Waste-to-Energy Process Model

1. Introduction

The objective of the combustion process model is to calculate the cost and life-cycle inventory (LCI) parameters for a MSW waste-to-energy (WTE) facility. Costs and LCI parameters are calculated on the basis of user input and default design information that is described in this document. Based on the cost and LCI design information, coefficients are calculated in the process model to represent the cost and environmental burdens associated with a WTE facility. The coefficients take into account both the quantity and composition of the waste input to a WTE facility and are used in the solid waste management model to calculate the total system cost and LCI parameters for solid waste management alternatives that involve WTE.

The mathematical equations used for model development are presented in the main body of the report. Tables containing defaults for the model parameters are presented at the end of this report. The defaults are derived in Appendices A-C.

Section 2 describes how a user could model an existing WTE facility. Section 3 presents the design basis for a new WTE facility. The governing equations for the economic parameters are described in Section 4. The LCI parameters that occur at the facility (e.g., combustion emissions) are described in Section 5. The equations for calculating LCI parameter offsets associated with the WTE facility's displacement of electricity generation at a regional power plant is presented in Section 6. Section 7 describes the LCI equations for processes that support the operation of the facility but that are located offsite. Section 8 includes the equations for calculating net LCI parameters associated with use of a WTE facility. Section 9 shows how other parameters of interest are calculated, for example, the power (MW) rating of the plant. The defaults that are provided for the model user are discussed in Section 10. Inputs from other process models are listed in Section 11. Finally, Section 12 lists those parameters that are reported to the decison support system.

2. Existing WTE facilities

The WTE facility that is included as an option in the MSW system may be an existing or new WTE facility. As described in Section 3, new facilities are assumed to have advanced air pollution control equipment that may not be present in existing facilities. If the user chooses to model an existing facility, it is assumed that much of the cost and LCI information are known. The user is advised to override the default emission factors that have been provided in this document because their development assumes a design for a new WTE facility. Wherever possible, defaults for existing facilities have been provided. For instance, air pollutant emission parameters have been provided based on existing facilities since performance of existing facilities may be somewhat different than that of new facilities. As described above, default data are presented in tables at the end of the report.

While nearly all new WTE facilities recover energy, this is not true of all existing facilities. To model an existing facility that does not recover energy, the user must set a very high heat rate, e.g. 10^9 Btu/kWh. The setting of a very high heat rate will result in zero kWhs of electricity generated from the combustion of the waste. In this case, the combustion facility would not offset any emissions associated with electricity generation at the regional power plant.

3. Conceptual design of a new MSW Waste-to-Energy Facility

The discussion below describes four basic designs of a WTE facility upon which several of the cost and LCI functions described in Sections 4 and 5 are based. All four designs assume that the facility will be operated to maintain compliance with all applicable regulations.

Forecasts of the WTE industry were considered in developing the four WTE facility designs. A 1989 EPA cost study forecasted 64% of the total new capacity to be of mass burn design, 27% RDF, 3% modular, and 7% fluidized-bed or gasification facilities. Of the mass burn plants, the majority (85%) were forecasted to have waterwall furnaces [1]. Though comprising only 3% of expected capacity, the percentage of the number of new plants that are of modular design is expected to be significantly larger than 3% because they are generally of smaller capacity. Virtually all new solid waste combustion systems currently under construction in the United States include energy recovery systems to help offset operating costs and to reduce the capital costs of air pollution control equipment [2]. Based on these forecasts, WTE facilities of smaller capacities are assumed to be of modular design. Larger facilities are assumed to be of mass burn/waterwall design. Energy recovery is included for all designs.

Many of our cost assumptions and cost default data are based on four model plants that were described in a 1989 study to estimate the cost implications for proposed emission standards [1]. The four plants, all of which recover energy, include a 100 ton per day (TPD) modular/starved air plant, a 240 TPD modular/excess air plant, and two mass burn/waterwall facilities handling 800 and 2,250 TPD, respectively. A brief review of the processes occurring in each of these plants follows.

Referring first to the larger mass burn combustors (800, 2250 TPD), unprocessed waste, after removal of large, bulky items, is delivered by an electric overhead crane from a tipping floor to a feed hopper that conveys the waste into a combustion chamber. Hydraulic rams push the refuse from the fuel chute onto the first of several grates. The first section, or drying grate, is intended to remove the moisture in the waste prior to ignition. The second, or burning, grate is where the majority of active burning takes place. The third grate is where remaining combustibles in the waste are burned. Bottom ash is discharged from the finishing grate into a water-filled ash quench pit or ram discharger. From there, the moist ash is discharged to a conveyor system and transported to an ash load-out area prior to disposal. Ferrous is recovered from the ash via a magnet. Water-filled tubes located in the walls of the combustor recover the waste heat that is used to generate electricity.

Combustion air, drawn in from the tipping floor area, is added from beneath the grate by way of underfire air plenums. Typically, mass burn waterwall combustors are operated with 80 to 100 percent excess air. The flue gas exits the combustor and passes through additional heat recovery sections through several air pollution control devices. Because the combustion air is drawn from the tipping floor area, the rolling stock emissions that may consist of a few hours use of a front-end loader per day are treated by the combustion process and air pollution control equipment (APCE).

The APCE assumed to be present in a modern WTE facility includes a spray dryer for acid gas control, injection of activated carbon for mercury control, ammonia or urea injection for NOx control (by conventional selective non-catalytic reduction) and a fabric filter for PM control. After the air pollution control equipment, the flue gas is released to the atmosphere through the plant stack. The fly ash is collected, mixed with the bottom ash, and sent to a landfill. In addition, air pollution monitoring equipment is installed in the facility.

The basic design of a modular starved air combustor includes two separate combustion chambers, referred to as the "primary" and "secondary" chambers. Waste is batch-fed to the primary chamber by a hydraulically activated ram. Waste moves through the primary chamber slowly and retention times are long, lasting up to 12 hours. Auxiliary fuels may be added during startup or if there are problems. Air is supplied to the primary chamber at sub-stoichiometric levels, resulting in a flue gas rich in unburned hydrocarbons. Air is mixed with the hot flue gas before entering the second combustion chamber to complete the burning. Energy is recovered in a waste heat boiler. The flue gas then passes through air pollution control equipment that is assumed to include the same processes described above.

Modular excess air combustors are similar to modular starved air combustors with the exception that the air is supplied in excess of stoichiometric requirements and a portion of the flue gas is re-circulated to maintain desired temperatures in the primary and secondary chambers.

The methodology used to estimate combustion costs is described in the following section. The default values for the required input data are developed based on a regression of the four model plants described above (see Appendix A).

Energy recovered by the WTE facility is credited as an energy gain in the LCI inventory because it is assumed to displace electricity production that depends upon conventional fuels (e.g., coal, natural gas). The exact mix of the energy that is offset is specified by the user in the COMMON process model. Documentation for the Common process model is in preparation. Net emissions from the WTE facility are the emissions from the combustion facility minus the emissions that would have otherwise been produced by the type of utility generation being displaced.

A word about the convention used in the subsequent cost and LCI equations: Unless stated otherwise, "tons" refers to "wet tons waste processed by the combustor". Italicized words represent variable names and are consistent with the variable names in the Excel spreadsheets where the process model described here has been implemented.

4. Cost functions

WTE facility costs are divided into five components: capital cost, operation and maintenance cost, revenue from electricity generation and revenue from ferrous recovery. The cost functions are presented below. Default cost factors are derived in Appendix A.

4.1 Capital costs

The plant's capital cost includes the cost of combustors, ash handling system, turbine, and air pollution control and monitoring devices. The capital cost of a WTE facility is calculated from a unit capital cost with units of dollars per ton/yr capacity. It is adjusted with a capacity factor to account for the fact that the plant cannot operate at full capacity at all times. In addition, it can be expressed in annual terms using a capital recovery factor that is dependent upon a book lifetime and discount rate. The following equation determines the capital cost:

Equation 1

$$WTE\_capital\_cost\_per\_ton_i = \frac{Unit\_WTE\_capital\_cost \cdot CRF}{WTE\_capacity\_factor}$$

where

WTE_capital_cost_per ton$_i$ is the capital cost per ton of waste component processed by the combustor. It carries units of $/ ton waste component processed. As the equation indicates, the cost per ton of waste component will be the same for all waste components.

Unit_WTE_capital_cost is the capital cost per unit of a combustor's design capacity. This is the assumed basis for the capital costing of the plant. The unit of the coefficient is $/(design capacity tons processed/yr).

CRF is the capital recovery factor that enables the conversion of the capital costs into annual terms. It is a function of the facility life, *WTE_lifetime*) and an appropriate *Discount_rate*. Microsoft Excel's PMT() function is used (argument PV=1, FV=0). For a *Discount_rate* ≠ 0, it is calculated as follows:

$$CRF = \frac{Discount\_rate \cdot (1 + Discount\_rate)^{WTE\_lifetime}}{1 - (1 + Discount\_rate)^{WTE\_lifetime}}$$

WTE_capacity_factor reflects the fact that the plant will not always run at is full design capacity. The design capacity will be somewhat higher to compensate for shutdown time due to maintenance and repair. It is unitless (actual (wet ton/yr)/capacity (wet ton/yr)). This value must be between 0 and 1.

The total capital cost for the WTE facility is found by summing over all waste components.

Equation 2

$$WTE\_capital\_cost = \sum_{i}^{\#\_waste\_components} WTE\_capital\_cost\_per\_ton_i \cdot WTE\_feed\_rate_i$$

where

WTE_capital_cost is the total annual capital cost of the WTE facility ($/yr).

$WTE\_capital\_cost\_per\_ton_i$ was defined by Equation 1. ($/ton waste component)

$WTE\_feed\_rate_i$ is the rate at which waste component i is processed by the combustor (tons waste component/yr)

4.2 Operation & maintenance cost

The operation and maintenance (O&M) cost of the WTE facility includes the labor, overhead, taxes, administration, insurance, indirect costs, auxiliary fuel cost, electricity cost and maintenance cost. It does not include the cost for disposing of the combustion residue and spray dryer residue, nor does it include the revenue from electricity generation. The O&M cost coefficient depends upon the unit O&M cost, the rate at which waste enters the plant, and the capacity factor:

Equation 3

$$WTE\_O\&M\_cost\_per\_ton_i = \frac{Unit\_WTE\_O\&M\_cost}{WTE\_capacity\_factor}$$

where

$WTE\_O\&M\_cost\_per\_ton_i$ is the annual O&M cost per ton waste component i. It does not include the revenues generated from sale of the electricity produced nor the ash disposal cost. It carries units of ($/yr)/(ton waste component/yr), or simply $/ton waste component.

Unit_WTE_O&M_cost is the O&M cost per unit of a combustor's rated capacity, where capacity is expressed in tons waste per yr. The coefficient's unit is ($/yr)/(ton/yr design capacity).

WTE_capacity_factor is defined in Equation 1.

The total O&M cost for the plant is:

Equation 4

$$WTE\_O\&M\_cost = \sum_{i}^{\#\_waste\_components} WTE\_O\&M\_cost\_per\_ton_i \cdot WTE\_feed\_rate_i$$

where

WTE_O&M_cost is the total annual O&M cost of the WTE facility ($/yr).

$WTE\_O\&M\_cost\_per\_ton_i$ was defined by Equation 3. ($/ton waste component)

$WTE\_feed\_rate_i$ is defined in Equation 2 (wet tons waste component/yr).

4.3 Revenue from recovery of ferrous

Ferrous can be recovered from the bottom ash and can provide some revenue to help offset the costs of the WTE facility. Based on calculations shown in Appendix D, the cost of a magnet to separate the iron from the bottom ash is sufficiently small in comparison to the imprecise estimate of the ferrous scrap price that it can be ignored.

The amount of ferrous waste components recovered from the WTE facility is:

Equation 5

$$WTE\_tons\_Fe\_recovered\_from\_ash\_per\_ton_i = WTE\_ton\_recyclable\_Fe\_per\_ton_i \cdot WTE\_Fe\_ash\_recovery\_rate_i$$

where

$WTE\_tons\_Fe\_recovered\_from\_ash\_per\_ton_i$ is the amount of ferrous recovered from the ash per ton waste component i processed by the WTE facility (tons ferrous recovered/ton waste component). This value will be nonzero only for Ferrous cans and Other ferrous metal.

$WTE\_ton\_recyclable\_Fe\_per\ ton_i$ is the amount of recyclable ferrous per ton waste component i processed by the WTE facility (tons recyclable ferrous/ton waste component). This value is equal to 1 for Ferrous cans and Other ferrous metal and zero for all other waste components.

$WTE\_Fe\_ash\_recovery\_rate_i$ is the fraction (by weight) of recyclable Fe that is recovered from the bottom ash of the WTE facility (ton ferrous recovered / ton ferrous in bottom ash). Note that this applies only to "Ferrous cans" and "Other ferrous metal". For these two categories, this parameter is the same and is equal to another parameter, defined here, *WTE_Fe_ash_recovery_rate* (no subscript).

The revenue per ton waste component from the sale of a recyclable ferrous waste component is given by Equation 6.

Equation 6

$$WTE\_Fe\_revenue\_per\_ton_i = WTE\_Fe\_from\_ash\_per\_ton_i \cdot Scrap\_price_i$$

where

> $WTE\_Fe\_revenue\_per\_ton_i$ is the revenue per ton of waste component i processed that is generated from sale of the recyclable Fe scrap. ($/ton waste component).
>
> $WTE\_tons\_Fe\_recovered\_from\_ash\_per\_ton_i$ is defined by Equation 5 (ton Fe recovered/ton waste component i). This will be nonzero only for the components, Ferrous cans and Other ferrous metal..
>
> $Scrap\_price_i$ is the sale price of recyclable waste component i. For Ferrous cans and Other ferrous metal, this parameter is equal to another parameter defined here, $Scrap\_price_{Fe}$ ($/ton ferrous recovered).

Total revenue from the ferrous recovery is given by:

Equation 7

$$WTE\_ferrous\_revenue = \sum_i WTE\_feed\_rate \cdot WTE\_Fe\_revenue\_per\_ton_i$$

where

> $WTE\_ferrous\_revenue$ is the total revenue associated with recovery of the recyclable ferrous material from the bottom ash ($/yr).
>
> $WTE\_feed\_rate_i$ is defined in Equation 2 (ton waste component/yr).
>
> $WTE\_Fe\_revenue\_per\_ton_i$ is given by Equation 6. The only waste components for which this value may be nonzero are Ferrous cans and Other Ferrous metal ($/ton waste component).

4.4 Revenue from electricity generation

Electricity that is generated by recovery of heat from combustion of waste is sold to an end user. The recovery of the heat is not perfectly efficient. This inefficiency is represented by the heat rate of the plant which is an input parameter. The energy produced per ton of waste component can be determined from the following equation:

Equation 8

$$WTE\_kWh\_per\_ton_i = \frac{Heating\_value_i \cdot \left(\frac{2000lb}{ton}\right)}{Heat\_rate}$$

WTE_kWh_per_ton$_i$ is the energy generated as electricity from the combustion of the waste. (kWh electricity/ton of waste component).

Heating_value$_i$ is the heating value of waste component i (Btu/wet lb waste component).

Heat_rate is a measure of the efficiency of the plant, the number of Btu's fuel needed to generate one kWh. (Btu/kWh).

Equation 9

$$Electricity\_revenue\_per\_ton_i = WTE\_kWh\_per\_ton_i \cdot Electricity\_price$$

where

Electricity_revenue_per_ton$_i$ is the revenue generated from the sale of the electricity produced from the combustion of one ton of waste component i ($/ton waste component)

WTE_kWh_per_ton$_i$ was defined in Equation 8 (*kWh electricity/ton of waste component*).

Electricity_price is the sale price of the electricity expressed in *$/kWh*. This is a user input parameter that will vary by region. (*$/kWh)*

Equation 10

$$WTE\_electricity\_revenue = \sum_{i}^{\#\_waste\_components} Electricity\_revenue\_per\_ton_i \cdot WTE\_feed\_rate_i$$

where

WTE_electricity_revenue is the annualized revenue generated by the WTE facility ($/yr).

Electricity_revenue_per_ton$_i$ is defined in Equation 9 ($/ton waste component)

WTE_feed_rate$_i$ is defined in Equation 2 (wet tons waste component/yr).

4.5 Total annualized cost

The total annualized cost of the WTE facility, not including the revenue from electricity generation, is the sum of the annualized capital, and O&M minus the revenue generated from sale of the ferrous recovered from the bottom ash:

Equation 11

$$WTE\_cost\_excluding\_kWh\_revenue = WTE\_capital\_cost + WTE\_O\&M\_cost - WTE\_ferrous\_revenue$$

where

WTE_cost_excluding_kWh_revenue is the annual cost of the WTE facility that excludes the revenue from sale of the generated electricity ($/yr).

WTE_capital_cost is defined by Equation 2 ($/yr).

WTE_O&M_cost is defined by Equation 4 ($/yr).

WTE_ferrous_revenue is defined by Equation 7. ($/yr)

Including the revenue from electricity generation,

Equation 12

$$WTE\_cost = WTE\_cost\_excluding\_kWh\_revenue - WTE\_electricity\_revenue$$

where

WTE_cost is the annual cost of the WTE facility ($/yr).

WTE_cost_excluding_kWh_revenue is defined by Equation 11 ($/yr).

4.6 Total cost coefficient

The total cost coefficient for a particular waste component is:

Equation 13

$$Cost\_coefficient_i = WTE\_capital\_cost\_per\_ton_i + WTE\_O\_M\_cost\_per\_ton_i - WTE\_electricity\_revenue\_per\_ton_i - WTE\_Fe\_revenue\_per\_ton_i$$

where

$WTE\_capital\_cost\_per\ ton_i$ is defined in Equation 1. It carries units of $/ ton waste component processed.

WTE_O&M_cost_per_ton$_i$ is defined in Equation 3. It carries units of ($/yr)/(ton waste component/yr), or simply $/ton waste component.

4.7 Total cost per ton

The total cost of the WTE facility per ton MSW not including the revenue from electricity generation is:

Equation 14

$$WTE\_cost\_per\_ton\_excluding\_kWh\_revenue = \frac{WTE\_cost\_excluding\_kWh\_revenue}{WTE\_feed\_rate}$$

where

WTE_cost_per_ton_excluding_kWh_revenue is the cost per ton of the WTE facility that excludes the revenue from sale of the generated electricity ($/yr).

WTE_feed_rate is defined Equation 29.

Including electricity revenue:

Equation 15

$$WTE\_cost\_per\_ton = \frac{WTE\_cost}{WTE\_feed\_rate}$$

where

WTE_cost_per_ton is the cost per aggregate ton of waste at the WTE facility. ($/yr).

WTE_feed_rate is defined Equation 29.

5. LCI contributions at the WTE facility

Equations to calculate the LCI contributions that occur at the WTE facility are presented in this section. Default data are presented in Table 2 through Table 6 and are derived in Appendices B and C.

5.1 Energy consumption

Energy consumption is an LCI parameter. The WTE plant itself consumes no energy that is based upon conventional fuels, with the exception of a very small amount of fossil fuels (less than 1% heat release) used to fire up the combustors. In-house energy needs are met with the energy derived from the combustion of the waste and these needs are reflected in the heat rate. The electricity produced from the combustion of the waste is assumed to displace conventional electricity production . The offsets in energy consumption are discussed in Section 6.

5.2 Air emissions

Defaults for air emission parameters are presented in Table 2 through Table 6. Table 2 presents emission factors for carbon dioxide that are divided into two groups--biomass-derived and fossil fuel-derived. The development of the CO_2 factors is described in Appendix B.

As described in Appendix B, each of the nonmetals including SO_2, HCl, NO_x, CO, PM and dioxins/furans is assumed to be controlled to concentration specific to each pollutant because WTE facilities are operated to comply with target emission levels. Three sets of default concentrations are provided that are based, respectively, on the regulatory standards, average performance of new combustors, and average performance of older combustion facilities. All are shown in Table 4. The calculation of the emission factors for these pollutants is dependent on the emitted concentration and the flue gas production of the waste component. It is given by the following equation where the concentration is specified in pounds per cubic meter flue gas. Equation 16 a, b and c show the conversion of the pollutant concentration from the more conventional units of ppmv, mg/dscm and ng/dscm to lb/dscm:

Equation 16

$$WTE\_air_{i,p} = Flue\_gas\_per\_ton_i \cdot Concentration_p$$

$$\text{for p} = \text{SO}_2\text{, HCl, NOx, CO, PM, Dioxins/Furans}$$

where

$WTE\_air_{i,p}$ is the emissions of nonmetal air pollutant p per ton of waste component i processed where p is SO_2, HCl, NOx, or CO. For CO_2, which is split into biomass-derived and fossil fuel-derived, the emission factor is known directly. (lbs pollutant emitted/ton waste component).

$Flue\_gas\_per\_ton_i$ is the total amount of flue gas generated as measured after the air pollution control equipment. It is measured as dry standard cubic meter corrected to 7% oxygen (dscm), generated from combustion of one ton of waste component i. (dscm/ton waste component)

$Concentration_p$ is the concentration of pollutant p in the flue gas after the air polution control equipment measured as lbs pollutant per dry standard cubic meter corrected to 7% oxygen (dscm). (lbs pollutant/dscm). This value is calculated differently for different pollutants.

For SO2, HCl, NOx, and CO:

$$Concentration_p = ppmConcentration_p \cdot \frac{1}{10^6} \cdot MW_p \cdot \frac{1}{22.4} \cdot \frac{1}{10^3} \cdot 10^3 \cdot 2.2 \qquad \text{(Eq. 19a)}$$

for p = SO_2, HCl, NO_x, and CO

where

ppmvConcentration$_p$ is the concentration of p measured as ppmv, parts per million by volume. This value is input in these units because the regulatory standard for these pollutants is expressed in the same units (ppmv).

MW$_p$ is the molecular weight of pollutant p. This value is: SO_2, 64; HCl, 36.45; NOx (as NO_2), 46; CO, 28. (grams/mole).

For particulate matter:

$$Concentration_p = mgConcentration_p \cdot \frac{1}{10^6} \cdot 2.2 \qquad \text{(Eq. 19b)}$$

for p = PM

where

mgConcentration$_p$ is the concentration of p measured as mg/dscm corrected to 7% oxygen. This value is input in these units because the regulatory standard for this pollutant is expressed in the same units (mg/dscm)

For dioxins/furans:

$$Concentration_p = ngConcentration_p \cdot \frac{1}{10^{12}} \cdot 2.2 \qquad \text{(Eq. 19c)}$$

for p = Dioxins / furans

where

ngConcentration$_p$ is the concentration of p measured as ng/dscm corrected to 7% oxygen. This value is input in these units because the regulatory standard for this pollutant is expressed in the same units (ng/dscm)

The emission factors for metals are calculated somewhat differently. They are determined from an uncontrolled emission factor and removal efficiencies. The development of these parameters is described in Appendix C.

