
**INTEGRATED SOLID
WASTE
MANAGEMENT
TOOLS:**

**“MEASURING THE
ENVIRONMENTAL
IMPACT OF WASTE
MANAGEMENT
SYSTEMS”**



Environment
Canada

Environnement
Canada



April 2004

PREFACE

Since the mid-1980s municipal solid waste and the environmental consequences associated with its management have received a great deal of attention in industrialized countries.

Research into the environmental effects of waste management practices has shown that the 'preferred' option(s) for waste management depends upon a number of site specific factors, including:

- The characteristics of the waste;
- The efficiency of the waste collection and processing systems required by different waste management practices;
- The availability and proximity of markets for recovered materials;
- The end use of the materials recovered from the waste stream;
- The emission standards to which waste management facilities are designed and operated;
- The cost effectiveness of the environmental protection obtained by different waste management practices;
- The social preferences of the community;

The recognition that there is no single practice that is always preferred over others, has given rise to the concept of integrated solid waste management (IWM).

IWM considers the full range of waste streams to be managed and views the available waste management practices as a menu of options from which waste managers can evaluate waste management options based on site-specific environmental, economic and social considerations.

CSR: Corporations Supporting Recycling and the Environment and Plastics Industry Council commissioned the development of an environmental analysis model to evaluate the life cycle environmental and energy effects of waste management processes as a tool to guide municipal waste managers in the evaluation of waste management systems.

The City of London, Ontario, a co-participant in the project, was the initial test case and has furthered the development of the model through its direct application in London's Continuous Improvement System.

More recently, Environment Canada has been a major contributor to the upgrading and extension of the processes of waste management considered by the model.

The objective of the project is to provide Canadian municipalities with a tool that will enable them to evaluate the environmental performance of the various elements of their existing

or proposed waste management systems thereby leading towards the goal of ISWM Life Cycle Assessment (LCA). LCA is used to assess the environmental impacts of products from cradle to grave, is increasingly being applied to the evaluation of waste management strategies. It should be noted however that there is a fundamental difference between the life cycle boundaries of products and wastes. The life cycle of a product starts with the extraction of raw materials (through activities such as mining, logging, etc.) and ends with the final disposal of a product. The life cycle of a waste on the other hand, starts when a material is discarded into the waste stream and ends when the waste material has either been converted into a resource (such as recycled material or recovered energy) or, when it has been finally disposed. Life cycle studies of waste materials cannot therefore be used as a basis for comparing products.

The environmental analysis model uses life cycle methodology to quantify the energy consumed and the emissions released from a user specified waste management system. The model has been structured so that it uses data specific to the user municipality to ensure applicability of the results and accuracy. At the same

time, in order to allow the user the ability to undertake a 'first level' screening evaluation, default values have been provided, wherever possible.

Data used in the model has been derived from sources such as governments in Canada, the U.S., and Europe together with other material published in recognized journals. Documentation of the sources of data used in the model and the algorithms involved in the calculations are presented in a more detailed report available on the web-site devoted to the model.

The environmental analysis model has been peer reviewed by an independent panel of five reviewers with expertise in life cycle analysis and waste management. The review panel was chosen independently of CSR and EPIC.

The model, its development and improvement is overseen by a multi-disciplined steering committee currently comprised of the following individuals:

- C. Cirko, EPIC;
- F.H. Edgecombe, EPIC;
- M. Gagnon, Procter and Gamble, Canada;
- G. Perry, City of Toronto, Ontario;
- M.E. Haight, University of Waterloo;
- D. Jackson, Environment Canada;
- G. Love, CSR;
- M. Kelleher, RIS International;

- S. Massicotte, La Régie de gestion des matières résiduelles de la Mauricie;
- J. Schubert, City of Edmonton, Alberta;
- G. South, Miller Waste Inc.; and
- P. Veiga, Town of Markham, Ontario.

Professor M.E. Haight of the Faculty of Environmental Science of the University of Waterloo (Canada) has been contracted to maintain the model and manage its distribution.

The model is available free of charge to any interested party upon registration. A web-site devoted to the model has been created and may be

accessed through the University of Waterloo web-site at www.iwm-model.uwaterloo.ca, or through the web-sites of CSR and EPIC, www.csr.org or www.plastics.ca/epic.

- Included also on the web-site are:
- Case histories demonstrating the use of the model by actual practitioners.
 - A more detailed report that documents the sources of data that form the back-bone of the model and the algorithms used to do the calculations.

