 1.6 (FWD/POTW) times the weight of the 100 kg of food waste in byproducts. The MSW systems generate a fraction, which for the MSW Collection/Compost system is 0.18 times, the MSW Collection/WTE system is 0.02 times and the MSW Collection/Landfill is 0.11 times the weight of the 100 kg of food waste in byproducts.

10.5.4. ***Total water.*** The total water flows to the environment range over two orders of magnitude from a low of 60 lb per 100 kg for the MSW Collection/Compost system to 3800 lb per 100 kg for the FWD/OSS. Because of the contribution of FWD carrier water, the two wastewater systems have over an order of magnitude higher water flows than the wastewater systems, as shown below. There is a MSW Collection/Landfill contribution from leachate.

1.	MSW Collection/Compost	(59 lb per 100 kg)
2.	MSW Collection/WTE	(67 lb per 100 kg)
3.	MSW Collection/Landfill	(230 lb per 100 kg)
4.	FWD/POTW	(2300 lb per 100 kg)
5.	FWD/OSS	(3800 lb per 100 kg)

10.5.5. ***Total waterborne wastes.*** Total waterborne wastes are a very small percent of total flows to the environment for each system, ranging from 0.1% for the FWD/POTW system to 0.02% for the MSW Collection/Compost system. Bicarbonate ion from the decomposition of food waste and attributed to dissolved solids for the FWD/POTW system is the highest contribution. For all systems but the MSW Collection/Compost system, the disposal system makes the larger contribution to total waterborne wastes. Systems are shown below arranged from lowest to highest.

1.	MSW Collection/Compost	(0.04 lb per 100 kg FW)
2.	MSW Collection/WTE	(0.10 lb per 100 kg FW)
3.	MSW Collection/Landfill	(0.12 lb per 100 kg FW)
4.	FWD/POTW	(2.8 lb per 100 kg FW)
5.	FWD/OSS	(13 lb per 100 kg FW)

10.5.6. ***Total flows to the environment.*** Table 10.13 shows the percentage contributions of air, solid and water flows to total flows to the environment. Total flows to the environment vary over one order of magnitude with the MSW Collection/Landfill system (370 lb per 100 kg food waste) the lowest and the FWD/OSS (4800 lb per 100 kg food waste) the highest. Waterborne wastes make negligible contributions to each system. With the exception of the FWD/OSS, total solid and construction wastes make small contributions to the total flows to the environment. As might be predicted because of FWD carrier water, water is the predominant flow for both wastewater systems, over 80% of the total flows. Water also contributes over half the total flows for the MSW Collection/Landfill system. In general, due to FWD carrier water, wastewater systems are an order of magnitude higher in total flows than the MSW systems. To one significant digit, all three MSW systems are the same. Systems are arranged below from lowest to highest total flows to the environment.

1.	MSW Collection/Compost	(370 lb per 100 kg FW)
2.	MSW Collection/Landfill	(370 lb per 100 kg FW)
3.	MSW Collection/WTE	(1100 lb per 100 kg FW)
4.	FWD/POTW	(2800 lb per 100 kg FW)

5. FWD/OSS (4800 lb per 100 kg FW)

Table 10.13. Contributions to total flows to the environment.

	FWD/OSS	FWD/POTW	MSW Collection/Compost	MSW Collection/WTE	MSW Collection/Landfill
	%	%	%	%	%
Total air emissions	3	4	73	83	30
Total SW and CW	10	0	1	0	2
Total other	6	12	11	0	7
Total water	80	83	16	16	62
Total waterborne wastes	0	0	0	0	0
Total flows	100	100	100	100	100

Table 10.14 shows total life-cycle flows to the environment minus food waste (FW) and FWD carrier water (CW). For all systems, water is the largest flow to the environment and is about 70% of the total for all system, except for the FWD/POTW for which it is over 90%. Air emissions range from about 1/5 to 1/3 of the total for MSW systems, in large part from the contribution of the MSW Collection system. Solid and construction waste is about 1/5 of the

Table 10.14. Flows to the environment minus food waste and FWD carrier water.