Equation 17

$$WTE\_air_{i,m} = Uncontrolled\_emission\_factor_{i,m} \cdot (1 - Removal\_efficiency_m)$$

for m = Cd, Pb, Hg, As, B, Cr, Cu, Ni, Sb, Se, and Zn

where

$WTE\_air_{i,m}$ is the emissions of metal air pollutant m per ton of waste component i processed where m is Cd, Pb, Hg, As, B, Cr, Cu, Ni, Sb, Se and Zn. (lbs pollutant emitted/ton waste component).

$Uncontrolled\_emission\_factor_{i,m}$ is the emissions of metal m per ton of waste component i **before** stack gas treatment (lbs metal emitted/ton waste component).

$Removal\_efficiency_m$ is the removal efficiency of metal m by the air pollution controls. (expressed as a fraction, unitless).

Total annual air emissions at the WTE facility are given below:

Equation 18

$$WTE\_air_p = \sum_{i}^{\#\_waste\_components} WTE\_air_{i,p} \cdot WTE\_feed\_rate_i$$

for p = metal and nonmetal air pollutants

where

WTE_air_p is the total annual air emissions of pollutant p from the WTE facility. The index p includes the nonmetals and metals indicated in Equation 16 and Equation 17, respectively, and includes emissions for methane, ammonia and hydrocarbons. (lbs/yr)

$WTE\_air_{i,p}$ was defined in Equation 16 and Equation 17 for nonmetals (not including methane, ammonia and hydrocarbons) and metals, respectively. The values for methane, ammonia and hydrocarbons are direct inputs. (lb/ton waste component)

$WTE\_feed\_rate_i$ is defined in Equation 2 (wet tons waste component/yr).

5.3 Solid waste

WTE residue refers to combustion residue and flue gas cleaning residue. Combustion residue includes fly and bottom ash attributed to combustion of the waste. The bottom ash includes combustible materials that do not combust due to inefficiencies of the combustors. The cleaning residue includes the solid salts formed in the neutralization of the acid gases. The cleaning residue is removed along with the fly ash by the fabric filter bags.

Equation 19

$$\boldsymbol{Ton\_APCE\_residue\_per\_ton_i = Ton\_lime\_per\_ton_i + Ton\_ammonia\_per\_ton_i + Ton\_carbon\_per\_ton_i}$$

$Ton\_APCE\_residue\_per\_ton_i$ is the amount of air pollution control equipment (APCE) residue collected by the fabric filter system per ton of waste component i. This includes spray dryer residue (the salts formed from neutralization of the acid) and any other residue from the carbon injection and NOx control equipment. (ton APCE residue/ton waste component).

$Ton\_lime\_per\_ton_i$ is the mass of lime used at the WTE facility and is assumed to be equal to the mass of APCE residue collected by the fabric filter system per ton of waste component i that is attributed to the addition of lime for acid gas control. This includes the spray dryer residue (the salts formed from neutralization of the acid). (ton lime residue/ton waste component).

$Ton\_ammonia\_per\_ton_i$ is the amount of APCE residue collected by the fabric filter system per ton of waste component i that is attributed to the addition of ammonia for control of NOx. (ton ammonia residue/ton waste component).

$Ton\_carbon\_per\_ton_i$ is the amount of APCE residue collected by the fabric filter system per ton of waste component i that is attributed to the addition of carbon injection for mercury control. (ton carbon injection residue/ton waste component).

The amount of WTE residue generated by each waste component is determined by the following equation:

Equation 20

$$Ton\_WTE\_residue\_per\_ton_i = Ton\_combustion\_residue\_per\_ton_i \cdot (1 - Recovery\_rate\_from\_ash_i) + Ton\_APCE\_residue\_per\_ton_i$$

Ton_WTE_residue_per_ton$_i$ is the amount of residue generated per ton of waste component i (ton WTE residue/ton waste component).

Ton_combustion_residue_per_ton$_i$ is defined in Equation 5. (ton combustion residue/ton waste component).

Recovery_rate_from_ash$_i$ is the fraction of waste component i that is found in the ash and recovered. With the exception of the categories, Ferrous cans and Ferrous other, this value is zero. For these categories, this parameter is equal to *Recovery_rate_from_ash*$_{Fe}$ that is defined in Equation 5. (ton waste component recovered/ton waste component in bottom ash).

Ton_APCE_residue_per_ton$_i$ is defined in Equation 19.

The total mass of WTE residues generated is calculated by Equation 21.

Equation 21

$$Tons\_WTE\_residue = \sum_{i}^{\#\_waste\_components} Ton\_WTE\_residue\_per\_ton\_waste_i \cdot WTE\_feed\_rate_i$$

where

Tons_WTE_residue is the annual generation of residue (combustion and cleaning residue) from the WTE facility.

Ton_WTE_residue_per_ton$_i$ is defined by Equation 20 (ton WTE residue/ton waste component).

WTE_feed_rate$_i$ is defined in Equation 2 (ton waste component/yr) .

5.4 Waterborne emissions

The WTE facility is assumed to be zero discharge with respect to waterborne pollutants. Nevertheless the user may override the defaults of zero. The waterborne pollutants included are dissolved solids, suspended solids, BOD, COD, Oil, Sulfuric acid, Iron, Ammonia, Copper, Cadmium, Arsenic, Mercury, Phosphate, Selenium, Chromium, Lead and Zinc. Below, the calculations and required inputs are shown.

Equation 22

$$WTE\_water_p = WTE\_water\_emission\_per\_ton_{i,p} \cdot \sum_{i}^{\#\_waste\_components} WTE\_feed\_rate_i$$

where

WTE_water_p is the waterborne emissions of pollutant p by the WTE facility (lbs pollutant/yr). The waterborne pollutants include dissolved solids, suspended solids, BOD, COD, Oil, Sulfuric acid, Iron, Ammonia, Copper, Cadmium, Arsenic, Mercury, Phosphate, Selenium, Chromium, Lead and Zinc.

$WTE\_water\_emission\_per\_ton_{i,p}$ is the waterborne emissions of pollutant p attributed to one ton of waste component i (lbs pollutant/ton waste component). The waterborne pollutants include dissolved solids, suspended solids, BOD, COD, Oil, Sulfuric acid, Iron, Ammonia, Copper, Cadmium, Arsenic, Mercury, Phosphate, Selenium, Chromium, Lead and Zinc.

$WTE\_feed\_rate_i$ is defined in Equation 2 (ton waste component/yr).

6. LCI parameter offsets

It is assumed that one kWh produced by the WTE facility will displace one kWh produced by a mix of conventional power stations. The exist mix of the fuels to be used at the conventional power stations is defined by the user and is described in detail in the Energy Process model documentation. The equation to determine net life cycle inventory coefficients for the air pollutants, water pollutants, and solid waste is given below:

Equation 23

$$WTE\_offset_{i,p} = WTE\_kWh\_per\_ton_i \cdot WTE\_offset\_per\_kWh_p$$

for p = air pollutants (metals and nonmetals), water pollutants, solid wastes and energy usage.

where

$WTE\_offset_{i,p}$ is the life cycle inventory offset for the parameter p per ton of waste component i from the utilization of a WTE facility. The index p represents air pollutants (metals and nonmetals), water pollutants, solid wastes, and energy usage. (see respective sections for units).

$WTE\_kWh\_per\_ton_i$ is defined in Equation 8. (kWh electricity/ton of waste component).

$WTE\_offset\_per\_kWh_p$ is the amount of LCI parameter displaced per kWh of electricity generated by the WTE facility. The index p represents air pollutants (metals and nonmetals), water pollutants, solid wastes, and energy usage. This set of parameters is described in detail in the Electric Energy process model documentation. For p = energy consumption this parameter is equal to *reg_comb_btu_offset_per_elec_kwh* (Btu displaced/kWh generated by WTE facility). For the air pollutants, water pollutants and solid wastes, this parameter is referenced by "a_p comb_offset", "w_p comb_offset", and "swp comb_offset" where "p" is to be substituted with the pollutant name or solid waste number (see respective sections for units)

Total offsets for each LCI parameter is given by:

Equation 24

$$WTE\_offset_p = \sum_{i}^{\#\_waste\_components} WTE\_offset_{i,p} \cdot WTE\_feed\_rate_i$$

for p = air pollutants (metals and nonmetals), water pollutants, solid wastes and energy usage.

where

WTE_offset_p are the total offsets of LCI parameter p that are associated with the displacement of electricity generation from conventional fuels. The index p represents air pollutants (metals and nonmetals), water pollutants, solid wastes, and energy usage. (see respective sections for units).

$WTE\_offset_{i,p}$ is defined in Equation 23. (see respective sections for units).

$WTE\_feed\_rate_i$ is defined in Equation 2 (tons waste component/yr).

7. Offsite LCI

The production of the lime was identified as the only major contributor to LCI related to the production of materials consumed during the operation of the WTE facility. In this section, equations are given to estimate the LCI at the site where the lime is manufactured and by the producers of energy consumed in the lime manufacture.

Equation 25

$$WTE\_offsite\_LCI_{i,p} = \left(\begin{array}{l} Fuel\_LCI\_per\_ton\_lime_{i,p} \\ + Process\_LCI\_per\_ton\_lime_{i,p} \end{array} \right) \cdot Ton\_lime\_per\_ton_i$$

for p = all LCI parameters but energy usage

$$= \left(\sum_{f} Fuel\_units\_per\_ton\_lime_f \cdot Btu\_per\_fuel\_unit_f \right) \cdot Ton\_lime\_per\_ton_i$$

for p = energy usage, f = fuel type

where

WTE_offsite_LCI$_{i,p}$ is the amount of LCI parameter p that does not occur at the combustion facility site per ton of waste component i processed where p is any of the LCI parameters but energy usage. This includes all emissions (process-related and combustion and precombustion fuel-related emissions) involved with the production of materials (currently only lime) that are consumed as a result of the operation of the combustion facility. (LCI units/ton waste component).

Fuel_LCI_per_ton_lime$_{i,p}$ is the fuel-related amount of LCI parameter p per ton of lime manufactured. (LCI units/ton waste component).

Process_LCI_per_ton_lime$_{i,p}$ is the process-related amount of LCI parameter p per ton of lime manufactured. (LCI units/ton waste component).

Fuel_units_per_ton lime$_f$ is the number of units of fuel f consumed in the manufacture of one ton of lime. The fuel types include electricity, natural gas, LPG, coal, distillate oil, residual oil, gasoline, truck diesel, rail diesel, nuclear, hydropower and other. (fuel units/ton lime).

Btu_per_fuel_unit$_i$ is the number of Btu embodied in one unit of fuel f. (Btu/fuel unit).

The LCI totals occurring offsite are given by:

Equation 26

$$WTE\_offsite\_LCI_p = \sum_{i}^{\#\_waste\_components} WTE\_offsite\_LCI_{i,p} \cdot WTE\_feed\_rate_i$$

for p = air pollutants (metals and nonmetals), water pollutants, solid wastes and energy usage.

where

WTE offsite_LCI$_p$ is the total for LCI parameter p that is attributed to offsite processes that support the operation of the combustion facility. The index p represents air pollutants (metals and nonmetals), water pollutants, solid wastes, and energy usage. (see respective sections for units).

WTE offsite_LCI$_{i,p}$ is defined in Equation 25. (see respective sections for units).

WTE_feed_rate$_i$ is defined in Equation 2 (tons waste component/yr).

8. Net LCI parameters

The net LCI parameters are the relevant ones to the management model. They take into account the LCI parameters of the WTE facility and the offsets associated with the displacement of electricity production based on conventional fuels. The equation to determine net life cycle inventory coefficients for the air pollutants, water pollutants, and solid waste is given below:

Equation 27

$$Net\_WTE_{i,p} = WTE_{i,p} - WTE\_offset_{i,p} + WTE\_offsite\_LCI_{i,p}$$

where

Net_WTE$_{i,p}$ is the net life cycle inventory of parameter p from the utilization of a WTE facility per ton of waste component i. The index p represents air pollutants (metals and nonmetals), water pollutants, solid wastes, and energy usage. (see respective sections for units).

WTE$_{i,p}$ is defined in Equation 16 (airborne emissions), Equation 21 (solid waste), and Equation 22 (waterborne emissions) . It is zero for energy usage. . (see respective sections for units)

WTE _offset$_{i,p}$ is defined in Equation 23. (see respective sections for units).

WTE_offsite_LCI$_{i,p}$ is defined in Equation 25. (LCI units/ton waste component.)

Total net values for each LCI parameter is given by:

Equation 28

$$Net\_WTE_p = WTE_p - WTE\_offset_p + WTE\_offsite\_LCI_p$$

for p = air pollutants (metals and nonmetals), water pollutants, solid wastes, and energy usage.

where

Net_WTE_p is the net value of the LCI parameter p that is associated with the displacement of electricity generation from conventional fuels. The index p represents air pollutants (metals and nonmetals), water pollutants, solid wastes, and energy usage. (see respective sections for units).

WTE_p is defined in Equation 18 (airborne emissions), Equation 20 (solid waste), and Equation 22 (waterborne emissions) . It is zero for energy usage. (see respective sections for units)

WTE_offset_p is defined inEquation 24. (see respective sections for units).

$WTE\_offsite\_LCI_p$ is defined inEquation 26. (see respective sections for units)

9. Other WTE parameters of interest

9.1 Total waste processed by the WTE facility

The total waste processed by the WTE is given by Equation 29.

Equation 29

$$WTE\_feed\_rate = \sum_{i}^{\#\_waste\_components} WTE\_feed\_rate_i$$

where

WTE_feed_rate is the total annual tons of waste processed by the WTE facility (tons waste/yr).

$WTE\_feed\_rate_i$ is defined in Equation 2 (wet tons waste component/yr).

9.2 Electricity production

The total amount of electricity produced is given by the following equation:

Equation 30

$$WTE\_kWh\_production = \sum_{i}^{\#\_waste\_components} WTE\_kWh\_per\_ton_i \cdot WTE\_feed\_rate_i$$

where

WTE_kWh_production is the energy generated by the WTE facility (kWh/yr).

$WTE\_kWh\_per\_ton_i$ is defined in Equation 8 (kWh/ton waste component)

$WTE\_feed\_rate_i$ is defined in Equation 2 (wet tons waste component/yr).

9.3 Rating of the WTE facility

The plant rating may be of interest to users. It is calculated as follows:

Equation 31

$$WTE\_rating = \frac{WTE\_kWh\_production}{\frac{24h}{day} \cdot \frac{365day}{yr} \cdot \frac{1000kW}{MW} \cdot WTE\_capacity\_factor}$$

where

WTE_rating is the design capacity in megawatts (MW).

WTE_kWh_production is defined in Equation 30 (kWh/yr).

WTE_capacity_factor is defined in Equation 1 (unitless).

10. Inputs to the WTE process model

This section describes the default parameter inputs to the WTE process model equations described previously. Appendices A-C describe in more detail the development of the default values for some of the cost and LCI parameters. Inputs to the WTE process model are indicated Table 1. Table 1, however, does not include the air pollution-related parameters. Table 2 through Table 6 provides the default values of the air pollution-related parameters.

10.1 General characteristics

WTE_lifetime is the book lifetime of the WTE facility. This value is assumed to be 20 yrs.

Error! Not a valid link. The default value, taken from [1], **Municipal Waste Combustors-Background information for proposed standards: 111(b) Model plant description and cost report** (EPA, 1989), is 0.91. This corresponds to 8000 hrs/yr operation.

Error! Not a valid link.

Error! Not a valid link. The default value for this parameter, 90%, is taken from [3], **Integrated Solid Waste Management**, p. 244-245.

Error! Not a valid link. The default value is 0.0070 tons lime/ ton waste. The default is based on an estimate of 2060 tons lime/yr for a 800 TPD facility (from Table 2-3 of [1], **Municipal Waste Combustors-Background information for proposed standards: 111(b) Model plant description and cost report** (EPA, 1989). (0.0070 = (2060/365)/800). Though the lime reacts with the acid gases to produce new solids and gases, it is reasonable to assume that one pound of reagent roughly corresponds to one pound of residue.

Error! Not a valid link. The default is 0.0015 tons ammonia/ton waste and is based on an estimate of 50 lbs ammonia/hr for a 400 TPD plant (from Table 3-6 of [2], **NOx Control Technologies Applicable to Municipal Waste Combustion**, EPA, 1994). (0.0015 = (50*24/2000)/400). Though the ammonia reacts with the NOx to produce new solids and gases, it is reasonable to assume that one pound of reagent roughly corresponds to one pound of residue.

Error! Not a valid link. The default is estimated to be 0.0004 tons residue/ton waste (based on 100 mg C/dscm-- personal communication with David White, Radian, 2/96-- and 4000 dscm/ton waste).

Error! Not a valid link. Perfect efficiency corresponds to a heat rate of 3,414 Btu/kWh. Tchobanoglous (p. 660) gives a range of 15,000-30,000 Btu/kWh for WTE facilities. For comparison, an estimate of 550 kWh/ton and 5000 Btu/lb corresponds to a heat rate of about 18,180 Btu/kWh (5000*2000/550). The default value we choose is 18,000 Btu/kWh.

10.2 Plant cost parameters

Error! Not a valid link. The default value is $207/(ton/yr capacity) in 1987-denominated dollars. Refer to Appendix A for the development of this default value. This value is multiplied by an inflator to convert the 1987-denominated dollars to the current year's dollars (see the Common process model documentation for information on cost escalation). Using the producer price index for 1997, this value is 253.

Error! Not a valid link. The default value is 43.4 ($/yr)/(ton/yr design capacity). This value is multiplied by an inflator to convert the 1987-denominated dollars to the current year's dollars. Refer to Appendix A for the development of this default value. Using the producer price index for 1997, this value is 53.

Error! Not a valid link.. The default value is 0.023 $/kWh in 1995 dollars. This value is multiplied by an inflator to convert the 1995-denominated dollars to the current year's dollars. Using the producer price index for 1997, this value is 0.024.

10.3 Life-cycle parameters

Error! Not a valid link.. The development of the default value is described in Appendix B.

Error! Not a valid link.. The index p can represent SO2, HCl, NOx, and CO. Several sets of defaults are provided. One applies to emissions at levels corresponding to the standards. The second applies to average performance at existing waste facilities. The third applies to average performance at new WTE facilities. See Appendix B for discussion of these defaults.

Error! Not a valid link.. The index p applies to PM (particulate matter). **Error! Not a valid link.**

Error! Not a valid link.. The index p stands for Dioxins/furans. **Error! Not a valid link.**

$WTE\_air_{i,p}$ is the lbs of pollutant p emitted at the WTE facility per ton of waste processed at the waste facility. For all but $CO_{2,}$, methane, hydrocarbons and ammonia, this value is calculated from other inputs. For CO_2, Table 2 presents the emission factors, broken down by biomass-derived and fossil fuel-derived. Refer to Appendix B for discussion of the development of CO_2 emission factors. For methane, hydrocarbons and ammonia, refer to Table 1. The estimate for methane, 0.003 lbs methane per ton waste, was obtained from an Ogden memo (David Sussman to Susan Thorneloe, EPA, August 26, 1996). The values for hydrocarbons and ammonia are as of yet not available but are thought to be small. Because limited data exist, values of zero are the current defaults for hydrocarbons and ammonia.

Error! Not a valid link. The default values are presented in Table 5. A description of the development of the default values for the parameters in Table 5 is provided in Appendix C.

Error! Not a valid link. Two sets of default removal efficiencies are listed in Table 4. The first set is based on average emissions at new facilities and the second set is based on average emissions at older facilities. The development of the default values for these parameters is detailed in Appendix C.

Error! Not a valid link. The default for all parameters but energy usage is given in Table 7. These values are provided by Franklin Associates, Limited (FAL) (based on FAL memo to Keith Weitz, RTI, dated 02/03/98, "Table 1. Data for the production of one ton of lime".) Where no information was provided, the values were assumed to be zero.

Error! Not a valid link. The default for all parameters but energy usage is given in Table 7. These values are provided by Franklin Associates, Limited (FAL) (based on FAL memo to Keith Weitz, RTI, dated 02/03/98, "Table 1. Data for the production of one ton of lime".) Where no information was provided, the values were assumed to be zero.

Error! Not a valid link. The default values are presented in Table 7. These values are provided by Franklin Associates, Limited (FAL) (based on FAL memo to Keith Weitz, RTI, dated 02/03/98, "Table 1. Data for the production of one ton of lime".)

Error! Not a valid link. The WTE plant is assumed to be zero discharge and, consequently, the defaults for the water pollutants are zero.

11. Inputs to the WTE process model from other process models

11.1 From the Common process model

There are many parameters that are used in several process models within the solid waste management model. Such parameters are grouped in a separate spreadsheet distinct from but linked to the WTE process model. These common parameters are described here. The following input values come from the Common process model:

$Scrap\_price_i$ is the sale price of recyclable waste component i. For Ferrous cans and Other ferrous metal, this parameter is equal to another parameter defined here, $Scrap\_price_{Fe}$ ($/ton ferrous recovered).

Discount_rate is the discount rate used in conjunction with the *WTE_lifetime* to calculate of the capital recovery factor. In the common process model, this parameter is named *CF_I*.

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11.2 From the Electric Energy process model

The following input values come from the Energy process model:

Error! Not a valid link..

Error! Not a valid link. The naming convention in the Electric Energy process model documentation is different. Generally, the name is reference by the abbreviation of the fuel, e.g., "ng" for natural gas, intersectioned by

12. Values reported to the Decision Support System display

The information that we propose to report to the Decision Support System includes:

Error! Not a valid link.. The LP model establishes these values according to the user inputs, constraints and the user-defined objective function.

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WTE_air_p is the total annual air emissions of pollutant p from the WTE facility. The index p includes the nonmetals and metals indicated in Equation 16 and Equation 17, respectively, and includes emissions for methane, ammonia and hydrocarbons. (lbs/yr)

Error! Not a valid link. The index p includes Particulates, PM10, NOx, Hydrocarbons, SO2, CO, CO2—biomass-derived and fossil fuel-derived, Ammonia, Pb, methane and HCl.