INTRODUCTION

GOAL

The goal of the environmental analysis model is to give municipalities a broad indication of the environmental effects of waste management decisions, and point to strategies that potentially can improve the environmental performance of the waste management system.

SYSTEM DEFINITION

Table 1 below shows the material/waste management practice combinations that can be evaluated by the environmental analysis model.

The system boundary for the environmental analysis model is shown in Figure 1.

The model evaluates the environmental burdens associated with waste management from the point at which a material is discarded into the waste stream to the point at which it is either converted into a useful material or, it is finally disposed. Based on this definition, the following processes are evaluated by the model:

- Waste collection;
- Waste transfer;
- Sorting of recyclable materials at a materials recovery facility

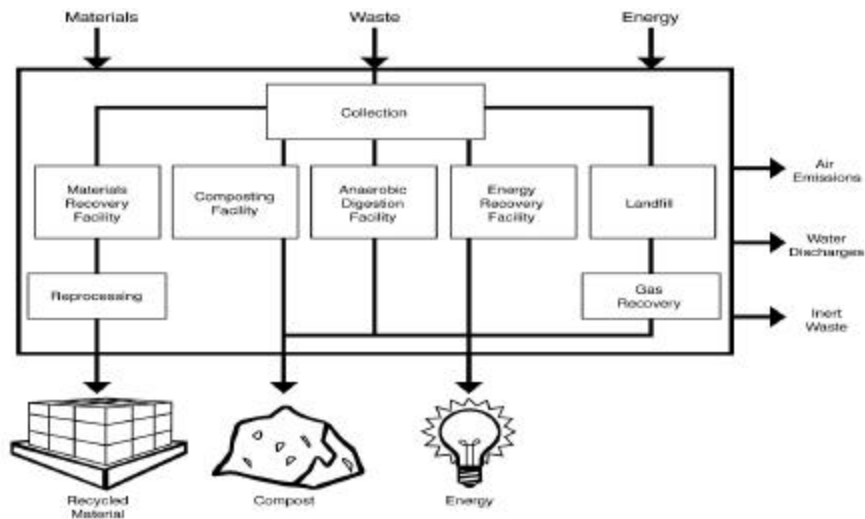
Table 1: Waste Material/Waste Management Practice Combinations Evaluated by the Model						
Material	Recycling	Composting	Anaerobic	Land	EFW	Landfilling
			Digestion	Application		
Paper	Y	Y	Y		Y	Y
Glass	Y				Y	Y
Ferrous Metals	Y				Y	Y
Aluminum	Y				Y	Y
Plastics	Y				Y	Y
Food Waste		Y	Y		Y	Y
Yard Waste		Y	Y	Y	Y	Y
Other Waste*					Y	Y

* Other waste includes textiles, rubber, diapers, kitty litter, tires, home renovation wastes, white goods and household hazardous waste.

(MRF);

- Reprocessing of recovered materials into recycled materials;

FIGURE 1: BOUNDARY DEFINITION



- ⚡⚡⚡ Composting;
- ⚡⚡⚡ Anaerobic digestion;
- ⚡⚡⚡ Energy recovery;
- ⚡⚡⚡ Landfilling.

Recycling, composting, anaerobic digestion and energy recovery result in the production of useful commodities namely, recycled materials, usable compost and energy. These commodities can be used in place of virgin materials, conventional soil amendments, and energy produced from the combustion of fossil fuels, respectively. To account for the benefits accruing from these waste management practices, the environmental analysis model estimates the amount of energy used and emissions produced from the production of the replaced commodity and accounts for them as avoided burdens. The avoided burdens are sub-

tracted from the burdens associated with the corresponding waste management practice to produce the net burdens associated with recycling, composting, anaerobic digestion and energy recovery.

Unlike emissions from other waste management processes, emissions from landfills may occur over a very long period of time, spanning hundreds of years. In theory, the landfill is part of the evaluated system when it is environmentally active (producing leachate and gas), but reverts to becoming a part of the environment when its active life is over. In the environmental analysis model, a time frame of 100 years has been used. Waste remaining in the landfill after this period is accounted for as residual waste by the model.