	FWD	FWD/OSS	FWD/POTW	MSW Collection	MSW Collection/ Compost	MSW Collection/ WTE	MSW Collection/ Landfill
	Total lb/ 100 kg FW	Total lb/ 100 kg FW	Total lb/ 100 kg FW	Total lb/ 100 kg FW	Total lb/ 100 kg FW	Total lb/ 100 kg FW	Total lb/ 100 kg FW
	280	2300	280	40	71	85	89
	%	%	%	%	%	%	%
Air	5	4	5	25	27	30	19
SW and CW	1	21	1	2	4	2	8
Other*	0	0	0	0	0	0	0
Water	94	75	94	73	70	68	72
Waterborne wastes	0	0	0	0	0	0	0
Total	100	100	100	100	100	100	100

*Other-septage (OSS); sludge (POTW); compost (Compost); ash (WTE); landfill residue (Landfill).

total flows to the environment from the FWD/OSS and 8% from the MSW Collection/

Landfill, in part from the assumption of 15% construction waste from all materials. For all other systems solid and construction waste is less than 5%. Waterborne wastes are a negligible percent of total flows for all systems, but depending on the species may not be insignificant in impact.

As shown in Figure 10.1. in general, as total flows to the environment increase, so do total system costs, all per 100 kg of food waste. Costs for processing 100 kg of food waste through the FWD/POTW system are low relative to what might be predicted from a linear relationship.

10.6. ***Comparison of flows from food waste.*** Table 10.15 gives a comparison of mass balances for food waste through the five systems. Briefly, it was assumed that all the decomposable solids decomposed in the FWD/OSS and the FWD/POTW systems and that all

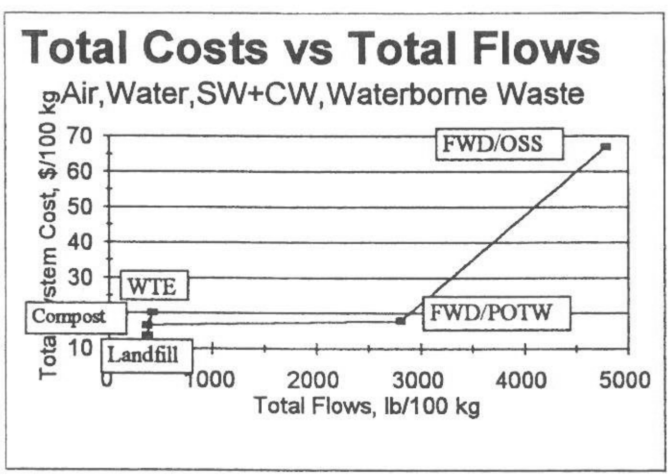


Figure 10.1. Total costs per 100 kg vs total flows per 100 kg.

the decomposable material was combusted in the MSW Collection/WTE system. In the MSW Collection/Compost system 95% of the decomposable material decomposed; in the MSW Collection/Landfill system 84% of the decomposable material decomposed.

The MSW Collection/WTE system required the most oxygen, about four times that for the FWD/POTW system. The MSW Collection/Compost required over twice the oxygen of the FWD/POTW system.

Sludge is the largest byproduct stream requiring management, about 1.1 times the weight of septage from the FWD/OSS. Compost, from the MSW Collection/Compost system weighs about one order of magnitude less and ash from the MSW Collection/WTE system weighs two orders of magnitude less (3 lb/100 kg FW). The 25 lb of MSW Collection/Landfill system dry residues per 100 kg FW require no subsequent management.

None of the methane from the FWD/OSS was available as an energy source; it was assumed that about 2/3 of the methane from the MSW Collection/Landfill system and all of that from the FWD/POTW system was captured and utilized as an energy source. Water was the largest flow to the environment from all systems; about 10 times as much was produced in wastewater systems (primarily FWD carrier water) as from MSW systems.