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Table 1. Various WTE Default parameter values

WTE lifetime	20	yr
WTE capacity factor	0.91	unitless
Heat rate	18,000	Btu's / kWh
Unit WTE capital cost	253.0	$/design tons per year
Unit WTE O&M cost	53.0	($/yr)/(design tons per year)
Electricity price	0.024	$ / kWh
WTE ton lime per ton waste	0.0071	ton lime/ton MSW
WTE ton ammonia per ton waste	0.0015	ton ammonia/ton MSW
WTE ton carbon per ton waste	0.0004	ton carbon/ton MSW
WTE ferrous ash recovery rate	90%	unitless
Methane air emissions	0.003	lb emitted/ton MSW
Ammonia air emissions	0	lb emitted/ton MSW
Hydrocarbons air emissions	0	lb emitted/ton MSW

Dollars have been inflated to 1997 using producer price index

Table 2. Carbon dioxide (fossil fuel and biomass) emission factors (lbs CO_2/ton waste component)

	Carbon dioxide	
	Biomass-derived	Fossil fuel-derived
Leaves	1,290	-
Grass	1,182	-
Branches	1,290	-
Old Newsprint	3,171	-
Old Corr. Cardboard	2,941	-
Office Paper	2,471	-
Phone Books	3,016	-
Books	2,875	-
Old Magazines	1,689	-
3rd Class Mail	2,103	-
Paper Other #1	2,471	-
Paper Other #2	2,605	-
Paper Other #3	2,471	-
Paper Other #4	2,471	-
Paper Other #5	2,471	-
Paper - Non-recyclable	2,471	-
Food Waste	1,009	-
Ferrous Cans	-	-
Ferrous Metal - Other	-	-
Ferrous - Non-recyclable	-	-
Aluminum Cans	-	-
Aluminum - Other #1	-	-
Aluminum - Other #2	-	-
Al - Non-recyclable	-	-
Glass - Clear	99	-
Glass - Brown	99	-
Glass - Green	99	-
Glass - Non-recyclable	99	-
HDPE - Translucent	-	5,828
HDPE - Pigmented	-	5,828
PET	-	4,250
Plastic - Other #1	-	2,611
Plastic - Other #2	-	6,052
Plastic - Other #3	-	6,052
Plastic - Other #4	-	6,052
Plastic - Other #5	-	6,052
Plastic - Non-Recyclable	-	6,052
Misc.	2,559	-

Note: Calculations shown in Appendix B.

Table 3. Flue gas production by waste component (dscm @ 7% oxygen/ton waste component)

Leaves	2,336
Grass	2,171
Branches	2,335
Old Newsprint	5,524
Old Corr. Cardboard	5,110
Office Paper	4,436
Phone Books	5,294
Books	5,072
Old Magazines	3,000
3rd Class Mail	3,858
Paper Other #1	4,436
Paper Other #2	4,678
Paper Other #3	4,436
Paper Other #4	4,436
Paper Other #5	4,436
Paper - Non-recyclable	4,436
Food Waste	1,899
Ferrous Cans	-
Ferrous Metal - Other	-
Ferrous - Non-recyclable	-
Aluminum Cans	-
Aluminum - Other #1	-
Aluminum - Other #2	-
Al - Non-recyclable	-
Glass - Clear	207
Glass - Brown	207
Glass - Green	207
Glass - Non-recyclable	207
HDPE - Translucent	13,519
HDPE - Pigmented	13,519
PET	7,064
Plastic - Other #1	5,652
Plastic - Other #2	13,009
Plastic - Other #3	13,009
Plastic - Other #4	13,009
Plastic - Other #5	13,009
Plastic - Non-Recyclable	13,009
Misc.	4,722

Note: Calculations in Appendix B.

Table 4. Default options for emitted concentration levels of nonmetal air pollutants

Pollutant	Default options			Units[3]
	Standard[1]	Average performance		
		Newer[4]	Older	
CO	100	26	-	ppmv
Dioxins/Furans	13	4.5	-	ng/dscm
PM	24	4.0	-	mg/dscm
SO2	30[2]	8.0	-	ppmv
HCl	25[2]	8.9	-	ppmv
NOx	150	136	-	ppmv

[1]New Standards (1995), Fact Sheet, New Municipal Waste Combustors--Subpart Eb Standards of Performance, EPA, 1995

[2]As the regulation is written, a combustion facility may alternatively be in compliance if uncontrolled emissions are reduced by a specified percentage (80% for SO2, 95% for HCl). Based on personal communication with Walt Stevenson, USEPA, February 1995, we have been advised to use the concentration standard rather than the percent reduction standard.

[3]All concentration levels reported in the table are corrected to 7% O2, dry basis.

[4]Performance data from MWC'S with spray dryer, fabric filter, selective non-catalytic reduction, and carbon injection. Summary of Performance Data from Colleen Kane, USEPA, to Walt Stevenson, USEPA (October 17, 1995).

Table 5. Uncontrolled metal emission factors (lbs metal/ton waste component) for Integrated Solid Waste Management categories*

Component name	As	B	Ba	Cd	Cr	Cu
Leaves	2.57E-05	1.28E-02	3.09E-05	1.46E-03	1.10E-03	2.96E-04
Grass	2.57E-05	1.28E-02	3.09E-05	1.46E-03	1.10E-03	2.96E-04
Branches	3.17E-06	5.45E-04	1.26E-05	2.68E-04	2.61E-04	1.93E-05
Old News Print	2.41E-06	2.20E-04	4.38E-06	2.44E-05	5.73E-04	7.78E-06
Old Corr. Cardboard	2.12E-06	7.51E-05	1.46E-06	2.44E-05	1.95E-05	1.29E-06
Office Paper	4.59E-06	5.33E-05	1.79E-06	2.44E-05	3.68E-05	3.43E-06
Phone Books	2.82E-06	1.48E-04	2.16E-06	2.44E-05	1.41E-05	4.28E-06
Books	1.41E-06	9.11E-04	1.45E-05	9.76E-05	9.41E-05	1.71E-05
Old Magazines	5.06E-06	1.19E-04	7.03E-06	3.50E-05	1.24E-04	1.34E-05
3rd Class Mail	4.23E-06	1.60E-04	3.32E-06	4.15E-04	3.57E-04	1.03E-05
Paper Other #1	3.23E-06	2.41E-04	4.96E-06	9.21E-05	1.74E-04	8.22E-06
Paper Other #2	3.23E-06	2.41E-04	4.96E-06	9.21E-05	1.74E-04	8.22E-06
Paper Other #3	3.23E-06	2.41E-04	4.96E-06	9.21E-05	1.74E-04	8.22E-06
Paper Other #4	3.23E-06	2.41E-04	4.96E-06	9.21E-05	1.74E-04	8.22E-06
Paper Other #5	3.23E-06	2.41E-04	4.96E-06	9.21E-05	1.74E-04	8.22E-06
Paper - Non-recyclable	4.23E-06	1.60E-04	3.32E-06	4.15E-04	3.57E-04	1.03E-05
Food Waste	4.23E-06	7.96E-03	4.04E-06	4.88E-04	2.44E-04	1.84E-05
Ferrous Cans	2.51E-05	3.84E-03	1.05E-06	1.08E-02	2.13E-03	4.90E-05
Ferrous Metal - Other	1.97E-02	3.26E-03	1.75E-04	5.37E-03	2.89E-03	1.88E-01
Ferrous - Non-recyclable	1.97E-02	3.26E-03	1.75E-04	5.37E-03	2.89E-03	1.88E-01
Aluminum Cans	1.14E-06	3.77E-04	2.84E-05	1.18E-03	9.90E-04	4.76E-04
Aluminum - Other #1	2.82E-06	3.63E-04	6.27E-06	1.24E-02	1.45E-03	1.20E-04
Aluminum - Other #2	5.28E-03	4.35E-04	9.88E-06	3.24E-03	7.59E-03	1.91E-04
Al - Non-recyclable	5.28E-03	4.35E-04	9.88E-06	3.24E-03	7.59E-03	1.91E-04
Glass - Clear	3.53E-06	2.15E-03	7.92E-05	1.17E-03	3.03E-04	9.42E-06
Glass - Brown	2.43E-05	7.08E-04	4.43E-05	4.15E-04	5.00E-04	3.94E-05
Glass - Green	3.46E-05	1.08E-03	1.13E-04	7.32E-05	1.02E-02	2.57E-06
Glass - Non-recyclable	9.45E-06	1.83E-03	8.16E-05	9.61E-04	1.52E-03	1.19E-05
HDPE - Translucent	1.76E-06	7.12E-04	1.94E-05	7.07E-04	1.62E-04	1.03E-05
HDPE - Pigmented	1.76E-06	7.12E-04	1.94E-05	7.07E-04	1.62E-04	1.03E-05
PET	2.82E-06	4.69E-03	1.86E-06	1.29E-03	1.81E-04	1.33E-05
Plastic - Other #1	2.12E-06	2.04E-03	1.36E-05	9.02E-04	1.68E-04	1.13E-05
Plastic - Other #2	2.12E-06	2.04E-03	1.36E-05	9.02E-04	1.68E-04	1.13E-05
Plastic - Other #3	2.12E-06	2.04E-03	1.36E-05	9.02E-04	1.68E-04	1.13E-05
Plastic - Other #4	2.12E-06	2.04E-03	1.36E-05	9.02E-04	1.68E-04	1.13E-05
Plastic - Other #5	2.12E-06	2.04E-03	1.36E-05	9.02E-04	1.68E-04	1.13E-05
Plastic - Non-Recyclable	2.17E-06	4.16E-04	2.47E-05	7.82E-03	1.70E-03	1.45E-05
Misc.	2.58E-03	3.35E-03	3.71E-05	6.24E-03	2.59E-03	2.38E-02
Pallets	1.20E-04	5.06E-04	6.48E-06	9.76E-06	6.29E-04	1.97E-05

*Emission factors in Table C-6 are matched to the above categories. Where there were more refined categories in the Burnaby study, the factors were composition weight-averaged. "Other" categories are the averages of all paper (plastic) products.

These values are derived in Appendix C.

Table 5. Uncontrolled metal emission factors (lbs metal/ton waste component) for Integrated Solid Waste Management categories, continued.

Component name	Hg	Ni	Pb	Sb	Se	Zn
Leaves	1.38E-03	8.00E-04	1.61E-02	4.60E-04	2.63E-07	1.69E-02
Grass	1.38E-03	8.00E-04	1.61E-02	4.60E-04	2.63E-07	1.69E-02
Branches	3.94E-04	3.66E-04	6.51E-03	6.87E-05	1.50E-07	5.75E-03
Old News Print	2.06E-03	1.00E-03	6.82E-04	1.97E-05	3.78E-07	9.51E-04
Old Corr. Cardboard	9.84E-05	1.29E-04	3.99E-04	1.32E-05	1.50E-07	4.64E-04
Office Paper	2.95E-04	2.68E-04	4.73E-04	2.03E-05	9.38E-07	9.65E-03
Phone Books	2.95E-04	1.46E-04	2.52E-04	1.06E-05	4.13E-07	3.71E-04
Books	1.97E-04	4.74E-05	5.26E-07	2.64E-07	4.88E-07	4.08E-03
Old Magazines	2.95E-04	4.45E-04	3.18E-04	4.23E-04	3.90E-07	1.27E-03
3rd Class Mail	3.94E-04	2.54E-04	2.41E-02	4.41E-05	1.13E-07	3.76E-03
Paper Other #1	5.20E-04	3.27E-04	3.75E-03	7.59E-05	4.10E-07	2.93E-03
Paper Other #2	5.20E-04	3.27E-04	3.75E-03	7.59E-05	4.10E-07	2.93E-03
Paper Other #3	5.20E-04	3.27E-04	3.75E-03	7.59E-05	4.10E-07	2.93E-03
Paper Other #4	5.20E-04	3.27E-04	3.75E-03	7.59E-05	4.10E-07	2.93E-03
Paper Other #5	5.20E-04	3.27E-04	3.75E-03	7.59E-05	4.10E-07	2.93E-03
Paper - Non-recyclable	3.94E-04	2.54E-04	2.41E-02	4.41E-05	1.13E-07	3.76E-03
Food Waste	2.95E-04	1.63E-04	7.57E-03	1.13E-04	1.88E-07	8.63E-03
Ferrous Cans	7.59E-03	5.45E-03	3.54E-02	7.66E-04	1.55E-07	2.00E-01
Ferrous Metal - Other	5.83E-03	2.80E-03	5.38E-02	7.38E-04	4.55E-05	2.72E-01
Ferrous - Non-recyclable	5.83E-03	2.80E-03	5.38E-02	7.38E-04	4.55E-05	2.72E-01
Aluminum Cans	3.55E-04	7.63E-04	4.85E-03	1.65E-04	3.75E-08	1.01E-02
Aluminum - Other #1	7.88E-04	1.37E-03	4.20E-07	2.64E-07	3.75E-08	5.56E-03
Aluminum - Other #2	3.33E-04	6.58E-04	7.32E-03	1.65E-04	2.07E-05	8.62E+00
Al - Non-recyclable	3.33E-04	6.58E-04	7.32E-03	1.65E-04	2.07E-05	8.62E+00
Glass - Clear	1.97E-04	3.44E-04	1.15E-02	1.28E-03	2.89E-06	2.78E-03
Glass - Brown	5.91E-04	7.73E-04	1.08E-02	2.24E-04	1.80E-06	1.16E-02
Glass - Green	9.84E-05	2.12E-03	2.10E-03	3.22E-04	2.25E-07	9.74E-04
Glass - Non-recyclable	2.26E-04	6.04E-04	1.03E-02	1.05E-03	2.41E-06	5.08E-03
HDPE - Translucent	1.97E-04	2.37E-04	6.37E-03	4.58E-04	1.88E-07	6.59E-03
HDPE - Pigmented	1.97E-04	2.37E-04	6.37E-03	4.58E-04	1.88E-07	6.59E-03
PET	1.97E-04	2.81E-04	6.46E-03	1.53E-03	1.88E-07	4.50E-03
Plastic - Other #1	1.97E-04	2.52E-04	6.40E-03	8.17E-04	1.88E-07	5.89E-03
Plastic - Other #2	1.97E-04	2.52E-04	6.40E-03	8.17E-04	1.88E-07	5.89E-03
Plastic - Other #3	1.97E-04	2.52E-04	6.40E-03	8.17E-04	1.88E-07	5.89E-03
Plastic - Other #4	1.97E-04	2.52E-04	6.40E-03	8.17E-04	1.88E-07	5.89E-03
Plastic - Other #5	1.97E-04	2.52E-04	6.40E-03	8.17E-04	1.88E-07	5.89E-03
Plastic - Non-Recyclable	2.12E-04	5.82E-04	3.42E-02	1.08E-03	1.90E-07	2.23E-02
Misc.	1.52E-03	9.89E-04	3.81E-02	1.34E-03	2.62E-04	6.67E-02
Pallets	3.94E-04	2.71E-05	3.41E-02	4.41E-06	3.75E-08	9.51E-03

*Emission factors in Table C-6 are matched to the above categories. Where there were more refined categories in the Burnaby study, the factors were composition weight-averaged. "Other" categories are the averages of all paper (plastic) products.

These values are derived in Appendix C.

Table 6. Default removal efficiencies for Metals

Pollutant	Average		
	New	Old[2]	Unit
As	99.9[3]	-	%
B	76.5[4]	-	%
Ba	99.8[3]	-	%
Cd	99.7[3]	-	%
Cr	99.3[3]	-	%
Cu	99.6[3]	-	%
Hg	92.7[1]	-	%
Ni	96.6[3]	-	%
Pb	99.8[3]	-	%
Sb	96.7[4]	-	%
Se	92.9[4]	-	%
Zn	99.7[4]	-	%

[1]Performance data from MWC's with spray dryer, fabric filter, selective non-catalytic reduction, and carbon injection. Summary of Performance Data from Colleen Kane, USEPA, to Walt Stevenson, USEPA (1995).

[2]Currently in consultation with Walt Stevenson, USEPA (May, 1995).

[3]Camden Cty., NJ study

[4]Average removal efficiencies observed at Burnaby plant.

Table 7. Fuel units consumed in the production of one ton of lime

Electricity	55.000	kwh
Natural gas	727.300	cu ft
LPG	0.012	gal
Coal	313.230	lb
Distillate oil	0.914	gal
Residual oil	0.317	gal
Gasoline	0.060	gal
Truck Diesel	0.536	gal
Rail Diesel	0.403	gal
Nuclear	1.3E-05	lb U238
Hydropower	1.563	thousand Btu
Other	1.146	thousand Btu

Source: These values are provided by Franklin Associates, Limited (FAL) (based on FAL memo to Keith Weitz, RTI, dated 02/03/98, "Table 1. Data for the production of one ton of lime".)

Table 8. LCI (excluding energy) per ton lime manufactured

		Lb per ton lime manufactered	
		Process-related	Fuel related
Lime air emissions: Nonmetals	Biomass CO2	0	0.095
	Fossil CO2	1600	958
	SO2	0	7.3
	HCl	0	2.35E-06
	NOx (as NO)	0	2.6
	Dioxins / Furans	0	0
	CO	0	0.7
	Total PM	4.3	1.1
	PM 10	0	0
	Methane	0	1.9
	Ammonia	0	4.00E-04
	Hydrocarbons	0	0.59
Lime air emissions: metal	As	0	3.00E-04
	B	0	0
	Cd	0	1.00E-04
	Cr	0	6.20E-04
	Cu	0	0
	Hg	0	8.60E-06
	Ni	0	4.20E-04
	Pb	0	3.70E-05
	Sb	0	1.46E-06
	Se	0	1.60E-06
	Zn	0	0
Lime water emissions	Dissolved Solids	0	2.189654865
	Suspended solids	0	0.085920901
	BOD	0	0.002339642
	COD	0	0.031834418
	Oil	0	0.038864966
	Sulfuric acid	0	0.007763387
	Iron	0	0.042058928
	Ammonia	0	0.000117549
	Copper	0	0
	Cadmium	0	0.000103083
	Arsenic	0	0
	Mercury	0	7.92949E-09
	Phosphate	0	0.003881693
	Selenium	0	0
	Chromium	0	9.93786E-05
	Lead	0	3.06948E-08
	Zinc	0	3.40623E-05
Lime solid waste		5	160

Source: These values are provided by Franklin Associates, Limited (FAL) (based on FAL memo to Keith Weitz, RTI, dated 02/03/98, "Table 1. Data for the production of one ton of lime".)

References

1. Municipal Waste Combustors-Background information for proposed standards: 111(b) Model plant description and cost report, EPA, 1989.
2. Tchobanoglous, George and Hilary Thisen, Samuel Vigil. Integrated solid waste management: engineering principles and management issues. Published by McGraw-Hill, Inc., 1993.
3. Integrated Solid Waste Management.
4. NOx Control Technologies Applicable to Municipal Waste Combustion, EPA, 1994.

Appendix A

Default values for the combustion cost parameters

A1. COST INFORMATION

The unit capital and operation & maintenance (O&M) costs are derived largely from Municipal Waste Combustors-Background Information for Proposed Standards: Model Plant Description and Cost Report (Cost Report) (USEPA, 1989).[1,3] This reference provides cost information for model combustor plants of different designs with varying degrees of pollution control that were expected to be constructed in the U.S. between 1990 and 1994. The information from this source was modified to improve its applicability to the management model. This analysis relies on the consideration of four model plants that were developed in a study to estimate the cost implications for proposed standards. The four plants include a 100 ton per day (TPD) modular/starved air plant, a 240 TPD modular/excess air plant, and two mass burn/waterwall facilities handling 800 and 2,250 TPD, respectively. Of the 10 non-RDF model plants examined by Cost Report, these four facilities were chosen based on the following reasoning:

1. The new plant will be of a mass burn/waterwall or modular plant design. The EPA cost study forecasted 64% of the total new capacity to be mass burn. Of the mass burn plants, the majority (85%) were forecasted to have waterwall furnaces.[1] Modular plants usually have smaller feed rates than mass burn plants and are assumed to be the preferred choice for smaller facilities.
2. The combustor will be designed to generate electricity. Virtually all new solid waste combustion systems currently under construction in the United States include energy recovery systems to help offset operating costs and to reduce the capital costs of air pollution control equipment.[2]

For each of the model plants, cost estimates were provided for three levels of air pollution control options. The most stringent air pollution control equipment option reported in the Cost Report is used. The equipment in this option is necessary to meet current standards. Additional controls for NOx and mercury are now necessary due to new standards not considered by Cost Study. Their costs are assessed separately in Section AA3 and are added to the Cost Study costs. The most stringent air pollution control equipment option reported in the Cost Report controls for particulate matter (PM), metals (arsenic, cadmium, chromium, nickel, lead and mercury), chlorinated dibenzo-p-dioxins and dibenzofurans (CDD/CDF), and acid gases (sulfur dioxide and hydrogen chloride) and includes:

a) Good combustion controls, e.g. exhaust gas cooling to promote destruction and inhibit formation of some pollutants.
b) Spray dryer (for best acid gas control)
c) Fabric filter (for best PM control and metals control)

Tables 7-2, 7-3, 7-22, and 7-26 of Cost Report present capital costs for the four model plants under consideration. Tables 7-5, 7-6, 7-23, 7-28 present annualized costs. The plant's capital cost includes the cost of combustors, ash handling system, turbine, and air pollution control and monitoring devices. The operation and maintenance cost of incineration is based on an 8000 hr/year operation, though wages are paid on an annual basis. This cost includes the labor, overhead, taxes, administration, insurance, indirect costs, auxiliary fuel cost, electricity cost and maintenance cost. Cost Report estimates include ash disposal costs in their O&M costs.

A2. MODIFICATIONS TO COST REPORT

The data from Cost Report have been modified to improve it applicability to the management model. The accounting changes to the cost data include:

- Subtracting capital recovery costs from annualized costs to account for O&M costs separately.
- Subtracting ash disposal costs from O&M costs to account for ash disposal costs separately.
- Addition of fixed and O&M costs of carbon injection for mercury control and NOx control. These costs are discussed in Section A3.

A3. COSTS FOR NOX CONTROL AND CARBON INJECTION

The following controls are likely to be necessary for compliance with Subpart Eb Standards of Performance (1995) for New Municipal Waste Combustors:

a) Conventional selective non-catalytic reduction (SNCR) for NOx control.

b) Carbon injection for mercury control.

Estimates for the costs associated with these controls are taken from Emissions Guidelines: Municipal Waste Combustors[4]. For a 730 Mg/day mass burn/waterwall plant, the capital cost impact of carbon injection and NOx control are provided in addition to an overall impact in terms of $/Mg. Table 3B of that document estimates the capital cost of including carbon injection to be 150,000 $ and for NOx control, 2 $ million. The total impact is estimated to be 0.37 $/Mg (0.41$/ton) and 2.39 $/Mg (2.63$/ton) for carbon injection and NOx control, respectively. The O&M costs of these controls are not directly indicated in the table but instead are embedded in the $/ton total cost impact values. In order to be in the form necessary to include them with the Cost Report estimates, the O&M cost was computed. The capital recovery costs were subtracted from the total cost impacts. Assuming a capital recovery factor of 0.0944 (7% interest rate and 20-yr book lifetime), the O&M costs were calculated to be 0.349 $/ton and 1.85 $/ton for carbon injection and NOx control, respectively. These costs were used to estimate the capital and annual O&M costs for the four design plants discussed in Section A4.

A4. DEVELOPMENT OF UNIT CAPITAL AND O&M COSTS

Unit capital costs and unit O&M costs have been developed from a linear regression of the four model plant costs. These unit costs include NOx control costs or the cost of carbon injection that were developed in Section A3.