Table 2: INDICATOR PARAMETERS

Indicator Parameter	Indicator of	Indicator Parameter	Indicator of
Energy Total Energy Consumed	Resource depletion		
Emissions to Air <u>Greenhouse Gases</u> Carbon dioxide (CO ₂) Methane (CH ₄)	Climate change	Emissions to Water <u>Heavy Metals</u> Lead (Pb) Cadmium (Cd) Mercury (Hg)	Health risk, environmental degradation
<u>Acid Gases</u> Nitrogen oxides (NO _x) Sulphur dioxide (SO ₂) Hydrogen Chloride (HCl)	Acidification, health risk	<u>Trace Organics</u> Dioxins & Furans (TEQ)	Health risk, environmental degradation
<u>Smog Precursors</u> Volatile Organic Compounds Nitrogen oxides (NO _x) Particulate Matter (<10 microns) (PM-10)	Urban smog formation, health risk	<u>Biochemical Oxygen Demand (BOD)</u>	Water quality, environmental degradation
<u>Heavy Metals</u> Lead (Pb) Cadmium (Cd) Mercury (Hg)	Health risk	Emissions to Land Residual Solid Waste	Land use disruption
<u>Trace Organics</u> Dioxins & Furans (TEQ)	Health risk		

INDICATOR PARAMETERS

The model estimates the energy consumed (or produced) and the emissions to air, water and land associated with different waste management practices. The specific indicator parameters evaluated and the environmental effects associated with these parameters are shown in Table 2.

CO₂ EMISSIONS FROM BIOGENIC SOURCES

The IPCC Guidelines for Natural Greenhouse Gas Inventories (1997) is an international standard which Canada and other countries agreed to follow in establishing inventories of GHG's. CO₂ emissions from biogenic sources are not to be counted on the basis that the materials were

originally grown by photosynthesis and during natural decay would have simply closed the loop of the carbon cycle with the release of the CO₂ back to atmosphere.

In MSW typical materials for which CO₂ emissions are not counted include paper, yard trimmings and food wastes. Thus for composting operations containing such materials the CO₂ emissions would be zero. CO₂ emissions arising from the combustion of fossil fuels such as by trucks hauling the above-noted materials to a compost operation would be counted.

CH₄ emissions from landfills are counted even though the source of the carbon is mainly biogenic. The rationale being that the CH₄ is created and emitted as a result of human activity. If the CH₄ emitted from a landfill is recovered as biogas and then either flared or combusted in an energy-producing apparatus the resulting CO₂ that is produced is not counted. Only the CH₄ emitted from landfills directly to the atmosphere is counted.

With respect to anaerobic digestion, all the CH₄ produced is typically combusted and so the resultant CO₂ emissions are not counted. In both the landfilling and anaerobic digestion operations just as described for composting, CO₂ emissions emitted from the consumption of fossil fuels while operating process equipment is

always counted.

LIMITATIONS

In using the environmental analysis model to evaluate waste management systems, users should be aware that the approach suffers from a number of limitations, specifically:

- ☞☞☞ It is not intended as a stand-alone tool but as a guide to supplement the tools and means currently available to municipalities. It allows a user to compare different waste management scenarios to obtain an indication of the environmental effect of proposed changes to a community's system. The model does not consider all available waste management processes. For example, the gasification of waste is not considered in this version of the model. The addition of modules to address this and other new technologies for waste management that may become available will be considered in subsequent versions.
- ☞☞☞ The model does not evaluate waste reduction and reuse activities, which occur before the waste is discarded into the waste stream. However, as reduction and reuse result in changes in the quantity and composition of waste that appears in the waste

stream, the model can be used to evaluate the effects of these activities on the energy consumed and emissions generated from a community's waste management system.

- ☞☞☞ The model does not address the management of all waste streams by all available practices. Specifically it does not address diversion programs for white goods, textiles, household hazardous waste and tires. It is recognized that a number of municipalities in Canada have special collection and/or drop-off programs for these materials. The model does not consider all possible environmental burdens from waste management processes. Only the parameters listed in Table 2 are evaluated.
- ☞☞☞ The environmental analysis model is based upon the best data available in the public domain when the model was developed. As new data for use in life cycle assessments, becomes available it will be incorporated into the model.
- ☞☞☞ The model also does not evaluate the energy and emissions associated with the production of infrastructure (e.g. collection vehicles, waste man-

agement facilities). In general, these have been found to be small relative to emissions from operations.

- ☞☞☞ The methodology used represents, to the best of our knowledge, the currently accepted practice for the conduct of life cycle studies for waste management processes.
- ☞☞☞ The model cannot prescribe the 'best' system, as that requires the input of a number of other considerations derived from site specific impact studies (health risk assessments, consideration of surrounding land use, background concentrations, etc.) and economic, social and political factors.