The MSW Collection/WTE system generated the most carbon dioxide, about 1.5 times that from the FWD/POTW system and almost double that from the MSW Collection/Landfill

Table 10.15. Comparison of flows generated from food waste (energy recovery not included).

	FWD/OSS	FWD/POTW	MSW Collection/Compost	MSW Collection/WTE	MSW Collection/Landfill
Inputs	lb	lb	lb	lb	lb
food waste water	154	154	154	154	154
food waste solids	66	66	66	66	66
decomposed solids	63	63	60	63	53
undecomposed solids	0	0	3	0	10
inert solids	3	3	3	3	3
oxygen	0	25	67	95	0
additional ammonia	1	0	0	0	0
carrier water	2273	2273	0	0	0
Total	2495	2519	288	315	221
Outputs					
solids					
compost*			39		
septage**	309				
sludge***		343			
TSS in effluent (dry)	12	0			
ash****				3	
landfill residues*****					25
carbon dioxide	34	53	85	117	34
methane	15	11		0	15
net water	148	159	163	192	146
H^+	0	0	0	0	0
HCO_3^-	0	2	0	0	0
$N_2 + NO$	0	0	0	3	0
carrier water******	1977	1950	0	0	0
Total	2495	2519	288	315	221

*Assume 50% moisture.

**4% solids and septage water subtracted from carrier water.

*** sludge- 5.8% solids.

****dry solids.

*****landfill residues (dry weight).

******Stoichiometric water required for hydrolysis reactions subtracted from carrier water.

system. The MSW Collection/Landfill system and the FWD/OSS generated about the same amount of methane, but because none was captured from the latter, emissions are almost 3 times higher.

10.7. ***Comparison of the FWD to MSW Collection system.*** The ultimate environmental impact of residential food waste is determined in the kitchen and depends on whether someone chooses to put food waste into the FWD or into the MSW stream. The default position for food waste is the MSW stream; the FWD transfers food waste to wastewater systems. Because both the FWD and the MSW Collection system transfer food waste to disposal systems and impact the ultimate flows to the environment from food waste, parameters for these two systems are compared in Table 10.16. The MSW Collection system requires about 17 times the land, about 18% of the total materials, 88% of the total system energy, is about half the high estimate and is about the same as the low estimate of the cost of the FWD; the total flows to the environment for the MSW Collection system are about 18% those of the FWD. The solid residues from wastewater systems, if land applied, return food waste nutrients to soil systems. Of the three MSW systems, only the MSW Collection/ Compost system returns food waste nutrients to soil.

10.8. ***Summary.*** This project represents a first cut comparison of food waste management systems. Even though an effort was made to select representative systems for each type of system and national data where it was available, only one of each type of system was investigated. It was beyond the scope of the project to determine to what degree parameters (land, materials, energy, costs and total flows to the environment) were specific to a particular system and to what degree they were specific to the type of system.

Table 10.16. Comparing the FWD and the MSW Collection system for total materials, total energy, total costs and total flows to the environment.

	FWD	MSW Collection
Land, ft^2/100 kg	0.0006	0.01
Materials	lb/100kg	lb/100kg
construction	0.1	2.7
process equipment, vehicles	0.1	0.2
electricity*	1.4	5.4
natural gas	0.5	0.0
diesel fuel	0.1	1.4
gasoline	0.7	0.0
FWD materials	1.5	0.0
water	260.4	38.5
food waste	0.0	0.0
other**	0.0	0.0
Total	264.9	48.2
Energy	Btu/100kg	Btu/100kg
embodied- materials	308	18983
embodied-process equipment/vehicles	1477	2027
electricity	6177	23373
natural gas	13126	0
diesel	3717	33856
gasoline	16780	0
FWD material	47197	0
water	557	81
food waste	0	0
other materials	0	0
Total	89329	78320
Costs-$/100kg	17.45	9.90
Comparison of total flows to the environment.		
	lb/100kg	lb/100kg
Total air emissions	14.11	9.87
Total SW and CW	1.62	0.97
Total water	260.42	38.50
Total waterborne wastes	0.03	0.03
Total flows	276.18	49.38