Table A- 1 shows the reported and regressed capital, O&M, and total annual costs. The values for total annual costs assume a capital recovery factor of 0.0802, corresponding to a 5% discount rate and 20 year lifetime. The fitted lines were found by minimizing the sum of the squares of the % deviations of the data points predicted by the lines from the data points in Table A- 1 and requiring that the lines go through the origin. Figure A- 1, Figure A- 2 and Figure A- 3 show the data points and fitted lines for capital, O&M and total annual costs, respectively. The linearization does not capture some economies of scale. Referring to Figure A- 3, it underestimates the cost of the 100 ton per day plant by 26% and overestimates the cost of the 2,250 ton per day plant by 28%. Estimates of the costs of plants with capacities from 700 to 1500 tons per day are predicted with less than 15% deviation.

The slopes of the regression lines are 75,489 $/(ton/day capacity), 9,639 ($/yr)/(ton/day capacity), and 15,826 ($/yr)/(ton/day) for unit capital cost, annual O&M unit cost and total annual unit cost, respectively.

Dividing by 365 days/yr yields the defaults values used by the management model: unit capital cost, $207/(ton/yr capacity); unit operating cost, $43.4/ton (1987 denominated dollars).

Table A- 1. Capital and O&M costs for four model plants used in the linear regression[1].

		Capital cost $1,000		Annual O&M cost $1000/yr		Annualized total $1000/yr	
Plant type	Tons per day	Before linearizing	Linearized	Before linearizing	Linearized	Before linearizing	Linearized
	0	0	0	0	0	0	0
Modular / starved air	100	8,964	7,549	1,414	964	2,134	1,583
Modular / excess air	240	18,798	18,117	2,908	2,313	4,416	3,798
Mass burn / waterwall	800	64,612	60,391	8,138	7,711	13,322	12,661
Mass burn / waterwall	2,250	142,489	169,849	16,377	21,687	27,811	35,609

Figure A- 1 Capital cost of WTE facility

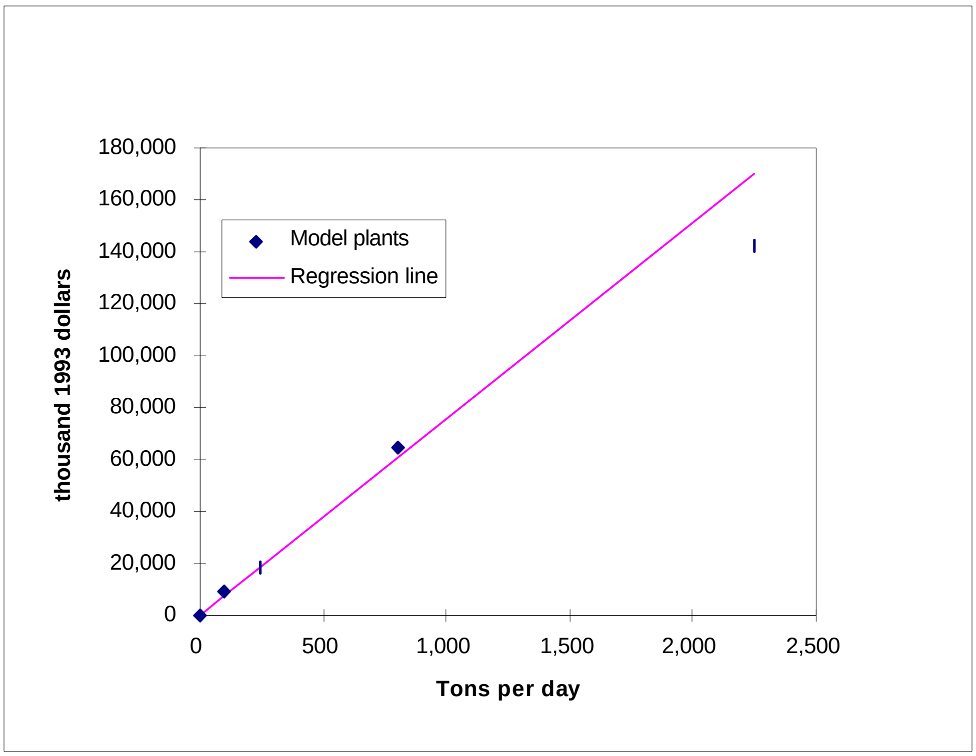


Figure A- 2 Annual O&M cost of WTE facility

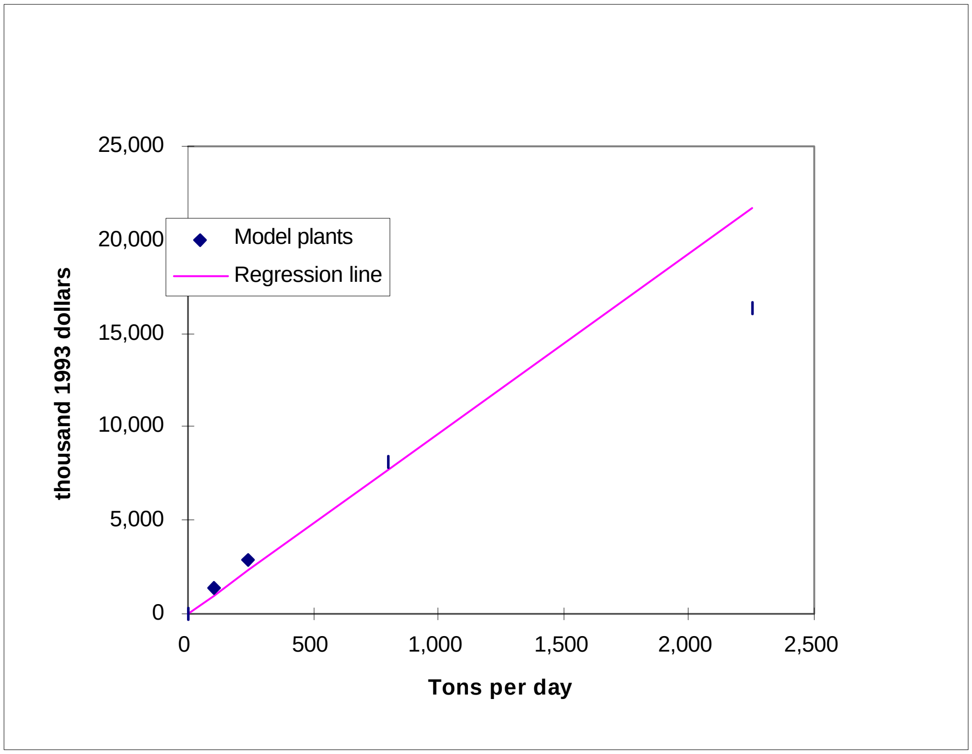
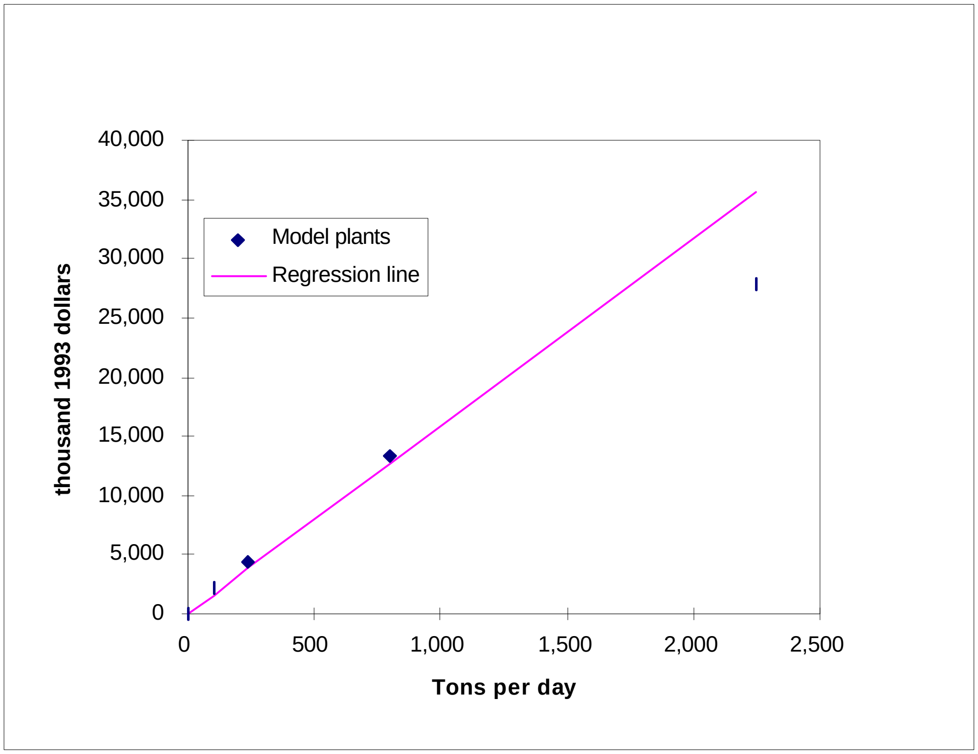


Figure A- 3 Total annual cost of WTE facility



A5. REFERENCES

1. Municipal Waste Combustors-Background information for proposed standards: 111(b) Model plant description and cost report, USEPA, 1989.
2. Tchobanoglous, George and Hilary Thisen, Samuel Vigil. Integrated solid waste management: engineering principles and management issues. Published by McGraw-Hill, Inc., 1993.
3. Municipal Waste Combustors-Background information for proposed standards: Cost procedures, USEPA, 1989.
4. Emission Guidelines: Municipal Waste Combustors, USEPA, 40 CFR Part 60, [AD-FRL]
5. Discussions with Mr. David White, Radian Corporation, Raleigh, NC.
6. NOx Control Technologies Applicable to Municipal Waste Combustion prepared for USEPA by Radian Corporation. December 1994.

Appendix B:

Nonmetal air emissions from municipal waste combustors

B1. INTRODUCTION

The methodology for estimating emissions of several nonmetal air pollutants from a municipal solid waste combustion facility is presented in this appendix. To estimate emissions for any waste composition, emission factors (EFs) for individual components of the waste are required in units of lbs pollutant/ton waste component.

The nonmetal emissions that are addressed here are: carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NOx), acid gases (SO_2, HCl), particulate matter (PM), and Dioxins/Furans (PCDD/F). With the exception of carbon dioxide for which there are no air pollution controls, the nonmetal pollutants are assumed to be controlled to specific concentration levels that are independent of the waste stream composition. For these pollutants, the model user may select from one of three sets of default concentration levels that are shown in Table B-1. The first set of defaults is based on the federal standards for municipal waste combustors per Standards of Performance (1995) for New Municipal Waste Combustors (Subpart Eb). The second and third sets of defaults are based on average performance as observed at new and older facilities, respectively. The remainder of this appendix presents the methodology used to calculate emission factors in units of lbs pollutant/ton waste component.

Table B-1. Default options for emitted concentration levels

Pollutant	Default options			Units[3]
	Standard[1]	Average performance		
		Newer[4]	Older	
CO	100	26	-	ppmv
Dioxins/Furans	13	4.5	-	ng/dscm
PM	24	4.0	-	mg/dscm
SO2	30[2]	8.0	-	ppmv
HCl	25[2]	8.9	-	ppmv
NOx	150	136	-	ppmv

[1]New Standards (1995), Fact Sheet, New Municipal Waste Combustors--Subpart Eb Standards of Performance, EPA, 1995

[2]As the regulation is written, a combustion facility may alternatively be in compliance if uncontrolled emissions are reduced by a specified percentage (80% for SO2, 95% for HCl). Based on personal communication with Walt Stevenson, USEPA, February 1997, we have been advised to use the concentration standard rather than the percent reduction standard.

[3]All concentration levels reported in the table are corrected to 7% O2, dry basis.

[4]Performance data from MWC'S with spray dryer, fabric filter, selective non-catalytic reduction, and carbon injection. Summary of Performance Data from Colleen Kane, USEPA, to Walt Stevenson, USEPA (October 17, 1995).

B2. METHODOLOGY USED TO DETERMINE EMISSION FACTORS

Emissions of CO2 (fossil and biomass derived) are calculated based on a stoichiometric equation for waste combustion. The balanced stoichiometric combustion equation used here is:

Eq. B- 1

$$C_cH_hN_nS_sO_oCl_l + \alpha\left(O_2 + 3.78N_2\right) + wH_2O \rightarrow$$
$$cCO_2 + \left(\frac{h}{2} + w - \frac{l}{2}\right)H_2O + sSO_2 + \left(3.78\alpha + \frac{n}{2}\right)N_2 + \left(\frac{o}{2} + \alpha + \frac{w}{2} - c - \frac{h}{4} - \frac{w}{2} + \frac{l}{4} - s\right)O_2 + lHCl$$

where α is the number of moles of air supplied, w is the number of moles of water and c, h, n, s, n, and l are the number of moles of the elements C, H, N, S, O and Cl in one mole of the combusted fraction of waste. The values of these parameters can be obtained from an ultimate analysis of each of the solid waste components. There are several assumptions associated with using Eq. B- 1 to estimate the amount of flue gas generated by a mole of waste and the amount of the products generated. These are:

1. All fuel bound nitrogen is converted to N_2.
2. All fuel-bound sulfur is converted to SO_2.
3. Ash is inert.
4. The volume of CO and NOx are negligible in the calculation of total flue gas.

From the combustion equation, an emission factor for CO2 can be calculated. This is shown in Section B2.1. The emissions of SO2, HCl, CO, Dioxins/Furans, PM, and NOx, also rely on the stoichiometric analysis, though indirectly. As described in Section B1, the emissions of these pollutants are assumed to be at specific concentration levels. To convert the standards, expressed in concentration units (e.g., mg/dscm), to emission rates, the flow rate of the flue gas must be known. The flue gas flow rate can also be determined from the stoichiometric analysis. The methodology for calculating the emission factors of the pollutants, CO, Dioxins/Furans, PM, and NOx, is discussed in Section B2.2. The development of all emission factors is illustrated by way of an example involving corrugated cardboard.

B2.1 Emission factor for CO_2

This section develops an emission factor for CO2. A 100 gram sample of cardboard is considered for illustration purposes. Table B- 4 shows the results of the calculations at each step for cardboard.

1. Determine the chemical formula for the combusted fraction of cardboard from an ultimate analysis.

Limited data exist on ultimate analyses of solid waste components. The source of the data used in this analysis is Tillman (1991) and Barlaz (1997). Barlaz (1997) estimates of the percent carbon and nitrogen were used in place of those from Tillman (1991). However, the relative proportions of the sulfur, nitrogen, chlorine and oxygen content were taken from Tillman (1991). For the plastics, however, the fractions by weight were determined from the chemical formulas (e.g., HDPE = $(CH_2\text{-}CH_2)n$) and the respective molecular weights (Barlaz (1997)).

Column 2 of Table B- 2 shows the fraction (by weight) of the constituents C, H, O, S, N and Cl in the portion of cardboard that combusts. Table B- 3 shows the elemental fractions by weight, moisture content and uncombusted fraction that were used to calculate emission factors for *all* waste categories. Uncombusted fraction refers to the fraction of moisture-free cardboard that does not combust including nonvolatile solids and volatile solids that do not combust due to inefficiencies in the combustor chamber (see Common process model documentation for derivation of uncombusted fraction).

Table B- 2. Calculation of chemical formula for cardboard from ultimate analysis

	1	*2*	*3*	*4*
	Molecular weight (g/mole)	**Fraction by weight**	**Combusted mass in a 100 g sample of cardboard (as collected)**	**Moles in combusted fraction of the 100 g sample (col. 3/col.1)**
C	12	46.9%	40.1	3.342
H	1	6.6%	5.643	5.643
O	16	46.04%	39.4	2.46
N	14	0.0009%	0.00077	0.000055
Cl	35.5	0.16%	0.13	0.00376
S	32	0.3%	0.26	0.00802
		100.0%	85.5	

Table B- 3. Ultimate analysis for waste components, moisture content and uncombusted fraction

Waste component	Combusted portion							Moisture content	Uncombusted fraction
	C	H	O	N	Cl	S	Total		
Leaves	49.4%	7.0%	41.9%	1.0%	0.3%	0.4%	100.0%	60.0%	11.0%
Grass	45.3%	7.3%	44.0%	2.8%	0.3%	0.4%	100.0%	60.0%	11.0%
Branches	49.4%	7.1%	42.3%	0.5%	0.3%	0.4%	100.0%	60.0%	11.0%
Old Newsprint	49.2%	6.4%	43.9%	0.1%	0.2%	0.3%	100.0%	6.0%	6.5%
Old Corr. Cardboard	46.9%	6.6%	46.0%	0.0%	0.2%	0.3%	100.0%	5.0%	10.0%
Office Paper	40.3%	7.6%	50.7%	0.0%	1.0%	0.3%	100.0%	6.0%	11.1%
Phone Books	49.2%	6.5%	43.1%	0.1%	0.9%	0.3%	100.0%	6.0%	11.1%
Books	46.9%	6.8%	45.0%	0.1%	0.9%	0.3%	100.0%	6.0%	11.1%
Old Magazines	34.3%	8.0%	57.0%	0.1%	0.2%	0.4%	100.0%	6.0%	28.5%
3rd Class Mail	34.3%	8.4%	55.7%	0.1%	1.1%	0.4%	100.0%	6.0%	11.1%
Paper Other #1	40.3%	7.6%	50.6%	0.1%	1.0%	0.3%	100.0%	6.0%	11.1%
Paper Other #2	40.3%	7.6%	50.6%	0.1%	1.0%	0.3%	100.0%	6.0%	6.2%
Paper Other #3	40.3%	7.6%	50.6%	0.1%	1.0%	0.3%	100.0%	6.0%	11.1%
Paper Other #4	40.3%	7.6%	50.6%	0.1%	1.0%	0.3%	100.0%	6.0%	11.1%
Paper Other #5	40.3%	7.6%	50.6%	0.1%	1.0%	0.3%	100.0%	6.0%	11.1%
Paper - Non-recyclable	40.3%	7.6%	50.6%	0.1%	1.0%	0.3%	100.0%	6.0%	11.1%
Food Waste	50.8%	7.1%	35.6%	5.3%	1.1%	0.2%	100.0%	70.0%	9.8%
Ferrous Cans	47.4%	6.3%	45.3%	1.1%	0.0%	0.0%	100.0%	3.0%	100.0%
Ferrous Metal - Other	47.4%	6.3%	45.3%	1.1%	0.0%	0.0%	100.0%	3.0%	100.0%
Ferrous - Non-recyclable	47.4%	6.3%	45.3%	1.1%	0.0%	0.0%	100.0%	3.0%	100.0%
Aluminum Cans	47.4%	6.3%	45.3%	1.1%	0.0%	0.0%	100.0%	2.0%	100.0%
Aluminum - Other #1	47.4%	6.3%	45.3%	1.1%	0.0%	0.0%	100.0%	2.0%	100.0%
Aluminum - Other #2	47.4%	6.3%	45.3%	1.1%	0.0%	0.0%	100.0%	2.0%	100.0%
Al - Non-recyclable	47.4%	6.3%	45.3%	1.1%	0.0%	0.0%	100.0%	2.0%	100.0%
Glass - Clear	45.5%	9.1%	36.4%	9.1%	0.0%	0.0%	100.0%	2.0%	97.0%
Glass - Brown	45.5%	9.1%	36.4%	9.1%	0.0%	0.0%	100.0%	2.0%	97.0%
Glass - Green	45.5%	9.1%	36.4%	9.1%	0.0%	0.0%	100.0%	2.0%	97.0%
Glass - Non-recyclable	45.5%	9.1%	36.4%	9.1%	0.0%	0.0%	100.0%	2.0%	97.0%
HDPE - Translucent	85.7%	14.3%	0.0%	0.0%	0.0%	0.0%	100.0%	2.0%	5.4%
HDPE - Pigmented	85.7%	14.3%	0.0%	0.0%	0.0%	0.0%	100.0%	2.0%	5.4%
PET	62.5%	4.2%	33.3%	0.0%	0.0%	0.0%	100.0%	2.0%	5.4%
Plastic - Other #1	38.4%	4.8%	0.0%	0.0%	56.8%	0.0%	100.0%	2.0%	5.4%
Plastic - Other #2	89.0%	11.0%	0.0%	0.0%	0.0%	0.0%	100.0%	2.0%	5.4%
Plastic - Other #3	89.0%	11.0%	0.0%	0.0%	0.0%	0.0%	100.0%	2.0%	5.4%
Plastic - Other #4	89.0%	11.0%	0.0%	0.0%	0.0%	0.0%	100.0%	2.0%	5.4%
Plastic - Other #5	89.0%	11.0%	0.0%	0.0%	0.0%	0.0%	100.0%	2.0%	5.4%
Plastic - Non-Recyclable	89.0%	11.0%	0.0%	0.0%	0.0%	0.0%	100.0%	2.0%	5.4%
Misc.	51.3%	6.9%	38.4%	0.8%	0.9%	1.5%	100.0%	20.0%	15.0%

According to Table B- 3, 5% of the 100 g cardboard sample, or 5 g, is water. Of the remaining 95 grams, Table B- 3 indicates that 10%, or 9.5 g, will not combust. Therefore, the amount of cardboard that combusts is 95g-9.5g, or 85.5 g. According to the ultimate analysis in Table B- 2, there are 40.1 g of carbon in the combusted portion of the 100 g sample. Column 3 of Table B- 2 shows the mass of the other elements in the combusted portion of the 100 g sample.

The number of moles of C, H, O, N, Cl, and S in the combusted fraction of OCC is simply the grams of each element in the sample divided by the element's molecular weight. For example, there are 40.1/12, or 3.342, moles of carbon per 100 g of wet OCC. The moles of all the elements are shown in column 4 of Table B- 2. Based on Table B- 4, the stoichiometric formula for cardboard, shown generically in Eq. B- 1 as $C_cH_hO_oN_nCl_lS_s$, is $C_{3.342}H_{5.643}O_{2.46}N_{0.000055}\ Cl_{0.00376}S_{0.00802}$. In the 100 g sample there is one mole of $C_{3.342}H_{5.643}O_{2.46}N_{0.000055}\ Cl_{0.00376}S_{0.00802}$.

2. Based on the combustion equation (Eq. B- 1), calculate the moles of CO2 produced from the combustion of the one mole of $C_{3.342}H_{5.643}O_{2.46}N_{0.000055}\ Cl_{0.00376}S_{0.00802}$ that is in the 100 gram sample.

According to Eq. B- 1, for every mole of carbon in the waste, one mole of CO2 is produced since carbon is not a constituent of any of the other gaseous products. The parameter α does not affect the CO2 production. Therefore, one mole of $C_{3.342}H_{5.643}O_{2.46}N_{0.000055}Cl_{0.00376}S_{0.00802}$ results in 3.342 moles CO_2.

Table B- 4. Calculating the cardboard emission factor for CO2

	1	2	3	4
Pollutant	Molecular weight of gas pollutant (g/mole)	Moles pollutant produced/ 100 g sample of cardboard processed	Grams pollutant produced/ 100 g cardboard processed	Emission factor (lbs pollutant emitted/ ton cardboard)
CO2	44	3.342	147.0	2,941

3. Determine the grams of CO_2 that are produced from the combustion of the one mole of $C_{3.07}H_{5.08}O_{2.213}N_{0.008}\ Cl_{0.003}S_{0.00719}$ in the 100 g sample of cardboard.