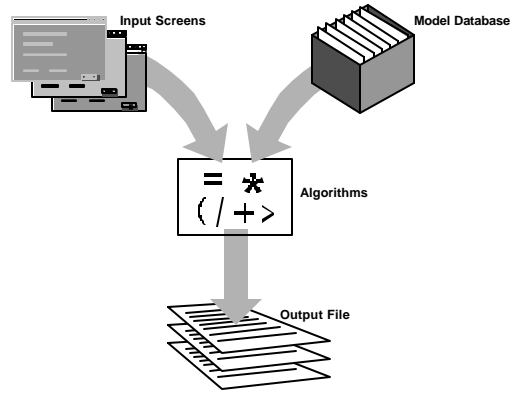
ADDITIONAL INFORMATION

Additional information on the boundaries, data sources, parameters and assumptions used in the development of the environmental analysis model is provided in a project report available under the publications section of the model's web-site.

THE ENVIRONMENTAL MODEL

The environmental life cycle invento-

Figure 2: STRUCTURE OF THE ENVIRONMENTAL ANALYSIS MODEL



ry model is an Excel 2000™ model (with all the patches applied) with a Visual Basic graphical interface. The following are required to run the model:

- P4 computer or higher;
- Microsoft Excel™ 2000 (with all the patches applied) software; and
- 256 Megabytes of RAM.

The structure of the model is depicted graphically in Figure 2 above.

Before running the model, users must ensure that the level of security is set to medium. This is accomplished by selecting the following: tools – options – security – macro – security – select medium security level.

DATA INPUT

A “Visual Basic” interface allows the

user to insert data in a very simple manner. One merely puts the data into the “boxes” of a series of input screens.

The model contains twelve main input screens (Input Screens A to J), as follows:

- Input Screen A: Quantity and Composition of Waste
- Input Screen B: Waste Flow
- Input Screen C: Waste Collection, Transfer and Transportation
- Input Screen D: Electric Grid Selection
- Input Screen E: Recycling
- Input Screen F: Materials Recovery Facility
- Input Screen G: Composting
- Input Screen G2: Anaerobic Digestion

Input Screen G3: Anaerobic Digestion Process

Input Screen H: Land Application

Input Screen I: Energy from Waste

Input Screen J: Landfilling

In addition, the Input screens C, D and I have subsidiary screens which allow a user to enter additional information about the processes addressed by the main screens.

These screens are accessed from the respective main screens. Navigation back and forth among the different screens is easily achieved by selecting the ‘next’ and ‘back’ buttons.

The following is a detailed description of the input data required on each of the screens.

INPUT SCREEN A - WASTE GENERATION AND COMPOSITION

Input Screen A asks the user to enter the total quantity of waste collected at the curb (recyclables, organics and garbage) and the composition of the total waste stream in tonnes. The model contains a default waste composition that can be used if the user lacks site-specific waste composition data. The model applies the default or user specified composition data to the specified quantity of waste to estimate the quantity of each waste component flowing through the waste management system. In the upper right corner the user can have all the identified wastes enter directly into an anaerobic digestion facility.

Input Screen A: WASTE GENERATION AND COMPOSITION

Input Screen B: WASTE FLOW

INPUT SCREEN B - WASTE FLOW

Input Screen B requires the user to enter the following waste flow data:

1. Quantity of waste sent for recycling;
2. Quantity of waste sent for composting;
3. Quantity of waste sent for anaerobic digestion;
4. Quantity of waste sent for land application;
5. Quantity of waste sent for energy recovery;
6. Quantity of waste sent to landfill.

Input Screen C: COLLECTION AND TRANSPORTATION

INPUT SCREEN C - COLLECTION AND TRANSPORTATION

Input Screen C requires the following data on the collection and transportation of waste in the system being modeled:

1. Distance driven by collection trucks;
2. Type of fuel;
3. Fuel efficiency;
4. Transfer Station: The user is required to indicate whether any of the waste streams are routed to a waste management facility (MRF, compost facility, anaerobic digestion facility, EFW or landfill) via a transfer station. If 'yes', then the subsidiary screen shown below, 'Transfer and Transportation' will appear. If 'no' is selected, Input

Screen D will appear.

TRANSFER AND TRANSPORTATION

1. Energy consumed in Transfer Station Operations;
2. Transfer Station: The waste streams routed through a transfer station should be selected;
3. Distance from transfer station to EFW;
4. Distance from transfer station to landfill;
5. Distance from transfer station to the MRF;
6. Distance from transfer station to the composting facility;
7. Distance from transfer station to the anaerobic digestion (AD) facility.