Systems were compared based on unit factors (Btu/lb concrete, lb carbon dioxide/lb aluminum, etc.) that ranged in age and reliability. A large investment in time was required to assemble the unit factors used for this project. Where they were available, they were in widely dispersed information sources, of different quality and different units. Unit factors for energy sources were from Franklin Associates, Ltd., a private consulting firm. Even though Franklin Associates, Ltd. is at the forefront of life-cycle analysis development, and their unit factors are accepted in practice, their assumptions are not always transparent and the resulting factors are by definition unverifiable. Unit factors for water and waterborne wastes were difficult to find and may be dated. With pretreatment standards for industry becoming increasingly more stringent and costly, both quantities of and pollutant loadings in water discharged by industry have decreased. To make doing a life-cycle inventory a cost-effective process, an infrastructure in unit factors is needed that is accurate, current and readily available to the public.

The most critical information in assessing the impact of the FWD on food waste management systems, including how much food waste is introduced into wastewater collection systems through FWDs, the composition of FWD food waste, the trend in solids- total, suspended or volatile- in wastewater since FWDs were introduced, is not known. The total mass of food waste passing through each system, used to prorate system parameters for wastewater systems from household appliances, was based on studies completed in the 1970s of inputs to rural wastewater systems from household appliances. Food purchased today is more processed than food purchased in the 1970s, which means that more of the inedible materials have been removed, reducing potential food waste. Furthermore, dollars spent for food consumed away from home have increased. Both indicate that potential food waste entering households is less today than in the 1970s and it follows that food waste entering household wastewater systems from FWDs is also less. There are more households with FWDs today, presently about 40%, but potentially less food waste produced and less carrier water per household FWD. It was beyond the scope of this project to address commercial applications of FWDs, but the use of FWDs in restaurants and institutions also increases the food waste solids content of wastewater. For a municipal wastewater treatment facility, 100 kg of residential FWD FW is potentially a smaller fraction of the total FWD food waste solids and the total solids entering the system today than 25 years ago.

Potential food waste (the difference between food production and consumption) appears to have increased in all categories- energy, carbohydrate, fat and protein- between 1980 and 1990. Carbohydrate represents the most and protein the least wasted food parameter. No data exists on what is actually occurring in kitchens to determine the fate of a particular food waste and in light of nutrition scientists' studies (self-reported) of food discards, it may not be possible to get unbiased information from households on this subject. Whether a particular food waste is disposed of through a FWD, pets, down the toilet, to a backyard compost pile or to the MSW stream impacts the composition and energy content of food waste.

The purpose of the FWD is to reduce food waste particle size, yet no studies were found which took well characterized food waste through a FWD, evaluating the particle size reduction and the fate of particles in each size range in wastewater collection and subsequent treatment systems. Food wastes, particularly the soluble, readily degradable fraction, are likely to be degraded, hydrolyzed or somewhat transformed during the several hour transit through sewers. The concentration of soluble, readily degradable carbon in wastewater is the dominant rate limiting factor in nutrient removal processes in wastewater treatment plants.

Since 1960, food waste in MSW has declined as a percentage of the total MSW stream (from 13.9% to 6.7%), and in the amount generated per person per day (from 0.37 lb/c/day to 0.29 lb/c/day). Food waste disposers used at the rate of 0.21 lb food waste/c/d (Table 3.8) from 40% of the households in the U.S. can account for most of the decline. Food waste (0.21 lb/c/d) going down FWDs represents about 5% of the total (4.3 lb/c/d) 1990 U.S. MSW stream generated. Because food waste processed through a FWD is not counted as source reduction or recycling, recovery rates for food waste in the U.S. MSW stream are presently reported as essentially zero.