The grams of CO_2 produced per 100 g of cardboard combusted is simply the number of moles CO_2 produced, 3.342, multiplied by the molecular weight of CO_2, 44 grams/mole. This value is 147.0 grams CO_2 produced per 100 g of cardboard processed. This value can be found in column 3 of Table B- 4.

4. Calculate the emission factor for CO2.

Note that the ratios developed in step 3 are in dimensionless units: grams gas produced per 100 grams processed. These can be easily converted to the desired units, lbs gas produced per ton waste processed. As indicated in step 2, 147.0 grams CO2 is produced per 100 grams cardboard processed. Therefore, 147.0 tons CO2 is produced per 100 tons cardboard processed, or 1.47 tons CO2 is produced per ton cardboard processed. Multiplying by the number of lbs in one ton, 2000, yields an emission factor for CO2. This value is 2,941 lbs CO2 produced per ton of cardboard processed and is shown in column 4 of Table B- 4. The CO2 emission factors for all waste components are shown in Table B- 5.

Table B- 5. Carbon dioxide emission factors by waste component (lbs CO2/ton waste component)

	Carbon dioxide	
	Biomass-derived	Fossil fuel-derived
Leaves	1,290	-
Grass	1,182	-
Branches	1,290	-
Old Newsprint	3,171	-
Old Corr. Cardboard	2,941	-
Office Paper	2,471	-
Phone Books	3,016	-
Books	2,875	-
Old Magazines	1,689	-
3rd Class Mail	2,103	-
Paper Other #1	2,471	-
Paper Other #2	2,605	-
Paper Other #3	2,471	-
Paper Other #4	2,471	-
Paper Other #5	2,471	-
Paper - Non-recyclable	2,471	-
Food Waste	1,009	-
Ferrous Cans	-	-
Ferrous Metal - Other	-	-
Ferrous - Non-recyclable	-	-
Aluminum Cans	-	-
Aluminum - Other #1	-	-
Aluminum - Other #2	-	-
Al - Non-recyclable	-	-
Glass - Clear	99	-
Glass - Brown	99	-
Glass - Green	99	-
Glass - Non-recyclable	99	-
HDPE - Translucent	-	5,828
HDPE - Pigmented	-	5,828
PET	-	4,250
Plastic - Other #1	-	2,611
Plastic - Other #2	-	6,052
Plastic - Other #3	-	6,052
Plastic - Other #4	-	6,052
Plastic - Other #5	-	6,052
Plastic - Non-Recyclable	-	6,052
Misc.	2,559	-

B2.2 Emission factors for SO2, HCl, CO, Dioxins/Furans, PM, and NOx

There are 3 steps required to estimate the emission factors for SO2, HCl, CO, Dioxins/Furans, PM, and NOx. The example below presents the steps for estimating the emission factors assuming concentrations equal to the regulatory limits.

1. From Eq. B- 1, determine an expression for the moles of dry flue gas produced from the processing of 100 grams cardboard.

Referring to Eq. B- 1, the moles of dry flue gas produced, G, is simply the sum of the moles of each of the products excluding the moles of water:

Eq. B- 2

$$G = c + s + \left(3.78\alpha + \frac{n}{2}\right) + \left(\frac{o}{2} + \alpha + \frac{w}{2} - c - \frac{h}{4} - \frac{w}{2} + \frac{l}{4} - s\right) + l$$

Some of these terms cancel out and the expression can be simplified to

Eq. B- 3

$$G = \frac{o}{2} + 4.78\alpha - \frac{h}{4} + \frac{5l}{4} + \frac{n}{2}$$

Plugging in the coefficients from the molecular formula developed in step 1, $C_{3.342}H_{5.643}O_{2.46}N_{0.000055}\,Cl_{0.00376}S_{0.00802}$, the dry moles of flue gas, G, produced from the processing of 100 grams cardboard is found to be

Eq. B- 4

$$G = 4.78\alpha - 0.155$$

Note that the dry moles flue gas is related to the amount of air added to the combustion chamber. The parameter α is related to excess air. Excess air refers to the percent of air supplied in excess of the minimum stoichiometric requirement for combustion of the waste. With reference to Eq. B-1, for a known compound, the stoichiometric requirement of air can be found by solving for the α that results in an oxygen concentration of zero in the flue gas. By definition, the term percent excess air is α divided by the α that corresponds to zero oxygen concentration in the flue gas minus one.

2. Find the number of dry flue gas moles when α is such that the concentration of oxygen in the flue gas is 7%.

The standards listed in Table B-1 were written in such a way that the volume of flue gas is corrected to 7% oxygen (by volume). The amount of excess air, which is related to the parameter α, therefore does not influence the number of dry flue gas moles produced. We can find the α that corresponds to a concentration of 7% oxygen in the dry flue gas. The number of moles of oxygen in the flue gas, G_O, is taken from Eq. B- 1:

Eq. B- 5

$$G_O = \frac{o}{2} + \alpha + \frac{w}{2} - c - \frac{h}{4} - \frac{w}{2} + \frac{l}{4} - s \; = \; \frac{o}{2} + \alpha - c - \frac{h}{4} + \frac{l}{4} - s$$

We require that the percent oxygen in the dry flue gas is 7%, or that:

Eq. B- 6

$$\frac{G_O}{G} = \frac{\frac{o}{2} + \alpha - c - \frac{h}{4} + \frac{l}{4} - s}{\frac{o}{2} + 4.78\alpha - \frac{h}{4} + \frac{5l}{4} + \frac{n}{2}} = 7\%$$

The parameter α that satisfies *Eq. B- 6* is:

Eq. B- 7

$$\alpha = -0.699o + 1.50c + 0.35h - 0.244l + 1.50s + 0.053n$$

Substituting this value of α back into Eq. B- 3 yields the total dry flue gas moles corrected to 7% oxygen:

Eq. B- 8

$$G = -2.84o + 7.184c + 1.42h + 0.083l + 7.184s + 0.751n$$

Substituting for the molecular subscripts of $C_{3.342}H_{5.643}O_{2.46}N_{0.000055}\,Cl_{0.00376}S_{0.00802}$ developed in step 1 for cardboard, *Eq. B- 8* indicates that 25.095 dry flue gas moles (corrected to 7% oxygen) are produced for every 100 g cardboard processed. This can be converted to 0.5621 dscm @ 7% oxygen per 100 g cardboard processed by knowing that at standard conditions a mole occupies 22.4 liters, or 0.0224 cubic meters (0.5621=25.095*0.0224). Knowing that 100g corresponds to 0.00011 tons (100/1000*2.2/2000) leads to the flue gas factor of 5,110 dscm/ton of cardboard processed.

The flue gas production for each waste component is presented in Table B- 6. These are the default values provided in the decision support tool. Note that they are based on the ultimate analysis and moisture content presented in Table B- 3.

Table B- 6. Flue gas production by waste component (dscm @ 7% oxygen/ton waste component)

Leaves	2,336
Grass	2,171
Branches	2,335
Old Newsprint	5,524
Old Corr. Cardboard	5,110
Office Paper	4,436
Phone Books	5,294
Books	5,072
Old Magazines	3,000
3rd Class Mail	3,858
Paper Other #1	4,436
Paper Other #2	4,678
Paper Other #3	4,436
Paper Other #4	4,436
Paper Other #5	4,436
Paper - Non-recyclable	4,436
Food Waste	1,899
Ferrous Cans	-
Ferrous Metal - Other	-
Ferrous - Non-recyclable	-
Aluminum Cans	-
Aluminum - Other #1	-
Aluminum - Other #2	-
Al - Non-recyclable	-
Glass - Clear	207
Glass - Brown	207
Glass - Green	207
Glass - Non-recyclable	207
HDPE - Translucent	13,519
HDPE - Pigmented	13,519
PET	7,064
Plastic - Other #1	5,652
Plastic - Other #2	13,009
Plastic - Other #3	13,009
Plastic - Other #4	13,009
Plastic - Other #5	13,009
Plastic - Non-Recyclable	13,009
Misc.	4,722

3. Calculate the emission factors for SO2, HCl, CO, Dioxins/Furans, PM, and NOx using the results from step 2 and the corresponding standards listed in Table B-1.

For Dioxins/Furans and PM the standard is written as mass per volume on a dry, 7% oxygen basis. The emission factors are simply the standards multiplied by the value of 5,110 dscm flue gas (at 7% oxygen) generated per ton of cardboard processed that was determined in step 3. Some conversions are necessary to achieve the desired units, lbs pollutant emitted per ton of waste component processed.

$$EF_{Dioxins/Furans} = \frac{13ng}{dscm} \cdot \frac{g}{10^9 ng} \cdot \frac{kg}{1000g} \cdot \frac{2.2lb}{kg} \cdot \frac{5{,}110dscm}{ton} = 1.46 \cdot 10^{-7} \frac{lb\_emitted}{ton\_OCC\_processed}$$

$$EF_{PM} = \frac{24mg}{dscm} \cdot \frac{g}{10^3 mg} \cdot \frac{kg}{1000g} \cdot \frac{2.2lb}{kg} \cdot \frac{5{,}110dscm}{ton} = 0.27 \frac{lb\_emitted}{ton\_OCC\_processed}$$

The standards for SO2, HCl, CO and NOx are on a ppmv basis (see Table B-1). Therefore their molecular weights are needed for the determination of emission factors that are calculated as follows:

$$EF_{SO2} = \frac{30dscm\_SO2}{10^6 dscm} \cdot \frac{1000l\_SO2}{dscm\_SO2} \frac{mole\_SO2}{22.4l\_SO2} \frac{64g\_SO2}{mole\_SO2} \cdot \frac{kg}{1000g} \cdot \frac{2.2lb}{kg} \cdot \frac{5{,}110dscm}{ton}$$
$$= 0.96 \frac{lb\_SO2\_emitted}{ton\_OCC\_processed}$$

$$EF_{HCl} = \frac{25dscm\_HCl}{10^6 dscm} \cdot \frac{1000l\_HCl}{dscm\_HCl} \frac{mole\_HCl}{22.4l\_HCl} \frac{36.5g\_HCl}{mole\_HCl} \cdot \frac{kg}{1000g} \cdot \frac{2.2lb}{kg} \cdot \frac{5{,}110dscm}{ton}$$
$$= 0.46 \frac{lb\_HCl\_emitted}{ton\_OCC\_processed}$$

$$EF_{CO} = \frac{100dscm\_CO}{10^6 dscm} \cdot \frac{1000l\_CO}{dscm\_CO} \frac{mole\_CO}{22.4l\_CO} \frac{28g\_CO}{mole\_CO} \cdot \frac{kg}{1000g} \cdot \frac{2.2lb}{kg} \cdot \frac{5{,}110dscm}{ton}$$
$$= 1.41 \frac{lb\_emitted}{ton\_OCC\_processed}$$

$$EF_{NOx} = \frac{150dscm\_NOx}{10^6 dscm} \cdot \frac{1000l\_NOx}{dscm\_NOx} \frac{mole\_NOx}{22.4l\_NOx} \frac{30g\_NOx}{mole\_NOx} \cdot \frac{kg}{1000g} \cdot \frac{2.2lb}{kg} \cdot \frac{5{,}110dscm}{ton}$$
$$= 2.26 \frac{lb\_emitted\_as\_NO}{ton\_OCC\_processed}$$

Table B- 7 lists the CO, Dioxins/Furans, PM, and NOx emission factors for OCC assuming that each pollutant is emitted at the regulatory limit. The emission factors for other waste categories can be found in Table B- 8. If a user wishes to use emission factors representative of the average performance of new facilities, then the values in Table B- 8 should be multiplied by the ratio of the average emission performance (Table B-1), divided by the regulatory standard. These values are presented in Table B-9. Default emission factors based on older facilities will be presented in Table B-10 when such data are available. The user may change these values if desired.

Table B- 7. Cardboard emission factors based on Standards of Performance (1995) for CO, Dioxins/Furans, PM and NOx (lb pollutant emitted/ton cardboard processed)

Pollutant	**Emission factor (lb pollutant emitted/ ton cardboard)**
SO2	0.96
HCl	0.46
Dioxins/Furans	1.46×10^{-7}
PM	0.27
CO	1.41
NOx	2.26

Table B- 8. Emission factors based on emissions at USEPA regulatory limits

	Emission Factors based on Standards of Performance (1995) (lbs pollutant/ton waste component)					
	SO2	HCl	NOx (as NO)	Dioxins / Furans	CO	PM
Leaves	0.440	0.209	1.032	6.68E-08	0.642	0.123
Grass	0.409	0.195	0.960	6.21E-08	0.597	0.115
Branches	0.440	0.209	1.032	6.68E-08	0.642	0.123
Old Newsprint	1.042	0.495	2.441	1.58E-07	1.519	0.292
Old Corr. Cardboard	0.964	0.458	2.259	1.46E-07	1.405	0.270
Office Paper	0.836	0.398	1.960	1.27E-07	1.220	0.234
Phone Books	0.998	0.474	2.340	1.51E-07	1.456	0.280
Books	0.957	0.455	2.242	1.45E-07	1.395	0.268
Old Magazines	0.566	0.269	1.326	8.58E-08	0.825	0.158
3rd Class Mail	0.727	0.346	1.705	1.1E-07	1.061	0.204
Paper Other #1	0.837	0.398	1.961	1.27E-07	1.220	0.234
Paper Other #2	0.882	0.419	2.068	1.34E-07	1.286	0.247
Paper Other #3	0.837	0.398	1.961	1.27E-07	1.220	0.234
Paper Other #4	0.837	0.398	1.961	1.27E-07	1.220	0.234
Paper Other #5	0.837	0.398	1.961	1.27E-07	1.220	0.234
Paper - Non-recyclable	0.837	0.398	1.961	1.27E-07	1.220	0.234
Food Waste	0.358	0.170	0.839	5.43E-08	0.522	0.100
Ferrous Cans	0.000	0.000	0.000	0	0.000	0.000
Ferrous Metal - Other	0.000	0.000	0.000	0	0.000	0.000
Ferrous - Non-recyclable	0.000	0.000	0.000	0	0.000	0.000
Aluminum Cans	0.000	0.000	0.000	0	0.000	0.000
Aluminum - Other #1	0.000	0.000	0.000	0	0.000	0.000
Aluminum - Other #2	0.000	0.000	0.000	0	0.000	0.000
Al - Non-recyclable	0.000	0.000	0.000	0	0.000	0.000
Glass - Clear	0.039	0.019	0.092	5.92E-09	0.057	0.011
Glass - Brown	0.039	0.019	0.092	5.92E-09	0.057	0.011
Glass - Green	0.039	0.019	0.092	5.92E-09	0.057	0.011
Glass - Non-recyclable	0.039	0.019	0.092	5.92E-09	0.057	0.011
HDPE - Translucent	2.549	1.212	5.975	3.87E-07	3.718	0.714
HDPE - Pigmented	2.549	1.212	5.975	3.87E-07	3.718	0.714
PET	1.332	0.633	3.122	2.02E-07	1.943	0.373
Plastic - Other #1	1.066	0.507	2.498	1.62E-07	1.554	0.298
Plastic - Other #2	2.453	1.166	5.750	3.72E-07	3.578	0.687
Plastic - Other #3	2.453	1.166	5.750	3.72E-07	3.578	0.687
Plastic - Other #4	2.453	1.166	5.750	3.72E-07	3.578	0.687
Plastic - Other #5	2.453	1.166	5.750	3.72E-07	3.578	0.687
Plastic - Non-Recyclable	2.453	1.166	5.750	3.72E-07	3.578	0.687
Misc.	0.890	0.423	2.087	1.35E-07	1.299	0.249

Table B- 9. Emission factors based on average performance of new facilities

	Emission Factors based on average performance of new facilities (lbs pollutant/ton waste component)					
	SO2	HCl	NOx (as NO)	Dioxins / Furans	CO	PM
Leaves	0.117	0.075	0.936	2.31E-08	0.167	0.021
Grass	0.109	0.069	0.870	2.15E-08	0.155	0.019
Branches	0.117	0.075	0.936	2.31E-08	0.167	0.021
Old Newsprint	0.278	0.176	2.214	5.47E-08	0.395	0.049
Old Corr. Cardboard	0.257	0.163	2.048	5.06E-08	0.365	0.045
Office Paper	0.223	0.142	1.778	4.39E-08	0.317	0.039
Phone Books	0.266	0.169	2.121	5.24E-08	0.379	0.047
Books	0.255	0.162	2.033	5.02E-08	0.363	0.045
Old Magazines	0.151	0.096	1.202	2.97E-08	0.215	0.026
3rd Class Mail	0.194	0.123	1.546	3.82E-08	0.276	0.034
Paper Other #1	0.223	0.142	1.778	4.39E-08	0.317	0.039
Paper Other #2	0.235	0.149	1.875	4.63E-08	0.334	0.041
Paper Other #3	0.223	0.142	1.778	4.39E-08	0.317	0.039
Paper Other #4	0.223	0.142	1.778	4.39E-08	0.317	0.039
Paper Other #5	0.223	0.142	1.778	4.39E-08	0.317	0.039
Paper - Non-recyclable	0.223	0.142	1.778	4.39E-08	0.317	0.039
Food Waste	0.096	0.061	0.761	1.88E-08	0.136	0.017
Ferrous Cans	0.000	0.000	0.000	0	0.000	0.000
Ferrous Metal - Other	0.000	0.000	0.000	0	0.000	0.000
Ferrous - Non-recyclable	0.000	0.000	0.000	0	0.000	0.000
Aluminum Cans	0.000	0.000	0.000	0	0.000	0.000
Aluminum - Other #1	0.000	0.000	0.000	0	0.000	0.000
Aluminum - Other #2	0.000	0.000	0.000	0	0.000	0.000
Al - Non-recyclable	0.000	0.000	0.000	0	0.000	0.000
Glass - Clear	0.010	0.007	0.083	2.05E-09	0.015	0.002
Glass - Brown	0.010	0.007	0.083	2.05E-09	0.015	0.002
Glass - Green	0.010	0.007	0.083	2.05E-09	0.015	0.002
Glass - Non-recyclable	0.010	0.007	0.083	2.05E-09	0.015	0.002
HDPE - Translucent	0.680	0.431	5.417	1.34E-07	0.967	0.119
HDPE - Pigmented	0.680	0.431	5.417	1.34E-07	0.967	0.119
PET	0.355	0.225	2.831	6.99E-08	0.505	0.062
Plastic - Other #1	0.284	0.180	2.265	5.6E-08	0.404	0.050
Plastic - Other #2	0.654	0.415	5.213	1.29E-07	0.930	0.114
Plastic - Other #3	0.654	0.415	5.213	1.29E-07	0.930	0.114
Plastic - Other #4	0.654	0.415	5.213	1.29E-07	0.930	0.114
Plastic - Other #5	0.654	0.415	5.213	1.29E-07	0.930	0.114
Plastic - Non-Recyclable	0.654	0.415	5.213	1.29E-07	0.930	0.114
Misc.	0.237	0.151	1.892	4.67E-08	0.338	0.042

B3. SUMMARY

Emission factors have been developed for CO_2, SO_2, HCl, CO, Dioxins/Furans, PM, and NOx. A stoichiometric approach was used involving a combustion equation and ultimate analysis of the components of solid waste.

B4. REFERENCES

1. Personal communication, Walt Stevenson, USEPA, February 1997.
2. New Standards (1995), Fact Sheet, New Municipal Waste Combustors--Subpart Eb Standards of Performance, EPA, 1995
3. Code of Federal Regulations, CFR40, Pt.60, App. A, Meth.20, pg 970, July 1, 1990, Protection of Environment.
4. Flagan, R. C., Seinfeld, J. H., Fundamentals of Air Pollution Engineering, Prentice-Hall, Inc., 1988
5. AP-42 (1995), Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources, Fifth Edition, AP-42, January 1995.
6. Tillman, D. A., The Combustion of Solid Fuels & Wastes, Academic Press, San Diego, 1991.
7. Personal communication, Barlaz, M.A, North Carolina State University, June 20, 1997.

Appendix C:

Metals air emissions from municipal waste combustors

C1. INTRODUCTION

This appendix presents a methodology for estimating metals emissions for any mixture of solid waste entering a combustor. Emission factors in units of lbs metal/ton waste component are developed for 12 metals, including As, B, Ba, Cd, Cr, Cu, Hg, Ni, Pb, Sb, Se and Zn. Section 2 briefly discusses alternative approaches that could be used to estimate metals emissions as a function of the waste entering the combustor. Section 3 discusses the approach adopted to estimate emissions from any mixture of waste.

C2. ALTERNATIVE APPROACHES FOR ESTIMATING UNCONTROLLED EMISSION FACTORS

Metals in solid waste can volatilize and be released to the atmosphere when the waste is combusted. The amount of the metal that volatilizes and escapes through the air pollution control equipment is a complex function of how the metal is bound to the waste, the temperatures attained during combustion and other physical and chemical factors. Unfortunately, due to our limited understanding, we are unable to model these processes.

Given that we cannot mechanistically model metals emissions, the next best option would be to use statistical models that associate metal emissions to waste component inputs. The only accepted statistical study that attempts to do this is the *Burnaby report*. Unfortunately, the statistical results contained in the Burnaby report are insufficient for developing a sound approach for estimating metals emissions for any waste mixture.

The limitation of the Burnaby report lies in its experimental design. The study attempted to relate metal emissions to natural day-to-day variation in waste composition. For that waste category for which there was ample day-to-day variation and the actual contribution of metals emissions was sufficiently large, statistical significance was found. However, the variation in waste composition was small for many waste categories. As a result, statistically significant relationships between many waste components and metals could not be demonstrated. The limited statistical information prevented identification of most of the important relationships. The Burnaby study concludes: "Failure to implicate a component does not mean that it is not a significant source. It simply means that either the unidentified component was relatively constant between runs or metals analyses were not done." ("Conclusions", Burnaby final report, Volume II, Section 11, Page 11-14.)

In light of the deficiencies of the Burnaby report for the purpose at hand, it would be wrong to attribute emissions only to the waste components for which statistical significance was found. The remaining options identified include:

Option 1. Assume emissions vary only with the mass, not the composition, of solid waste entering the combustor.

Option 2. Develop metals emission factors based on metals composition of individual waste components. Assume that emissions attributed to a waste component are in proportion to its metals content.

Option 3. For each waste component, develop factors that reflect the relative ability of the metals to be released.

Each of these options has drawbacks. Option 1 is the simplest and probably most common approach used thus far. It assumes that metal emissions per unit of mass of solid waste are the same across waste types, regardless of whether the waste type contains any of that metal. Option 2 is somewhat more sophisticated. However, it assumes that the tendency of a metal to volatilize and escape through the stack is the same regardless of how it is bound to the waste. Option 3 would require much subjective input based on very little evidence.

Option 2 was adopted for the combustion process model. The specific methodology for determining emission factors by waste constituent is described below.