10.8.1. ***System summaries.*** Table 10.17 gives a simple ranking of the five systems for 12 parameters of importance, including land, system materials and energy (minus food waste and carrier water), cost, water, wastewater, waterborne wastes, air emissions, acid gases, greenhouse gases, solid and construction waste and system food waste byproducts. Methane weights are multiplied by four to account for its higher potency as a greenhouse gas. The rankings for each system are averaged and given a final ranking.

10.8.1.1. ***FWD/OSS.*** The FWD/OSS overall ranks highest for land, materials, energy, cost, water, wastewater and waterborne wastes and solid and construction wastes per 100 kg of food waste. The difference in two on-site systems, designed with and without the FWD, is all attributable to the use of the FWD. The 100 kg of food waste represents a larger fraction of the total food waste and associated carrier water passing through this system over its design life than for any other system; and as a result more land, materials, etc. are attributable to the 100 kg of food waste. FWD carrier water is an important contribution overall to materials and to flows to the environment, contributing about 3/4 of the total flows to the environment.

10.8.1.2. ***FWD/POTW.*** The FWD/POTW system ranks in the middle of the five systems overall, for total system materials and for total system cost. The cost of the FWD makes up most of the total system cost; this cost is born by the homeowner. It has the lowest land and total system energy requirements of the five food waste management systems. It has second highest water, wastewater and waterborne wastes of the five systems, primarily due to FWD carrier water. About 85% of the total flows to the environment is water. The 100 kg of food waste and associated carrier water is a small fraction of the total flows and solids passing through the FWD/POTW over its 30 year design life.

Using MMSD as a model and assuming the FWD wastewater parameters (Table 3.8) measured in the 1970s overestimate FWD contributions to wastewater treatment facilities today, calculated contributions, from the 40% of households assumed to have FWDs, are small (about 0.1%) and are under 10% for each of the loadings (Table 6.60). Table 6.76, which gives secondary effluent for the present situation and calculated hypothetical systems if no or all households had a FWD, suggests that ammonia nitrogen, nitrate nitrogen, total

Table 10.17. System ranked by issue (1-low; 5-high).						
		FWD/ OSS	FWD/ POTW	MSW Collection/Compost	MSW Collection/WTE	MSW Collection/Landfill
land	ft^2/100 kg	20.432	0.003	0.814	0.020	0.202
rank		5	1	4	2	3
materials(minus FW and CW)	lb/100kg	4881	287	90	116	338
rank		5	3	1	2	4
energy (minus exportable FW energy)	Btu/100kg	925824	45744	143299	286433	80112
rank		5	1	3	4	2
water	lb/100kg	3994	2547	64	75	83
rank		5	4	1	2	3
cost	$/100kg	67.20	17.94	16.60	20.30	13.65
rank		5	3	2	4	1
air emissions	lb/100kg	145	121	267	345	110
rank		3	2	4	5	1
acid gases (NOx and SO2)	lb/100kg	1.0	0.1	0.2	2.9	0.0
rank		4	2	3	5	1
greenhouse gases (4* $CH_4 + CO_2$)	lb/100kg	188	97	104	142	101
rank		5	1	3	4	2
wastewater	lb/100kg	3846	2334	59	67	229
rank		5	4	1	2	3
waterborne wastes	lb/100kg	12.6	2.8	0.0	0.06	0.12
rank		5	4	1	2	3
SW+CW	lb/100 kg	476	4	3	5	6
rank		5	2	1	3	4
FW byproduct	lb/100 kg	309	343	39	3	25
rank		4	5	3	1	2
Average Rank		4.7	2.7	2.3	3.0	2.4
rank		5	3	1	4	2

phosphorus and ortho phosphorus loadings in effluent are lower in the hypothetical system in which all households use FWDs than for the present situation or for the system assuming no households have a FWD. In the carbon limited wastewater treatment system, food waste carbon uptakes nitrogen and phosphorus, is assimilated into biomass and removed as sludge. Table 6.77 indicates that sludge total nitrogen and total phosphorus in thickened sludge is higher for the hypothetical situation in which all households have a FWD than for the present situation or for the situation in which no households have a FWD.