C3. METHODOLOGY FOR CALCULATING METALS EMISSIONS

The basic assumption underlying the methodology proposed here is that the mass emission rate of a metal will be directly proportional to its input to the combustor. The fraction of a metal that volatilizes and escapes through the stack is assumed to be the same across waste categories. The analysis relies on the Burnaby study to develop uncontrolled emission factors for each waste category and for each metal. Information from the Burnaby study is also used to calculate default removal efficiencies. Specifically, the analysis relies on data from Burnaby study, including 1) the metal content for each of 60 waste categories, 2) the total mass feed rate, and 3) emissions monitoring data.

C3.1 Uncontrolled emission factors

The proposed methodology is illustrated here. Consider a 1,000 kg aggregate waste sample. Using office paper and lead as an example, the steps involved in developing the uncontrolled emission factor for each waste category and metal are:

1. Compute the amount of office paper in a 1,000 kg MSW sample using the percent composition data from the Burnaby study.

   The amount of office paper in a 1,000 kg MSW sample is simply the percent composition of office paper taken from Table C-1, 2.69%, multiplied by 1,000 kg. This value is 26.9 kg office paper.

2. Using the lead content data, calculate the amount of the lead input to the incinerator in the form of the waste component.

   Table C-1 indicates that there are 4.5 grams of lead in 1000 kg of office paper. Thus, in the 1000 kg sample of MSW, in which there is 26.9 kg office paper (Step 1), there are 0.121 grams lead bound to office paper (4.5*26.9/1000).

3. Compute the total lead input of the 1000 kg sample.

   Steps 1 and 2 were carried out for the other waste categories. Table C-2 presents the input of the twelve metals by waste category for the 1000 kg sample. The total lead input, shown in the bottom row of Table C-2, was calculated to be 188 grams per 1,000 kg of MSW.

4. Calculate the feed rate of MSW to the Burnaby plant during the study period in units of 1000 kg MSW/min.

   Referring to Table C-3, 3,509 metric tons (metric ton = 1000 kg) MSW was burned during the 5 day test period. This corresponds to a feed rate of 0.487 metric tons per minute (3509/(5*24*60)).

5. Determine the uncontrolled metals emission rate from the flow rate data in Table C-4 and inlet measurements of metals in Table C-5.

   Table C-4 indicates the flow rate (dscm/min) and the percent oxygen and carbon dioxide in the flue gas (measured on a dry basis) for each of the ten Burnaby test runs. For the test runs applicable to lead, runs 2 and 6, the flow rate was 800 and 840 dscm/min. The flow rates as corrected to 11% oxygen are presented in the bottom row of Table C-4. This correction was necessary to express volume in units consistent with those of the inlet metals concentrations reported in Table C-5, dscm @ 11% oxygen. The corrected flow rates for runs 2 and 6 are 824 and 879 dscm/min.

   Table C-5 indicates that for runs 2 and 6, the concentration of lead at the inlet to the air pollution control equipment was 6,260 and 5,060 micrograms metal/dscm @11% oxygen, respectively. The uncontrolled emission rates of lead corresponding to these two runs is calculated as the product of the flow rate and concentration. The uncontrolled lead emission rates corresponding to runs 2 and 6 is 5.16×10^6 and 4.45×10^6 micrograms lead/min (824*6260 and 5060*879). The average uncontrolled lead emission rate is calculated to be 4.80×10^6 micrograms/min ($(5.16 \times 10^6 + 4.45 \times 10^6)/2$). The average uncontrolled emission rates are shown in Table C-5.

6. Calculate uncontrolled lead emissions from the 1,000 kg sample using the uncontrolled lead emission rate calculated in Step 5 and the MSW feed rate calculated in Step 4.

   The uncontrolled emission of lead in the units of micrograms of lead emitted per 1000 kg MSW combusted is the uncontrolled lead emission rate calculated in Step 4, 4.80×10^6 micrograms/min, divided by the MSW feed rate, 0.487 metric tons/min, calculated in Step 5. Thus, for the sample of 1,000 kg, there are 9.86×10^6 micrograms lead emitted/ 1000 kg MSW combusted. The corresponding values for all metals are also shown in Table C-5.

7. Calculate uncontrolled lead emissions per gram of lead input to the incinerator.

   The uncontrolled emissions per gram lead input to the incinerator can be calculated by dividing the grams lead emitted from the 1000 kg sample, 9.86×10^6 micrograms lead emitted/1000 kg MSW combusted (Step 6), by the grams of lead input to the combustor, 188 g Pb/1000 kg MSW (Step 3). This value is 5.25×10^4 micrograms lead in the flue gas prior to the air pollution control equipment per gram lead input to the incinerator. The corresponding values for all metals are also shown in Table C-5.

8. Calculate the lead emissions attributable to the office paper in the sample.

   Multiplying the value of 5.25×10^4 micrograms lead per gram lead input (Step 7) by the amount of lead bound to the office paper in the 1000 kg MSW sample, 0.121 grams lead (Step 2), results in an estimate of 6,353 micrograms lead emitted of uncontrolled Pb emissions from office paper.

9. Calculate the lead emissions per unit mass of office paper. This is the uncontrolled lead emission factor for office paper.

   Dividing the amount of lead emitted that is attributed to the office paper in the 1000 kg sample, 6,353 micrograms lead (Step 8), by the mass of office paper combusted, 26.9 kg (Step 1), leads to an uncontrolled lead emission factor for office paper of 236 micrograms of lead emitted per kg of office paper combusted. Converted to English units, this is 473 lbs lead in uncontrolled flue gas per million tons of office paper combusted. The uncontrolled emission factors for all waste categories and for all other metals are shown in Table C-6.

The uncontrolled emission factors shown in Table C-6 are for the categories as defined in the Burnaby report. For the purposes of this study, factors had to be developed for the categories as defined for use by the management model. In some cases there was a one-to-one correspondence between the categories. For instance, the office paper category in Burnaby maps perfectly to the office paper category in this study. In those cases where there was not a one-to-one correspondence, however, subjective judgment was used and the emission factors were weight-averaged where appropriate. For example, there is only one category for newspaper in this study while newspaper was broken down into three categories in the Burnaby study: glued (0.44%), black & white unglued (4.05%), and colored unglued (1.37%). One uncontrolled emission factor for newspaper was calculated from the weighted average of the three newspaper categories reported in the Burnaby study. The uncontrolled emission factors for the 12 metals (As, B, Ba, Cd, Cr, Cu, Hg, Ni, Pb, Sb, Se and Zn) are presented in Table C-7 for all waste categories as defined by this study.

C3.2 Metals removal efficiencies by air pollution control equipment

Where the fraction of a metal that partitions to the flue gas is based on the Burnaby study, the default air pollution control efficiencies are not. Two sets of default removal efficiencies are supplied. The first set consists of average removal efficiencies observed at *new* facilities while the second set consists of average removal efficiencies observed at *older* facilities. The default removal efficiencies are presented in Table C-8.

C3.3 Calculating controlled emission factors for a given waste mix

Controlled emission factors for any waste mix can be estimated from the uncontrolled emission factors and metal removal efficiencies developed above. Controlled emissions for lead, for example, are calculated as follows:

Eq. C- 1

$$Lead\_emissions = \sum_i TPD_i \cdot Uncontrolled\_EF_{Pb,i} \cdot \left(1 - Removal\_efficiency_{Pb}\right)$$

where *Lead_emissions* is the daily lead emissions from the combustor, TPD_i is the tons per day of waste component i being combusted, $Uncontrolled\_EF_{Pb,\,i}$ is the lead emission factor for waste component i, and $Removal\_efficiency_{Pb}$, is the removal efficiency of lead.

C3.4 Consideration of regulatory limits

It is possible that the application of the methodology proposed above will lead to an estimate of controlled emissions that violates an emission standard. This only applies to the three regulated metals, cadmium, mercury and lead. Metals standards of performance for new municipal waste combustors are presented in Table C-9. To investigate whether this may happen, we have considered different plausible waste mixes based on the emission factors listed in Table C- 7 and removal efficiencies in Table C-8.

The results of this analysis indicate that the violation of the lead, cadmium and mercury emissions is unlikely given either set of default removal efficiencies. Nevertheless, in the decision support tool the user will be alerted to any violation of the standard based on this methodology. Testing to see if the standard is violated requires determining if the mass emission rates exceed those corresponding to the standards, expressed as mg/dscm. The calculations required are similar to the treatment of particulate matter (PM) in Appendix B, “Nonmetal air emissions from municipal solid waste

C4. REFERENCES

[1]A.J. Chandler & Associates Ltd., Compass Environmental Inc., Rigo & Rigo Associates, Inc., The Environmental Research Group-University of New Hampshire, Wastewater Technology Centre. *Waste Analysis, Sampling, Testing and Evaluation (WASTE) Program: Effect of Waste Stream Characteristics on MSW Incineration: The Fate and Behaviour of Metals. The Final Report of the Mass Burn MSW Incineration Study (Burnaby, B.C.). Volume II. Technical Report***.** April 1993.

Table C- 1. Burnaby waste characterization and metals content (g metal/ 1000 kg waste component) for 60 waste categories and 12 metals

Group	Major category	Minor category		Fraction of MSW	As	B	Ba	Cd
Paper	**fine/ comp/ office**			2.690%	1.3	2.2	7.7	0.1
	books			0.300%	0.4	37.6	62.6	0.4
	magazines	**glued**		1.010%	1.1	2.5	24.2	0.001
		not glued		0.920%	1.8	7.6	36.9	0.3
	laminates	**wax/ plastic**		1.600%	0.7	3.7	22.3	0.3
		foil		0.250%	0.8	15.4	25.1	0.1
	newsprint	**glued**		0.440%	0.8	6.1	9.3	0.1
		notglued	**b&w**	4.050%	0.7	6.9	18.4	0.1
			color	1.370%	0.6	16.5	23.2	0.1
	browns	**corrugate**		7.400%	0.6	3.1	6.3	0.1
		kraft		1.980%	0.8	4.7	11.3	0.1
		box board		1.260%	0.7	6	31	0.2
	residual mixed			14.500%	1.2	6.6	14.3	1.7
Plastic	**film**	**color**		2.990%	0.5	13.7	169.8	6.6
		flexible		2.560%	0.7	29.7	11	2.8
		rigid		0.420%	0.3	5.4	128.5	37.2
	food/ beverage/ household	**1 (PET)**		0.080%	0.8	193.5	8	5.3
		2 (HDPE)		0.300%	0.5	29.4	83.5	2.9
		3 (PVC)		0.020%	0	7.2	0	4.5
		4 (LDPE)		0.010%	0.2	12	5	2.5
		5 (PP)		0.060%	0.5	5.3	1.5	1.9
		6 (PS)		0.020%	0.2	3.9	3.4	4.7
		nonident		0.860%	1.2	20	117.9	79.3
	housewares	**clear**		0.070%	0.1	0.5	18.5	0.9
		white		0.340%	0.2	7.1	8.5	2.5
		blue		0.070%	3.1	16.9	565	289.7
		yellow		0.100%	0.3	8.1	227.1	104.8
		other		0.840%	0.3	5.9	168.1	100.9
	toys and other			0.430%	0.5	9.5	83.1	75.8
	video tape/ film			0.010%	14.3	64.7	27.4	2195

Source: Table 9-5 of Burnaby report

Table C-1. Burnaby waste characterization and metals content (g metal/ 1000 kg waste component) for 60 waste categories and 12 metals, Continued

Group	Major category	Minor category		Fraction of MSW	As	B	Ba	Cd
Organics	**yard & garden**	**lawn/ plant**		11.230%	7.3	527.1	132.8	6
		branches		2.890%	0.9	22.5	54.2	1.1
	food waste	**organic**		6.060%	1.2	328.7	17.4	2
	wood	**finished**		3.540%	5.1	14.6	46.3	1.1
		unfinished		4.650%	34	20.9	27.9	0.04
	textiles			4.440%	0.4	6.9	23	2.8
	footwear			0.930%	0.7	5.6	91.9	11.9
Metals	**ferrous**	**beer**		0.050%	8.8	125.6	43	61.9
		soft drink		0.030%	8.8	125.6	43	61.9
		food		1.090%	7	161	1.7	43.1
		band & strap		0.180%	40	372	2.2	15
		elect motor		1.930%	9480	98	1274	9.1
	non-ferrous	**beer**		0.070%	0.2	9	67	3
		soft drink		0.110%	0.4	19.7	157.7	6
		food		0.160%	7215	17.2	10.3	1.7
		manufactured		0.520%	199	20	34	5.6
		foil/ pack		0.210%	0.8	15	27	51
		other		0.050%	8389	20	12	2
Glass	**combined**	**clear**		1.450%	1	88.8	340.8	4.8
		green		0.230%	9.8	44.6	486.6	0.3
		brown		0.210%	6.9	29.2	190.7	1.7
		other colour		0.040%	0.4	21.5	784.7	5.4
Inorganic	**light construction**	**rock/ sand/ dirt/ concrete/ ceramic**		0.960%	6	2850	807.8	20
		drywall/ plaster		0.100%	0.6	288	31	2
		insulation	**fglass**	0.004%	0.7	53.6	296.7	0.05
		other		0.700%	17.1	13.2	61.1	0.4
Small appliances	**electrical parts**	**plastic**		0.580%	777.1	11.8	1.4	3.6
Household hazardous	**batteries**	**carbon**		0.050%	2.8	18	14	31
		ni-cad		0.004%	4.4	70	12	120000
		alkaline		0.040%	1	59	7.6	1940
Fines				7.830%	6.6	45.5	48	4.4
Total[a]				97.3%				

Source: Table 9-5 of Burnaby report. Notes:
a)Sum of Fraction of MSW does not sum to 100% due to rounding error

Table C-1. Burnaby waste characterization and metals content (g metal/ 1000 kg waste component) for 60 waste categories and 12 metals, Continued

Group	Major category	Minor category		Cr	Cu	Hg	Ni
Paper	fine/ comp/ office			3.4	8	0.3	7.9
	books			8.7	40	0.2	1.4
	magazines	glued		16.6	26	0.3	17.6
		not glued		5.8	37	0.3	8.2
	laminates	wax/ plastic		3.2	7	0.1	5.4
		foil		44.6	226	0.1	8.7
	newsprint	glued		1.3	10	0.3	4.3
		notglued	b&w	3.8	13	2.9	6.2
			color	215.1	36	0.3	106.5
	browns	corrugate		1.8	3	0.1	3.8
		kraft		4.7	11	0.5	7.7
		box board		5.4	12	0.2	6.8
	residual mixed			33	24	0.4	7.5
Plastic	film	color		115.1	25	0.2	8
		flexible		83	20	0.2	5.9
		rigid		119.6	75	0.1	27.2
	food/ beverage/ household	1 (PET)		16.7	31	0.2	8.3
		2 (HDPE)		15	24	0.2	7
		3 (PVC)		2.6	2	0.1	2.6
		4 (LDPE)		4.7	10	0.1	4.2
		5 (PP)		31.6	16	0.1	6
		6 (PS)		7.1	9	0.1	5.7
		nonident		44.1	57	0.4	38.2
	houseware s	clear		6.4	7	0.1	15.6
		white		595.2	44	0.2	146.4
		blue		8.7	80	0.1	16.3
		yellow		1287	17	0.1	9
		other		359.3	29	0.3	2.8
	toys and other			229.1	98	0.1	27.7
	video tape/ film			94	38	0.2	17.6

Source: Table 9-5 of Burnaby report

Table C-1. Burnaby waste characterization and metals content (g metal/ 1000 kg waste component) for 60 waste categories and 12 metals, Continued

Group	Major category	Minor category		Cr	Cu	Hg	Ni
Organics	yard & garden	lawn/ plant		101.3	690	1.4	23.6
		branches		24.1	45	0.4	10.8
	food waste	organic		22.6	43	0.3	4.8
	wood	finished		113	109	0.2	8.3
		unfinished		58.1	46	0.4	0.8
	textiles			440.1	67	1.1	0.8
	footwear			1831	25	0.1	5.5
Metals	ferrous	beer		302.7	323	36.4	166
		soft drink		302.7	323	36.4	166
		food		188.8	99	5.6	160.4
		band & strap		492	119	0.02	41.7
		elect motor		289.1	744800	5.4	38.9
	non-ferrous	beer		95	1141	0.3	27.9
		soft drink		89.3	1094	0.4	19.1
		food		172	645	0.2	34.1
		manufactured		1354	194	0.2	7.2
		foil/ pack		134.3	279	0.8	40.4
		other		200	750	0.2	0
Glass	combined	clear		28	22	0.2	10.14
		green		943	6	0.1	62.7
		brown		46.2	92	0.6	22.8
		other colour		91.5	29	0.1	12.5
Inorganic	light construction	rock/ sand/ dirt/ concrete/ ceramic		167	134	0.3	155.8
		drywall/ plaster		8.6	7	0.3	4.2
		insulation	fglass	14.1	48	1.1	8.2
		other		34	112	0.1	23.5
Small appliances	electrical parts	plastic		251.3	915	0.1	4.4
Household hazardous	batteries	carbon		39	140	20.5	278
		ni-cad		64	53	0.3	315
		alkaline		74	12000	242	726
Fines				115	243	1.4	53.6

Source: Table 9-5 of Burnaby report

Table C-1. Burnaby waste characterization and metals content (g metal/ 1000 kg waste component) for 60 waste categories and 12 metals, Continued

Group	Major category	Minor category		Pb	Sb	Se	Zn
Paper	fine/ comp/ office			4.5	2.3	0.25	208
	books			0.005	0.03	0.13	88
	magazines	glued		0.4	1.6	0.08	36
		not glued		5.9	98.9	0.13	18
	laminates	wax/ plastic		7.1	3.7	0.05	16
		foil		92.3	20.2	0.02	119
	newsprint	glued		2.4	1.2	0.11	8
		notglued	b&w	7.2	2.5	0.11	19
			color	5.7	1.8	0.07	29
	browns	corrugate		3.8	1.5	0.04	10
		kraft		9.3	1.6	0.05	22
		box board		12	2.8	0.04	29
	residual mixed			229.4	5	0.03	81
Plastic	film	color		361.5	27.2	0.01	1132
		flexible		279.3	10.7	0.02	67
		rigid		33.7	17.1	0.04	52
	food/ beverage/ household	1 (PET)		61.5	174.1	0.05	97
		2 (HDPE)		60.6	52	0.05	142
		3 (PVC)		2160	29700	0.005	3
		4 (LDPE)		56	16	0.03	89
		5 (PP)		69.3	51.2	0.03	40
		6 (PS)		25	44	0.02	98
		nonident		157.7	101.3	0.15	273
	housewares	clear		61.7	24.3	0.02	108
		white		41.8	24.9	0.02	129
		blue		64.3	90.3	0.03	76
		yellow		2479	62.9	0.08	277
		other		647.3	254.7	0.22	199
	toys and other			102.6	93.4	0.03	349
	video tape/ film			882	211.7	0.02	774

Source: Table 9-5 of Burnaby report

Table C-1. Burnaby waste characterization and metals content (g metal/ 1000 kg waste component) for 60 waste categories and 12 metals, Continued

Group	Major category	Minor category		Pb	Sb	Se	Zn
Organics	yard & garden	lawn/ plant		153.6	52.2	0.07	365
		branches		61.9	7.8	0.04	124
	food waste	organic		72	12.8	0.05	186
	wood	finished		562.9	1.2	0.02	117
		unfinished		324.3	0.5	0.01	205
	textiles			126.2	96.4	0.03	142
	footwear			133.8	4	0.03	764
Metals	ferrous	beer		230.5	68.8	0.06	886
		soft drink		230.5	68.8	0.06	886
		food		344.3	88.2	0.04	4566
		band & strap		596	163	0.09	30
		elect motor		609.6	74.5	20.58	7332
	non-ferrous	beer		68	20	0.01	170
		soft drink		32.3	18	0.01	248
		food		95.5	25.8	16.34	445
		manufactured		94	23	5	400000
		foil/ pack		0.004	0.03	0.01	120
		other		111	30	19	518
Glass	combined	clear		109.3	144.7	0.77	60
		green		20	36.5	0.06	21
		brown		103.1	25.4	0.48	251
		other colour		90	154.3	0.16	1671
Inorganic	light construction	rock/ sand/ dirt/ concrete/ ceramic		1545	200.4	0.79	5118
		drywall/ plaster		38	38	0.2	21
		insulation	fglass	40.8	5.2	0.03	12
		other		30.1	0.8	0.003	57
Small appliances	electrical parts	plastic		662.3	4802	3045	63
Household hazardous	batteries	carbon		40	23	0.04	63000
		ni-cad		113	670	0.11	685
		alkaline		143	60	0.02	140000
Fines				258.5	45	0.13	854

Source: Table 9-5 of Burnaby report

Table C- 2. Metals input by waste category (g metal input/1000 kg MSW)[a]

Organics	**yard & garden**	**lawn/ plant**		0.820	59.193	14.913	0.674
		branches		0.026	0.650	1.566	0.032
	food waste	**organic**		0.073	19.919	1.054	0.121
	wood	**finished**		0.181	0.517	1.639	0.039
		unfinished		1.581	0.972	1.297	0.002
	textiles			0.018	0.306	1.021	0.124
	footwear			0.007	0.052	0.855	0.111
Metals	**ferrous**	**beer**		0.004	0.063	0.022	0.031
		soft drink		0.003	0.038	0.013	0.019
		food		0.076	1.755	0.019	0.470
		band & strap		0.072	0.670	0.004	0.027
		elect motor		182.96	1.891	24.588	0.176
	non-ferrous	**beer**		0.000	0.006	0.047	0.002
		soft drink		0.000	0.022	0.173	0.007
		food		11.544	0.028	0.016	0.003
		manufactured		1.035	0.104	0.177	0.029
		foil/ pack		0.002	0.032	0.057	0.107
		other		4.195	0.010	0.006	0.001
Glass	**combined**	**clear**		0.015	1.288	4.942	0.070
		green		0.023	0.103	1.119	0.001
		brown		0.014	0.061	0.400	0.004
		other colour		0.000	0.009	0.314	0.002
Inorganic	**light construction**	**rock/ sand/ dirt/ concrete/ ceramic**		0.058	27.360	7.755	0.192
		drywall/ plaster		0.001	0.288	0.031	0.002
		insulation	**fglass**	0.000	0.002	0.012	0.000
		other		0.120	0.092	0.428	0.003
Small appliances	**electrical parts**	**plastic**		4.507	0.068	0.008	0.021
Household hazardous	**batteries**	**carbon**		0.001	0.009	0.007	0.016
		ni-cad		0.000	0.003	0.000	4.800
		alkaline		0.000	0.024	0.003	0.776
Fines				0.517	3.563	3.758	0.345

a. Calculated from composition and metals content data from Table C-1. Ex: In a 1000 kg MSW sample, there is (2.69%*1000), or 26.9 kg office paper, in which there is 1.3 g As/1000 kg office paper. There is 0.0013*26.9, or 0.035 g As per 1000 kg MSW.

Table C- 2. Metals input by waste category (g metal input/1000 kg MSW)[a], Continued

Group	Major category	Minor category		As	B	Ba	Cd
Organics	yard & garden	lawn/ plant		0.820	59.193	14.913	0.674
		branches		0.026	0.650	1.566	0.032
	food waste	organic		0.073	19.919	1.054	0.121
	wood	finished		0.181	0.517	1.639	0.039
		unfinished		1.581	0.972	1.297	0.002
	textiles			0.018	0.306	1.021	0.124
	footwear			0.007	0.052	0.855	0.111
Metals	ferrous	beer		0.004	0.063	0.022	0.031
		soft drink		0.003	0.038	0.013	0.019
		food		0.076	1.755	0.019	0.470
		band & strap		0.072	0.670	0.004	0.027
		elect motor		182.96	1.891	24.588	0.176
	non-ferrous	beer		0.000	0.006	0.047	0.002
		soft drink		0.000	0.022	0.173	0.007
		food		11.544	0.028	0.016	0.003
		manufactured		1.035	0.104	0.177	0.029
		foil/ pack		0.002	0.032	0.057	0.107
		other		4.195	0.010	0.006	0.001
Glass	combined	clear		0.015	1.288	4.942	0.070
		green		0.023	0.103	1.119	0.001
		brown		0.014	0.061	0.400	0.004
		other colour		0.000	0.009	0.314	0.002
Inorganic	light construction	rock/ sand/ dirt/ concrete/ ceramic		0.058	27.360	7.755	0.192
		drywall/ plaster		0.001	0.288	0.031	0.002
		insulation	fglass	0.000	0.002	0.012	0.000
		other		0.120	0.092	0.428	0.003
Small appliances	electrical parts	plastic		4.507	0.068	0.008	0.021
Household hazardous	batteries	carbon		0.001	0.009	0.007	0.016
		ni-cad		0.000	0.003	0.000	4.800
		alkaline		0.000	0.024	0.003	0.776
Fines				0.517	3.563	3.758	0.345
Total metals input (g metal input / 1000 kg MSW)				**208**	**123**	**82**	**11**

(a). Calculated from composition and metals content data from Table C-1. Ex: In a 1000 kg MSW sample, there is (2.69%*1000), or 26.9 kg office paper, in which there is 1.3 g As/1000 kg office paper. There is 0.0013*26.9, or 0.035 g As per 1000 kg MSW.

Table C- 2. Metals input by waste category (g metal input/1000 kg MSW)[a], Continued

Group	Major category	Minor category		Cr	Cu	Hg	Ni
Paper	fine/ comp/ office			0.091	0.215	0.008	0.213
	books			0.026	0.120	0.001	0.004
	magazines	glued		0.168	0.263	0.003	0.178
		not glued		0.053	0.340	0.003	0.075
	laminates	wax/ plastic		0.051	0.112	0.002	0.086
		foil		0.112	0.565	0.000	0.022
	newsprint	glued		0.006	0.044	0.001	0.019
		notglued	b&w	0.154	0.527	0.117	0.251
			color	2.947	0.493	0.004	1.459
	browns	corrugate		0.133	0.222	0.007	0.281
		kraft		0.093	0.218	0.010	0.152
		box board		0.068	0.151	0.003	0.086
	residual mixed			4.785	3.480	0.058	1.088
Plastic	film	color		3.441	0.748	0.006	0.239
		flexible		2.125	0.512	0.005	0.151
		rigid		0.502	0.315	0.000	0.114
	food/ beverage/ household	1 (PET)		0.013	0.025	0.000	0.007
		2 (HDPE)		0.045	0.072	0.001	0.021
		3 (PVC)		0.001	0.000	0.000	0.001
		4 (LDPE)		0.000	0.001	0.000	0.000
		5 (PP)		0.019	0.010	0.000	0.004
		6 (PS)		0.001	0.002	0.000	0.001
		nonident		0.379	0.490	0.003	0.329
	houseware s	clear		0.004	0.005	0.000	0.011
		white		2.024	0.150	0.001	0.498
		blue		0.006	0.056	0.000	0.011
		yellow		1.287	0.017	0.000	0.009
		other		3.018	0.244	0.003	0.024
	toys and other			0.985	0.421	0.000	0.119
	video tape/ film			0.009	0.004	0.000	0.002

(a) Calculated from composition and metals content data from Table C-1. Ex: In a 1000 kg MSW sample, there is (2.69%*1000), or 26.9 kg office paper, in which there is 1.3 g As/1000 kg office paper. There is 0.0013*26.9, or 0.035 g As per 1000 kg MSW.

Table C- 2. Metals input by waste category (g metal input/1000 kg MSW)[a], Continued

Group	Major category	Minor category		Cr	Cu	Hg	Ni
Organics	yard & garden	lawn/ plant		11.376	77.487	0.157	2.650
		branches		0.696	1.301	0.012	0.312
	food waste	organic		1.370	2.606	0.018	0.291
	wood	finished		4.000	3.859	0.007	0.294
		unfinished		2.702	2.139	0.019	0.037
	textiles			19.540	2.975	0.049	0.036
	footwear			17.028	0.233	0.001	0.051
Metals	ferrous	beer		0.151	0.162	0.018	0.083
		soft drink		0.091	0.097	0.011	0.050
		food		2.058	1.079	0.061	1.748
		band & strap		0.886	0.214	0.000	0.075
		elect motor		5.580	14,375	0.104	0.751
	non-ferrous	beer		0.067	0.799	0.000	0.020
		soft drink		0.098	1.203	0.000	0.021
		food		0.275	1.032	0.000	0.055
		manufactured		7.041	1.009	0.001	0.037
		foil/ pack		0.282	0.586	0.002	0.085
		other		0.100	0.375	0.000	-
Glass	combined	clear		0.406	0.319	0.003	0.147
		green		2.169	0.014	0.000	0.144
		brown		0.097	0.193	0.001	0.048
		other colour		0.037	0.012	0.000	0.005
Inorganic	light construction	rock/ sand/ dirt/ concrete/ ceramic		1.603	1.286	0.003	1.496
		drywall/ plaster		0.009	0.007	0.000	0.004
		insulation	fglass	0.001	0.002	0.000	0.000
		other		0.238	0.784	0.001	0.165
Small appliances	electrical parts	plastic		1.458	5.307	0.001	0.026
Household hazardous	batteries	carbon		0.020	0.070	0.010	0.139
		ni-cad		0.003	0.002	0.000	0.013
		alkaline		0.030	4.800	0.097	0.290
Fines				9.005	19.027	0.110	4.197
Total metals input (g metal input / 1000 kg MSW)				**111**	**14,513**	**0.9**	**19**

Calculated from composition and metals content data from Table C-1. Ex: In a 1000 kg MSW sample, there is (2.69%*1000), or 26.9 kg office paper, in which there is 1.3 g As/1000 kg office paper. There is 0.0013*26.9, or 0.035 g As per 1000 kg MSW.

Table C- 2. Metals input by waste category (g metal input/1000 kg MSW)[a], Continued

Group	Major category	Minor category		Pb	Sb	Se	Zn
Paper	fine/ comp/ office			0.121	0.062	0.007	5.595
	books			0.000	0.000	0.000	0.264
	magazines	glued		0.004	0.016	0.001	0.364
		not glued		0.054	0.910	0.001	0.166
	laminates	wax/ plastic		0.114	0.059	0.001	0.256
		foil		0.231	0.051	0.000	0.298
	newsprint	glued		0.011	0.005	0.000	0.035
		notglued	b&w	0.292	0.101	0.004	0.770
			color	0.078	0.025	0.001	0.397
	browns	corrugate		0.281	0.111	0.003	0.740
		kraft		0.184	0.032	0.001	0.436
		box board		0.151	0.035	0.001	0.365
	residual mixed			33.263	0.725	0.004	11.745
Plastic	film	color		10.809	0.813	0.000	33.847
		flexible		7.150	0.274	0.001	1.715
		rigid		0.142	0.072	0.000	0.218
	food/ beverage/ household	1 (PET)		0.049	0.139	0.000	0.078
		2 (HDPE)		0.182	0.156	0.000	0.426
		3 (PVC)		0.432	5.940	0.000	0.001
		4 (LDPE)		0.006	0.002	0.000	0.009
		5 (PP)		0.042	0.031	0.000	0.024
		6 (PS)		0.005	0.009	0.000	0.020
		nonident		1.356	0.871	0.001	2.348
	houseware s	clear		0.043	0.017	0.000	0.076
		white		0.142	0.085	0.000	0.439
		blue		0.045	0.063	0.000	0.053
		yellow		2.479	0.063	0.000	0.277
		other		5.437	2.139	0.002	1.672
	toys and other			0.441	0.402	0.000	1.501
	video tape/ film			0.088	0.021	0.000	0.077

Calculated from composition and metals content data from Table C-1. Ex: In a 1000 kg MSW sample, there is (2.69%*1000), or 26.9 kg office paper, in which there is 1.3 g As/1000 kg office paper. There is 0.0013*26.9, or 0.035 g As per 1000 kg MSW.

Table C- 2. Metals input by waste category (g metal input/1000 kg MSW)[a], Continued

Group	Major category	Minor category		Pb	Sb	Se	Zn
Organics	yard & garden	lawn/ plant		17.249	5.862	0.008	40.990
		branches		1.789	0.225	0.001	3.584
	food waste	organic		4.363	0.776	0.003	11.272
	wood	finished		19.927	0.042	0.001	4.142
		unfinished		15.080	0.023	0.000	9.533
	textiles			5.603	4.280	0.001	6.305
	footwear			1.244	0.037	0.000	7.105
Metals	ferrous	beer		0.115	0.034	0.000	0.443
		soft drink		0.069	0.021	0.000	0.266
		food		3.753	0.961	0.000	49.769
		band & strap		1.073	0.293	0.000	0.054
		elect motor		11.765	1.438	0.397	141.51
	non-ferrous	beer		0.048	0.014	0.000	0.119
		soft drink		0.036	0.020	0.000	0.273
		food		0.153	0.041	0.026	0.712
		manufactu red		0.489	0.120	0.026	2,080
		foil/ pack		0.000	0.000	0.000	0.252
		other		0.056	0.015	0.010	0.259
Glass	combined	clear		1.585	2.098	0.011	0.870
		green		0.046	0.084	0.000	0.048
		brown		0.217	0.053	0.001	0.527
		other colour		0.036	0.062	0.000	0.668
Inorganic	light constructi on	rock/ sand/ dirt/ concrete/ ceramic		14.832	1.924	0.008	49.133
		drywall/ plaster		0.038	0.038	0.000	0.021
		insulation	fglass	0.002	0.000	0.000	0.000
		other		0.211	0.006	0.000	0.399
Small appliances	electrical parts	plastic		3.841	27.852	17.661	0.365
Household hazardous	batteries	carbon		0.020	0.012	0.000	31.500
		ni-cad		0.005	0.027	0.000	0.027
		alkaline		0.057	0.024	0.000	56.000
Fines				20.241	3.524	0.010	66.868
Total metals input (g metal input / 1000 kg MSW)				**188**	**63**	**18**	**2,627**

(a). Calculated from composition and metals content data from Table C-1. Ex: In a 1000 kg MSW sample, there is (2.69%*1000), or 26.9 kg office paper, in which there is 1.3 g As/1000 kg office paper. There is 0.0013*26.9, or 0.035 g As per 1000 kg MSW.

Table C- 3. Feed rate during Burnaby study period

3,509	1000 kg burned during test period of five days
0.487	1000 kg/min burned

Source: Table 2.2 of Burnaby Final Report

Table C- 4. Flow measurements at the inlet to the air pollution control equipment during Burnaby testing.

Test # -->	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Flow rate (dscm/min)	#N/A	800	#N/A	850	#N/A	840	#N/A	740	#N/A	830
% O2 on dry basis	#N/A	10.6	#N/A	11.1	#N/A	10.4	#N/A	10.4	#N/A	10.8
%CO2 on dry basis	#N/A	9.9	#N/A	8.8	#N/A	9.6	#N/A	9.8	#N/A	9.3
Flow adjust factor[a]	#N/A	1.030	#N/A	0.993	#N/A	1.047	#N/A	1.046	#N/A	1.015
Flow adjusted to 11% oxygen (dscm/min)	#N/A	824	#N/A	844	#N/A	879	#N/A	774	#N/A	842

Source: Table 5, pg. 15 of Emission Survey Monitoring Report, Vol. IV, Sect. 4 of Burnaby report

(a). $Flow\_adjustment\_factor = [N_2]\frac{0.11}{[O_2]} + 0.11 + [CO_2]\left(\frac{0.209 - 0.11}{0.209 - [O_2]}\right)$

where

$[N_2] = 1 - [O_2] - [CO_2]$

Notes: #N/A = not applicable; measurement not taken

Table C- 5. Inlet metals concentrations, uncontrolled emission rates (micrograms metal/min), uncontrolled emissions (micrograms/1000 kg MSW), and uncontrolled emission fraction (micrograms metal emitted/g metal input)

	Inlet metals concentration (micrograms/dscm @ 11% oxygen)a										Un-controlled emission rate[b] (micro-grams/min)	Un-controlled emissions[c] (micro-grams/ 1000 kg MSW burned)	Un-controlled emission fraction[d] (micro-grams metal emitted/g metal input)
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**			
As	N/A	270	N/A	130	N/A	130	N/A	N/A	N/A	320	179,018	367,322	1,764
B	N/A	820	N/A	930	N/A	860	N/A	N/A	N/A	820	726,847	1,491,393	12,115
Ba	N/A	6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	4,615	9,470	116
Cd	N/A	710	N/A	900	N/A	N/A	N/A	N/A	N/A	N/A	672,265	1,379,398	121,941
Cr	N/A	260	N/A	350	N/A	550	N/A	N/A	N/A	210	292,516	600,203	5,409
Cu	N/A	2,310	N/A	1,800	N/A	1,620	N/A	N/A	N/A	1,440	1,514,978	3,108,532	214
Hg	N/A	N/A	N/A	N/A	200	470	340	610	N/A	N/A	221,397	454,277	492,194
Ni	N/A	130	N/A	200	N/A	310	N/A	N/A	N/A	83	154,591	317,200	16,942
Pb	N/A	6,260	N/A	N/A	N/A	5,060	N/A	N/A	N/A	N/A	4,803,888	9,856,938	52,550
Sb	N/A	194	N/A	139	N/A	110	N/A	N/A	N/A	200	135,590	278,213	4,407
Se	N/A	26	N/A	10	N/A	13	N/A	N/A	N/A	30	16,642	34,147	1,877
Zn	N/A	39,900	N/A	31,000	N/A	34,000	N/A	N/A	N/A	35,400	29,688,491	60,916,824	23,187

Source for inlet metals concentrations: For Hg: Table 4 Hg Summary (mg/dscm @ 11% O2), pg. 14 of Emission Survey Monitoring Report, Vol. IV, Sect. 4 of Burnaby report. For all other metals: Table 3 Multimetal Stack Metal Concentrations (micrograms/dscm @ 11% O2), pg. 13 of Emission Survey Monitoring Report, Vol. IV, Sect. 4 of Burnaby report.

Notes:
N/A = not applicable. The measurement was not taken or metal spiking precluded use of the value for estimating emissions from normal plant operations.
(a) The metals concentrations for all but mercury were measured by the multimetals method. The multimetals approach was stated to seriously underestimate emission concentrations for mercury (p. 21 of reference). EPA method 101a was performed in the Burnaby study only for measuring concentrations in the stack, not the inlet. Here the KfK method is reported which was stated to yield similar results as the EPA method. Therefore inlet mercury concentrations as measured by the KfK method are reported in this table.
(b) Average of the products of the inlet metals concentration (micrograms/dscm) and adjusted inlet flow rates (dscm/min) from Table C-4. For As: Average of (270*824,130*844,130*879,320*842)=179,018 micrograms As/min
(c) Uncontrolled emission rate (micrograms/min) divided by the feed rate 0.487 metric tons burned/min (from Table C-3). For As: 179,018/0.487 = 367,322 micrograms As/1000 kg MSW.
(d) Uncontrolled emissions (micrograms/1000 kg MSW) divided by the total metals input (g metal input/1000 kg MSW) from Table C-2. For As: 367,322/208 = 1,764 micrograms As/g As input.

Table C- 6. Uncontrolled emission factors (lbs metal/ton waste component)[a]

Group	Major category	Minor category		As	B	Ba	Cd
Paper	**fine/ comp/ office**			4.59E-06	5.33E-05	1.79E-06	2.44E-05
	books			1.41E-06	9.11E-04	1.45E-05	9.76E-05
	magazines	**glued**		3.88E-06	6.06E-05	5.62E-06	2.44E-07
		not glued		6.35E-06	1.84E-04	8.57E-06	7.32E-05
	laminates	**wax/ plastic**		2.47E-06	8.97E-05	5.18E-06	7.32E-05
		foil		2.82E-06	3.73E-04	5.83E-06	2.44E-05
	newsprint	**glued**		2.82E-06	1.48E-04	2.16E-06	2.44E-05
		notglued	**b&w**	2.47E-06	1.67E-04	4.28E-06	2.44E-05
			color	2.12E-06	4.00E-04	5.39E-06	2.44E-05
	browns	**corrugate**		2.12E-06	7.51E-05	1.46E-06	2.44E-05
		kraft		2.82E-06	1.14E-04	2.63E-06	2.44E-05
		box board		2.47E-06	1.45E-04	7.20E-06	4.88E-05
	residual mixed			4.23E-06	1.60E-04	3.32E-06	4.15E-04
Plastic	**film**	**color**		1.76E-06	3.32E-04	3.95E-05	1.61E-03
		flexible		2.47E-06	7.20E-04	2.56E-06	6.83E-04
		rigid		1.06E-06	1.31E-04	2.99E-05	9.07E-03
	food/ beverage/ household	**1 (PET)**		2.82E-06	4.69E-03	1.86E-06	1.29E-03
		2 (HDPE)		1.76E-06	7.12E-04	1.94E-05	7.07E-04
		3 (PVC)		0.00E+00	1.74E-04	0.00E+00	1.10E-03
		4 (LDPE)		7.05E-07	2.91E-04	1.16E-06	6.10E-04
		5 (PP)		1.76E-06	1.28E-04	3.49E-07	4.63E-04
		6 (PS)		7.05E-07	9.45E-05	7.90E-07	1.15E-03
		nonident		4.23E-06	4.85E-04	2.74E-05	1.93E-02
	houseware s	**clear**		3.53E-07	1.21E-05	4.30E-06	2.19E-04
		white		7.05E-07	1.72E-04	1.98E-06	6.10E-04
		blue		1.09E-05	4.09E-04	1.31E-04	7.07E-02
		yellow		1.06E-06	1.96E-04	5.28E-05	2.56E-02
		other		1.06E-06	1.43E-04	3.91E-05	2.46E-02
	toys and other			1.76E-06	2.30E-04	1.93E-05	1.85E-02
	video tape/ film			5.04E-05	1.57E-03	6.37E-06	5.35E-01

(a) Uncontrolled emission fraction taken from Table C-5 (10-6 ton metal/ton metal input)*metals content (10-6 ton metal input/ton waste component) *2000 (lb/ton). For As and office paper: 1,764*1.3*2000*10-12=4.59*10-6 lb As emitted/ton office paper

Table C-6. Uncontrolled emission factors (lbs metal/ton waste component), Continued

Group	Major category	Minor category		As	B	Ba	Cd
Organics	yard & garden	lawn/ plant		2.57E-05	1.28E-02	3.09E-05	1.46E-03
		branches		3.17E-06	5.45E-04	1.26E-05	2.68E-04
	food waste	organic		4.23E-06	7.96E-03	4.04E-06	4.88E-04
	wood	finished		1.80E-05	3.54E-04	1.08E-05	2.68E-04
		unfinished		1.20E-04	5.06E-04	6.48E-06	9.76E-06
	textiles			1.41E-06	1.67E-04	5.34E-06	6.83E-04
	footwear			2.47E-06	1.36E-04	2.14E-05	2.90E-03
Metals	ferrous	beer		3.10E-05	3.04E-03	9.99E-06	1.51E-02
		soft drink		3.10E-05	3.04E-03	9.99E-06	1.51E-02
		food		2.47E-05	3.90E-03	3.95E-07	1.05E-02
		band & strap		1.41E-04	9.01E-03	5.11E-07	3.66E-03
		elect motor		3.34E-02	2.37E-03	2.96E-04	2.22E-03
	non-ferrous	beer		7.05E-07	2.18E-04	1.56E-05	7.32E-04
		soft drink		1.41E-06	4.77E-04	3.66E-05	1.46E-03
		food		2.54E-02	4.17E-04	2.39E-06	4.15E-04
		manufactu red		7.02E-04	4.85E-04	7.90E-06	1.37E-03
		foil/ pack		2.82E-06	3.63E-04	6.27E-06	1.24E-02
		other		2.96E-02	4.85E-04	2.79E-06	4.88E-04
Glass	combined	clear		3.53E-06	2.15E-03	7.92E-05	1.17E-03
		green		3.46E-05	1.08E-03	1.13E-04	7.32E-05
		brown		2.43E-05	7.08E-04	4.43E-05	4.15E-04
		other colour		1.41E-06	5.21E-04	1.82E-04	1.32E-03
Inorganic	light constructi on	rock/ sand/ dirt/ concrete/ ceramic		2.12E-05	6.91E-02	1.88E-04	4.88E-03
		drywall/ plaster		2.12E-06	6.98E-03	7.20E-06	4.88E-04
		insulation	fglass	2.47E-06	1.30E-03	6.89E-05	1.22E-05
		other		6.03E-05	3.20E-04	1.42E-05	9.76E-05
Small appliances	electrical parts	plastic		2.74E-03	2.86E-04	3.25E-07	8.78E-04
Household hazardous	batteries	carbon		9.88E-06	4.36E-04	3.25E-06	7.56E-03
		ni-cad		1.55E-05	1.70E-03	2.79E-06	2.93E+01
		alkaline		3.53E-06	1.43E-03	1.77E-06	4.73E-01
Fines				2.33E-05	1.10E-03	1.12E-05	1.07E-03

(a) Uncontrolled emission fraction taken from Table C-5 (10-6 ton metal/ton metal input)*metals content (10-6 ton metal input/ton waste component) *2000 (lb/ton). For As and office paper: 1,764*1.3*2000*10-12=4.59*10-6 lb As emitted/ton office paper

Table C-6. Uncontrolled emission factors (lbs metal/ton waste component)[a], Continued