Assuming that 1.75 kWh of electricity can be generated per pound of methane recovered, that all digester methane is recovered and that 90% is available for export, about 19 kWh of exportable electricity can theoretically be produced from 100 kg of food waste processed through the FWD/POTW.

10.8.1.3. ***MSW Collection/Compost.*** The MSW Collection/Compost system overall ranks the lowest. This system has the lowest total system materials and water requirements; it generates the lowest amount of wastewater and waterborne wastes. It has the highest land requirements of the three MSW systems. The total energy requirements are higher than the FWD/POTW and the MSW Collection/Landfill systems. The total system costs are similar to the other municipal systems. The total flows to the environment are the lowest, but very close to those for the MSW Collection/Landfill system; total flows are over 70% air emissions. Although food waste nutrients are returned to soil systems in the MSW Collection/Compost system, having food waste in the material being composted makes the regulations which apply to a facility more stringent.

10.8.1.4. ***MSW Collection/WTE.*** The MSW Collection/WTE system ranks second highest overall. It produces the most air emissions and acid gases, but the lowest amounts of food waste byproducts requiring management (ash). It has the lowest land requirements of the three MSW systems. Costs are highest of the three MSW systems and similar to the FWD/POTW system. Flows to the environment are about 80% air emissions. Because of food waste water of 70%, net energy recovered is assumed to be zero.

10.8.1.5. ***MSW Collection/Landfill.*** The MSW Collection/Landfill system, the non-delete option for managing MSW, ranks lowest of the five systems overall. It has one of the lowest energy requirements, the lowest cost of the five food waste management systems and produces low flows to the environment. About 60% of the total flows to the environment are water; 30% are air emissions.

Assuming the 1.75 kWh of electricity can be generated per pound of methane recovered and that 66% of the landfill methane can be recovered and 90% of the electricity is exportable, methane from 100 kg of landfilled food waste can theoretically produce 16 kWh of exportable electricity, about the same as that from the FWD/POTW system. However, government mandated programs which result in the removal of paper and yard waste from landfills, will lower the potential methane generated and the potential exportable electricity from landfill systems; these programs appear to be at cross purposes with programs promoting the development of landfill gas-to-energy.

10.9. ***Final Conclusions.*** Following are final conclusions from the life-cycle comparison of five food waste management systems:

1. As shown in Figure 10.1, in general, as total flows to the environment increase, so do

total system costs, all per 100 kg food waste. Rank by total system cost is a reasonable predictor of overall rank for the 12 selected parameters- total land, total system materials (minus food waste and carrier water), total system energy (minus food and carrier water energy), water, total system cost, air emissions, acid gases (NO_x and SO_x), greenhouse gases, wastewater, waterborne wastes, solid waste, and food waste byproducts.

2. Total flows to the environment from wastewater systems are about 10 times those from MSW systems, primarily because of FWD carrier water.

3. The FWD/OSS, the only rural system, ranked either first or second for most parameters. Because a larger fraction of the total FWD/OSS was attributable to the 100 kg of food waste; land, materials, energy and flows to the environment attributable to the 100 kg were higher for the rural system than for the four municipal systems.

4. The FWD/OSS has the highest flows to the environment of the five systems; most is water and waterborne wastes discharged with minimal performance control to the subsurface. About half of the effluent BOD_5 is discharged directly to the absorption bed which may contribute to biomass assimilation and clogging in the absorption bed. Although food waste carbon removes some ammonia-nitrogen from wastewater as it is assimilated into biomass, a system stoichiometric excess of ammonia-nitrogen remains to be discharged to the subsurface, potentially bypassing plant root zones to pollute groundwater.

5. The MSW Collection/WTE ranks second highest overall and for total system cost. Burning food waste yields little exportable energy in these systems, so diverting food waste to FWD/POTW systems should be defined as recycling and encouraged, just as diverting other recyclables with no heating value, such as metal and glass, is encouraged.

6. The FWD/POTW system ranks in the middle of the five systems overall and for total system materials and for total system cost. Most of the cost is for the FWD and is borne by the homeowner; the cost to process food waste through a POTW is less than $0.50 per 100 kg of food waste. The FWD/POTW has the lowest land and total system energy requirements but the highest food waste byproduct, sludge, requiring management.

7. Wastewater collection and treatment systems and MSW collection systems and landfills are required systems for both urban and rural residences for reasons of basic public health and sanitation. When a FWD is incorporated in a household wastewater collection system, there is redundancy in food waste management and most food waste can be managed through either system. Food waste going into a FWD/POTW system,

from which either effluent and/or sludge is/are returned to agricultural soils in compliance with Federal and state regulations and in which methane is collected and combusted to produce electricity, is being effectively recycled.

8. Adding food waste carbon to a carbon limited wastewater system contributes to a net removal of nutrients (nitrogen and phosphorus) from effluent, as nutrients are assimilated with carbon into biomass and removed from the system as sludge.

9. Land requirements for each system give a first approximation of a system's appropriation of and reduction in net primary productivity (mass of biomass produced per area or per Joule of incident energy). Even though impacts to net primary productivity are beyond the scope of this project, the FWD/POTW system with the lowest land requirements has the lowest impact on net primary productivity from 100 kg of food waste. When coupled with potential increases in net primary productivity from effluent and sludge nutrients, this system is potentially the most sustainable of the five systems.

10. The MSW Collection/Compost system ranks lowest overall; it has the lowest total system materials and water requirements and generates the lowest amount of wastewater and waterborne wastes. Food nutrients are returned to soil from compost systems.

11. Composting is an optional food waste management system that increases the redundancy in food waste management; however, wastewater collection/treatment and landfill systems are still required.

12. The MSW Collection/Landfill system is the default system for food waste management; it ranks next to lowest overall and lowest for cost. It also ranks low for water, wastewater, total air emissions and food waste byproducts.

13. As indicated in Table 10.7, for MSW systems the MSW Collection system contributes from half to 3/4 of the total system cost. Systematic diversion of wet, putrescible food waste from MSW to FWDs has the potential to produce drier, more storable MSW and reduce the need for weekly collection and the cost of MSW collection.

14. The MSW Collection system requires about 17 times the land, about 18% of the total materials, 88% of the total system energy, is about half the high estimate and is about the same as the low estimate of the cost of the FWD; the total flows to the environment for the MSW Collection system are about 18% those of the FWD, because there is no carrier water.

15. If household plumbing were redesigned to use non-potable water for flushing wastes (both human through toilets and food through FWDs), diverting food wastes to

municipal wastewater systems becomes a more sustainable choice.

10.10. *Final recommendations.*

1. Diverting food waste through FWDs to a POTW should be encouraged when solids' handling systems are adequate, methane is combusted to generate energy, and effluent and/or sludge are returned to soil; food waste is effectively being recycled and should be so designated in federal and state regulations.

2. Benefits to MSW management systems from the systematic use of FWDs should be quantified; because by transferring putrescible FW from solid to wastewater management systems, there is a reduction in regulatory requirements for MSW collection systems (weekly collection), landfill systems (daily cover requirement), compost systems (more stringent management requirements) and reduced solids' handling for WTE systems.

3. Separate regulations that give different design requirements for POTWs depending on FWD usage should be challenged, especially if no other household appliance or device is so listed.

4. To make the life-cycle inventory a cost-effective process, there needs to be an accurate, up-to-date data base of unit factors for water and waterborne wastes, air emissions and solid waste for materials and fuels that is readily available to the public.