Group	Major category	Minor category		Cr	Cu	Hg	Ni
Paper	fine/ comp/ office			3.68E-05	3.43E-06	2.95E-04	2.68E-04
	books			9.41E-05	1.71E-05	1.97E-04	4.74E-05
	magazines	glued		1.80E-04	1.11E-05	2.95E-04	5.96E-04
		not glued		6.27E-05	1.58E-05	2.95E-04	2.78E-04
	laminates	wax/ plastic		3.46E-05	3.00E-06	9.84E-05	1.83E-04
		foil		4.82E-04	9.68E-05	9.84E-05	2.95E-04
	newsprint	glued		1.41E-05	4.28E-06	2.95E-04	1.46E-04
		notglued	b&w	4.11E-05	5.57E-06	2.85E-03	2.10E-04
			color	2.33E-03	1.54E-05	2.95E-04	3.61E-03
	browns	corrugate		1.95E-05	1.29E-06	9.84E-05	1.29E-04
		kraft		5.08E-05	4.71E-06	4.92E-04	2.61E-04
		box board		5.84E-05	5.14E-06	1.97E-04	2.30E-04
	residual mixed			3.57E-04	1.03E-05	3.94E-04	2.54E-04
Plastic	film	color		1.25E-03	1.07E-05	1.97E-04	2.71E-04
		flexible		8.98E-04	8.57E-06	1.97E-04	2.00E-04
		rigid		1.29E-03	3.21E-05	9.84E-05	9.22E-04
	food/ beverage/ household	1 (PET)		1.81E-04	1.33E-05	1.97E-04	2.81E-04
		2 (HDPE)		1.62E-04	1.03E-05	1.97E-04	2.37E-04
		3 (PVC)		2.81E-05	8.57E-07	9.84E-05	8.81E-05
		4 (LDPE)		5.08E-05	4.28E-06	9.84E-05	1.42E-04
		5 (PP)		3.42E-04	6.85E-06	9.84E-05	2.03E-04
		6 (PS)		7.68E-05	3.86E-06	9.84E-05	1.93E-04
		nonident		4.77E-04	2.44E-05	3.94E-04	1.29E-03
	houseware s	clear		6.92E-05	3.00E-06	9.84E-05	5.29E-04
		white		6.44E-03	1.88E-05	1.97E-04	4.96E-03
		blue		9.41E-05	3.43E-05	9.84E-05	5.52E-04
		yellow		1.39E-02	7.28E-06	9.84E-05	3.05E-04
		other		3.89E-03	1.24E-05	2.95E-04	9.49E-05
	toys and other			2.48E-03	4.20E-05	9.84E-05	9.39E-04
	video tape/ film			1.02E-03	1.63E-05	1.97E-04	5.96E-04

(a) Uncontrolled emission fraction taken from Table C-5 (10-6 ton metal/ton metal input)*metals content (10-6 ton metal input/ton waste component) *2000 (lb/ton). For As and office paper: 1,764*1.3*2000*10-12=4.59*10-6 lb As emitted/ton office paper

Table C-6. Uncontrolled emission factors (lbs metal/ton waste component)[a], Continued

Group	Major category	Minor category		Cr	Cu	Hg	Ni
Organics	yard & garden	lawn/ plant		1.10E-03	2.96E-04	1.38E-03	8.00E-04
		branches		2.61E-04	1.93E-05	3.94E-04	3.66E-04
	food waste	organic		2.44E-04	1.84E-05	2.95E-04	1.63E-04
	wood	finished		1.22E-03	4.67E-05	1.97E-04	2.81E-04
		unfinished		6.29E-04	1.97E-05	3.94E-04	2.71E-05
	textiles			4.76E-03	2.87E-05	1.08E-03	2.71E-05
	footwear			1.98E-02	1.07E-05	9.84E-05	1.86E-04
Metals	ferrous	beer		3.27E-03	1.38E-04	3.58E-02	5.62E-03
		soft drink		3.27E-03	1.38E-04	3.58E-02	5.62E-03
		food		2.04E-03	4.24E-05	5.51E-03	5.44E-03
		band & strap		5.32E-03	5.10E-05	1.97E-05	1.41E-03
		elect motor		3.13E-03	3.19E-01	5.32E-03	1.32E-03
	non-ferrous	beer		1.03E-03	4.89E-04	2.95E-04	9.45E-04
		soft drink		9.66E-04	4.69E-04	3.94E-04	6.47E-04
		food		1.86E-03	2.76E-04	1.97E-04	1.16E-03
		manufactu red		1.46E-02	8.31E-05	1.97E-04	2.44E-04
		foil/ pack		1.45E-03	1.20E-04	7.88E-04	1.37E-03
		other		2.16E-03	3.21E-04	1.97E-04	0.00E+00
Glass	combined	clear		3.03E-04	9.42E-06	1.97E-04	3.44E-04
		green		1.02E-02	2.57E-06	9.84E-05	2.12E-03
		brown		5.00E-04	3.94E-05	5.91E-04	7.73E-04
		other colour		9.90E-04	1.24E-05	9.84E-05	4.24E-04
Inorganic	light constructi on	rock/ sand/ dirt/ concrete/ ceramic		1.81E-03	5.74E-05	2.95E-04	5.28E-03
		drywall/ plaster		9.30E-05	3.00E-06	2.95E-04	1.42E-04
		insulation	fglass	1.53E-04	2.06E-05	1.08E-03	2.78E-04
		other		3.68E-04	4.80E-05	9.84E-05	7.96E-04
Small appliances	electrical parts	plastic		2.72E-03	3.92E-04	9.84E-05	1.49E-04
Household hazardous	batteries	carbon		4.22E-04	6.00E-05	2.02E-02	9.42E-03
		ni-cad		6.92E-04	2.27E-05	2.95E-04	1.07E-02
		alkaline		8.01E-04	5.14E-03	2.38E-01	2.46E-02
Fines				1.24E-03	1.04E-04	1.38E-03	1.82E-03

(a) Uncontrolled emission fraction taken from Table C-5 (10-6 ton metal/ton metal input)*metals content (10-6 ton metal input/ton waste component) *2000 (lb/ton). For As and office paper: 1,764*1.3*2000*10-12=4.59*10-6 lb As emitted/ton office paper

Table C-6. Uncontrolled emission factors (lbs metal/ton waste component)[a], Continued

Group	Major category	Minor category		Pb	Sb	Se	Zn
Paper	fine/ comp/ office			4.73E-04	2.03E-05	9.38E-07	9.65E-03
	books			5.26E-07	2.64E-07	4.88E-07	4.08E-03
	magazines	glued		4.20E-05	1.41E-05	3.00E-07	1.67E-03
		not glued		6.20E-04	8.72E-04	4.88E-07	8.35E-04
	laminates	wax/ plastic		7.46E-04	3.26E-05	1.88E-07	7.42E-04
		foil		9.70E-03	1.78E-04	7.51E-08	5.52E-03
	newsprint	glued		2.52E-04	1.06E-05	4.13E-07	3.71E-04
		notglued	b&w	7.57E-04	2.20E-05	4.13E-07	8.81E-04
			color	5.99E-04	1.59E-05	2.63E-07	1.34E-03
	browns	corrugate		3.99E-04	1.32E-05	1.50E-07	4.64E-04
		kraft		9.77E-04	1.41E-05	1.88E-07	1.02E-03
		box board		1.26E-03	2.47E-05	1.50E-07	1.34E-03
	residual mixed			2.41E-02	4.41E-05	1.13E-07	3.76E-03
Plastic	film	color		3.80E-02	2.40E-04	3.75E-08	5.25E-02
		flexible		2.94E-02	9.43E-05	7.51E-08	3.11E-03
		rigid		3.54E-03	1.51E-04	1.50E-07	2.41E-03
	food/ beverage/ household	1 (PET)		6.46E-03	1.53E-03	1.88E-07	4.50E-03
		2 (HDPE)		6.37E-03	4.58E-04	1.88E-07	6.59E-03
		3 (PVC)		2.27E-01	2.62E-01	1.88E-08	1.39E-04
		4 (LDPE)		5.89E-03	1.41E-04	1.13E-07	4.13E-03
		5 (PP)		7.28E-03	4.51E-04	1.13E-07	1.85E-03
		6 (PS)		2.63E-03	3.88E-04	7.51E-08	4.54E-03
		nonident		1.66E-02	8.93E-04	5.63E-07	1.27E-02
	houseware s	clear		6.48E-03	2.14E-04	7.51E-08	5.01E-03
		white		4.39E-03	2.19E-04	7.51E-08	5.98E-03
		blue		6.76E-03	7.96E-04	1.13E-07	3.52E-03
		yellow		2.61E-01	5.54E-04	3.00E-07	1.28E-02
		other		6.80E-02	2.24E-03	8.26E-07	9.23E-03
	toys and other			1.08E-02	8.23E-04	1.13E-07	1.62E-02
	video tape/ film			9.27E-02	1.87E-03	7.51E-08	3.59E-02

(a) Uncontrolled emission fraction taken from Table C-5 (10-6 ton metal/ton metal input)*metals content (10-6 ton metal input/ton waste component) *2000 (lb/ton). For As and office paper: 1,764*1.3*2000*10-12=4.59*10-6 lb As emitted/ton office paper

Table C-6. Uncontrolled emission factors (lbs metal/ton waste component)[a], Continued

Group	Major category	Minor category		Pb	Sb	Se	Zn
Organics	yard & garden	lawn/ plant		1.61E-02	4.60E-04	2.63E-07	1.69E-02
		branches		6.51E-03	6.87E-05	1.50E-07	5.75E-03
	food waste	organic		7.57E-03	1.13E-04	1.88E-07	8.63E-03
	wood	finished		5.92E-02	1.06E-05	7.51E-08	5.43E-03
		unfinished		3.41E-02	4.41E-06	3.75E-08	9.51E-03
	textiles			1.33E-02	8.50E-04	1.13E-07	6.59E-03
	footwear			1.41E-02	3.53E-05	1.13E-07	3.54E-02
Metals	ferrous	beer		2.42E-02	6.06E-04	2.25E-07	4.11E-02
		soft drink		2.42E-02	6.06E-04	2.25E-07	4.11E-02
		food		3.62E-02	7.77E-04	1.50E-07	2.12E-01
		band & strap		6.26E-02	1.44E-03	3.38E-07	1.39E-03
		elect motor		6.41E-02	6.57E-04	7.72E-05	3.40E-01
	non-ferrous	beer		7.15E-03	1.76E-04	3.75E-08	7.88E-03
		soft drink		3.39E-03	1.59E-04	3.75E-08	1.15E-02
		food		1.00E-02	2.27E-04	6.13E-05	2.06E-02
		manufactu red		9.88E-03	2.03E-04	1.88E-05	1.85E+01
		foil/ pack		4.20E-07	2.64E-07	3.75E-08	5.56E-03
		other		1.17E-02	2.64E-04	7.13E-05	2.40E-02
Glass	combined	clear		1.15E-02	1.28E-03	2.89E-06	2.78E-03
		green		2.10E-03	3.22E-04	2.25E-07	9.74E-04
		brown		1.08E-02	2.24E-04	1.80E-06	1.16E-02
		other colour		9.46E-03	1.36E-03	6.01E-07	7.75E-02
Inorganic	light constructi on	rock/ sand/ dirt/ concrete/ ceramic		1.62E-01	1.77E-03	2.97E-06	2.37E-01
		drywall/ plaster		3.99E-03	3.35E-04	7.51E-07	9.74E-04
		insulation	fglass	4.29E-03	4.58E-05	1.13E-07	5.56E-04
		other		3.16E-03	7.05E-06	1.13E-08	2.64E-03
Small appliances	electrical parts	plastic		6.96E-02	4.23E-02	1.14E-02	2.92E-03
Household hazardous	batteries	carbon		4.20E-03	2.03E-04	1.50E-07	2.92E+00
		ni-cad		1.19E-02	5.90E-03	4.13E-07	3.18E-02
		alkaline		1.50E-02	5.29E-04	7.51E-08	6.49E+00
Fines				2.72E-02	3.97E-04	4.88E-07	3.96E-02

*(a) Uncontrolled emission fraction taken from Table C-5 (10-6 ton metal/ton metal input)*metals content (10-6 ton metal input/ton waste component) *2000 (lb/ton). For As and office paper: 1,764*1.3*2000*10-12=4.59*10-6 lb As emitted/ton office paper*

Table C- 7. Uncontrolled emission factors (lbs metal/ton waste component) for Integrated Solid Waste Management categories

Component name	As	B	Ba	Cd	Cr	Cu
Leaves	2.57E-05	1.28E-02	3.09E-05	1.46E-03	1.10E-03	2.96E-04
Grass	2.57E-05	1.28E-02	3.09E-05	1.46E-03	1.10E-03	2.96E-04
Branches	3.17E-06	5.45E-04	1.26E-05	2.68E-04	2.61E-04	1.93E-05
Old News Print	2.41E-06	2.20E-04	4.38E-06	2.44E-05	5.73E-04	7.78E-06
Old Corr. Cardboard	2.12E-06	7.51E-05	1.46E-06	2.44E-05	1.95E-05	1.29E-06
Office Paper	4.59E-06	5.33E-05	1.79E-06	2.44E-05	3.68E-05	3.43E-06
Phone Books	2.82E-06	1.48E-04	2.16E-06	2.44E-05	1.41E-05	4.28E-06
Books	1.41E-06	9.11E-04	1.45E-05	9.76E-05	9.41E-05	1.71E-05
Old Magazines	5.06E-06	1.19E-04	7.03E-06	3.50E-05	1.24E-04	1.34E-05
3rd Class Mail	4.23E-06	1.60E-04	3.32E-06	4.15E-04	3.57E-04	1.03E-05
Paper Other #1	3.23E-06	2.41E-04	4.96E-06	9.21E-05	1.74E-04	8.22E-06
Paper Other #2	3.23E-06	2.41E-04	4.96E-06	9.21E-05	1.74E-04	8.22E-06
Paper Other #3	3.23E-06	2.41E-04	4.96E-06	9.21E-05	1.74E-04	8.22E-06
Paper Other #4	3.23E-06	2.41E-04	4.96E-06	9.21E-05	1.74E-04	8.22E-06
Paper Other #5	3.23E-06	2.41E-04	4.96E-06	9.21E-05	1.74E-04	8.22E-06
Paper - Non-recyclable	4.23E-06	1.60E-04	3.32E-06	4.15E-04	3.57E-04	1.03E-05
Food Waste	4.23E-06	7.96E-03	4.04E-06	4.88E-04	2.44E-04	1.84E-05
Ferrous Cans	2.51E-05	3.84E-03	1.05E-06	1.08E-02	2.13E-03	4.90E-05
Ferrous Metal - Other	1.97E-02	3.26E-03	1.75E-04	5.37E-03	2.89E-03	1.88E-01
Ferrous - Non-recyclable	1.97E-02	3.26E-03	1.75E-04	5.37E-03	2.89E-03	1.88E-01
Aluminum Cans	1.14E-06	3.77E-04	2.84E-05	1.18E-03	9.90E-04	4.76E-04
Aluminum - Other #1	2.82E-06	3.63E-04	6.27E-06	1.24E-02	1.45E-03	1.20E-04
Aluminum - Other #2	5.28E-03	4.35E-04	9.88E-06	3.24E-03	7.59E-03	1.91E-04
Al - Non-recyclable	5.28E-03	4.35E-04	9.88E-06	3.24E-03	7.59E-03	1.91E-04
Glass - Clear	3.53E-06	2.15E-03	7.92E-05	1.17E-03	3.03E-04	9.42E-06
Glass - Brown	2.43E-05	7.08E-04	4.43E-05	4.15E-04	5.00E-04	3.94E-05
Glass - Green	3.46E-05	1.08E-03	1.13E-04	7.32E-05	1.02E-02	2.57E-06
Glass - Non-recyclable	9.45E-06	1.83E-03	8.16E-05	9.61E-04	1.52E-03	1.19E-05
HDPE - Translucent	1.76E-06	7.12E-04	1.94E-05	7.07E-04	1.62E-04	1.03E-05
HDPE - Pigmented	1.76E-06	7.12E-04	1.94E-05	7.07E-04	1.62E-04	1.03E-05
PET	2.82E-06	4.69E-03	1.86E-06	1.29E-03	1.81E-04	1.33E-05
Plastic - Other #1	2.12E-06	2.04E-03	1.36E-05	9.02E-04	1.68E-04	1.13E-05
Plastic - Other #2	2.12E-06	2.04E-03	1.36E-05	9.02E-04	1.68E-04	1.13E-05
Plastic - Other #3	2.12E-06	2.04E-03	1.36E-05	9.02E-04	1.68E-04	1.13E-05
Plastic - Other #4	2.12E-06	2.04E-03	1.36E-05	9.02E-04	1.68E-04	1.13E-05
Plastic - Other #5	2.12E-06	2.04E-03	1.36E-05	9.02E-04	1.68E-04	1.13E-05
Plastic - Non-Recyclable	2.17E-06	4.16E-04	2.47E-05	7.82E-03	1.70E-03	1.45E-05
Misc.	2.58E-03	3.35E-03	3.71E-05	6.24E-03	2.59E-03	2.38E-02

**Emission factors in Table C-6 are matched to the above categories. Where there were more refined categories in the Burnaby study, the factors were composition weight-averaged. "Other" categories are the averages of all paper (plastic) products.*

Table C-7. Uncontrolled emission factors (lbs metal/ton waste component) for Integrated Solid Waste Management categories

Component name	Hg	Ni	Pb	Sb	Se	Zn
Leaves	1.38E-03	8.00E-04	1.61E-02	4.60E-04	2.63E-07	1.69E-02
Grass	1.38E-03	8.00E-04	1.61E-02	4.60E-04	2.63E-07	1.69E-02
Branches	3.94E-04	3.66E-04	6.51E-03	6.87E-05	1.50E-07	5.75E-03
Old News Print	2.06E-03	1.00E-03	6.82E-04	1.97E-05	3.78E-07	9.51E-04
Old Corr. Cardboard	9.84E-05	1.29E-04	3.99E-04	1.32E-05	1.50E-07	4.64E-04
Office Paper	2.95E-04	2.68E-04	4.73E-04	2.03E-05	9.38E-07	9.65E-03
Phone Books	2.95E-04	1.46E-04	2.52E-04	1.06E-05	4.13E-07	3.71E-04
Books	1.97E-04	4.74E-05	5.26E-07	2.64E-07	4.88E-07	4.08E-03
Old Magazines	2.95E-04	4.45E-04	3.18E-04	4.23E-04	3.90E-07	1.27E-03
3rd Class Mail	3.94E-04	2.54E-04	2.41E-02	4.41E-05	1.13E-07	3.76E-03
Paper Other #1	5.20E-04	3.27E-04	3.75E-03	7.59E-05	4.10E-07	2.93E-03
Paper Other #2	5.20E-04	3.27E-04	3.75E-03	7.59E-05	4.10E-07	2.93E-03
Paper Other #3	5.20E-04	3.27E-04	3.75E-03	7.59E-05	4.10E-07	2.93E-03
Paper Other #4	5.20E-04	3.27E-04	3.75E-03	7.59E-05	4.10E-07	2.93E-03
Paper Other #5	5.20E-04	3.27E-04	3.75E-03	7.59E-05	4.10E-07	2.93E-03
Paper - Non-recyclable	3.94E-04	2.54E-04	2.41E-02	4.41E-05	1.13E-07	3.76E-03
Food Waste	2.95E-04	1.63E-04	7.57E-03	1.13E-04	1.88E-07	8.63E-03
Ferrous Cans	7.59E-03	5.45E-03	3.54E-02	7.66E-04	1.55E-07	2.00E-01
Ferrous Metal - Other	5.83E-03	2.80E-03	5.38E-02	7.38E-04	4.55E-05	2.72E-01
Ferrous - Non-recyclable	5.83E-03	2.80E-03	5.38E-02	7.38E-04	4.55E-05	2.72E-01
Aluminum Cans	3.55E-04	7.63E-04	4.85E-03	1.65E-04	3.75E-08	1.01E-02
Aluminum - Other #1	7.88E-04	1.37E-03	4.20E-07	2.64E-07	3.75E-08	5.56E-03
Aluminum - Other #2	3.33E-04	6.58E-04	7.32E-03	1.65E-04	2.07E-05	8.62E+00
Al - Non-recyclable	3.33E-04	6.58E-04	7.32E-03	1.65E-04	2.07E-05	8.62E+00
Glass - Clear	1.97E-04	3.44E-04	1.15E-02	1.28E-03	2.89E-06	2.78E-03
Glass - Brown	5.91E-04	7.73E-04	1.08E-02	2.24E-04	1.80E-06	1.16E-02
Glass - Green	9.84E-05	2.12E-03	2.10E-03	3.22E-04	2.25E-07	9.74E-04
Glass - Non-recyclable	2.26E-04	6.04E-04	1.03E-02	1.05E-03	2.41E-06	5.08E-03
HDPE - Translucent	1.97E-04	2.37E-04	6.37E-03	4.58E-04	1.88E-07	6.59E-03
HDPE - Pigmented	1.97E-04	2.37E-04	6.37E-03	4.58E-04	1.88E-07	6.59E-03
PET	1.97E-04	2.81E-04	6.46E-03	1.53E-03	1.88E-07	4.50E-03
Plastic - Other #1	1.97E-04	2.52E-04	6.40E-03	8.17E-04	1.88E-07	5.89E-03
Plastic - Other #2	1.97E-04	2.52E-04	6.40E-03	8.17E-04	1.88E-07	5.89E-03
Plastic - Other #3	1.97E-04	2.52E-04	6.40E-03	8.17E-04	1.88E-07	5.89E-03
Plastic - Other #4	1.97E-04	2.52E-04	6.40E-03	8.17E-04	1.88E-07	5.89E-03
Plastic - Other #5	1.97E-04	2.52E-04	6.40E-03	8.17E-04	1.88E-07	5.89E-03
Plastic - Non-Recyclable	2.12E-04	5.82E-04	3.42E-02	1.08E-03	1.90E-07	2.23E-02
Misc.	1.52E-03	9.89E-04	3.81E-02	1.34E-03	2.62E-04	6.67E-02

**Emission factors in Table C-6 are matched to the above categories. Where there were more refined categories in the Burnaby study, the factors were composition weight-averaged. "Other" categories are the averages of all paper (plastic) products.*

Table C- 8. Default removal efficiencies provided in Decision Support Tool

Pollutant	Average		Unit
	New	Old[2]	
As	99.9[3]	-	%
B	76.5[4]	-	%
Ba	99.8[3]	-	%
Cd	99.7[3]	-	%
Cr	99.3[3]	-	%
Cu	99.6[3]	-	%
Hg	92.7[1]	-	%
Ni	96.6[3]	-	%
Pb	99.8[3]	-	%
Sb	96.7[4]	-	%
Se	92.9[4]	-	%
Zn	99.7[4]	-	%

[1]Performance data from MWC'S with SD/FF/SNCR/CI, Summary of Performance Data from Colleen Kane to Walt Stevenson (1995)
[2]In consultation with Walt Stevenson, USEPA (May 1995).
[3]Camden Cty., NJ study
[4]Average removal efficiencies observed at Burnaby plant.

Table C- 9. Fact Sheet: New Municipal Waste Combustors—Subpart Eb Standards of Performance

Metal	Concentration limit (mg/dscm @ 7% oxygen)
Cadmium	0.02
Mercury	0.2[a]
Lead	0.08

[a]An alternative 85% reduction standard exists for Hg but is not considered in this analysis based on personal communication with Walt Stevenson, USEPA.