Input Screen: TRANSFER AND TRANSPORTATION

Input Screen D: ELECTRIC GRID SELECTION

Life Cycle Model - Input Screen D

ELECTRIC GRID SELECTION

Newfoundland
 Prince Edward Island
 Nova Scotia
 New Brunswick
 Quebec
 Ontario

Manitoba
 Saskatchewan
 Alberta
 British Columbia
 U.S. National
 Custom

< Back Next >

INPUT SCREEN D - ELECTRIC GRID SELECTION

Input Screen D allows a user to select the mix of methods used to produce the electricity that is used by

the waste management processes analyzed by the model. Alternatively, a user can specify a custom grid by selecting the 'custom' option on Screen D. If the 'custom' button is selected, the subsidiary screen shown below appears which allows the user

Life Cycle Model

Enter Breakdown of Electric Grid (%)

Coal []
 Natural Gas []
 Diesel & Light Fuel Oil []
 Heavy Fuel Oil []
 Hydro []
 Nuclear []

< Back Next >

to input the percentage of power generated by each of the generating methods shown.

INPUT SCREEN E - RECYCLING

Input Screen E will only appear if the user has entered a number greater

than zero for 'quantity of waste recycled' (input Screen B – item 1).

Amount sent for recycling: The total tonnes of waste collected for recycling entered on Input Screen B will automatically be displayed at the top of the screen.

1. Total Available for Recycling.

Input Screen E: RECYCLING

Recycling Recovery Amounts

AMOUNT SENT TO RECYCLING: [1]

TOTAL AVAILABLE FOR RECYCLING: PAPER [1]

STEEL [0]
ALUMINUM [0]
GLASS [0]
PLASTICS [0]

Newsprint [0]
 OCC [0]
 Tel. Direct. [0]
 Boxboard [0]
 Mixed [0]
 PET [0]
 HDPE [0]
 LLDPE [0]
 PP [0]
 PS [0]
 PVC [0]

AMOUNTS BEING RECYCLED: [0]

AMOUNTS BEING NOT RECYCLED: [0]

Remainder: [1]

Forest Sequestration: Yes No

Note: Enter recycling amounts as tonnes of material.

Notes < Back Next >

Values entered in Input Screen A in tonnes will appear on the left of the screen for each of the materials in the waste stream.

2. In the next column the user must enter the quantity in tonnes of each material subcategory of paper and plastics recovered for recycling. The aggregated total of paper and plastics recovered will appear automatically in the appropriate boxes in the column labeled 'Recycled'.
3. Since there are no subcategories for steel, aluminum and glass the user enters the quantities recovered in the appropriate boxes in the third column.

Once the various quantities of recovered materials have been entered the number in the box labeled remainder should equal zero. If it doesn't it means that the total recovered for recycling does not equal the previously designated 'amount sent for recycling' and an adjustment to the recovered quantities should be made before proceeding.

4. Forest Sequestration: In the lower right corner of this screen the user is provided the option

of accounting for what is called forest sequestration or the sequestration of carbon in trees. A few words of explanation about sequestration are probably warranted.

It is a well-known fact, that growing trees extract CO₂ from the atmosphere and through the process of photosynthesis convert the carbon in CO₂ into cellulose and lignin, etc. that form the structure (biomass) of the tree. When the trees are harvested for the manufacture of lumber or paper carbon is released. On the other hand when trees are planted or allowed to continue to grow the carbon is stored in the plant biomass. When the rate of uptake and storage exceeds the rate of release, carbon is "sequestered".

When paper products are recycled they displace virgin paper and ultimately trees that would otherwise be harvested remain in the forest extracting CO₂ from the atmosphere. Over the short term this provides an environmental benefit. When the forest sequestration button is turned on, the model accounts

for the benefit. There is an implicit assumption here that forests are managed and reforestation occurs so that the area under cultivation does not diminish. Over the long term some of the short-term benefits disappear as market forces result in less planting of new trees thus affecting the quantity of carbon being sequestered.

INPUT SCREEN F - MATERIALS RECOVERY FACILITY

Input Screen F will only appear if the user has entered a number greater than zero for 'quantity of waste recycled'.

1. Energy Consumption: the electricity and natural gas consumed by the MRF facility.

Input Screen F: MATERIALS RECOVERY FACILITY

- Percent residue: the per cent residue can be calculated or the model provides a default value of 5% which can be overwritten as required.
- Residue Management: the user should indicate whether the sorting residues are sent to a landfill or an incinerator.
- Distance to markets: the distance to market for each recovered material should be entered in kilometres.
- Distance from MRF to

landfill/incinerator: the distance that the MRF sorting residues have to be transported to a landfill or incinerator should be entered in kilometres.

INPUT SCREEN G - COMPOSTING

Input Screen G will only appear if the user has entered a number greater than zero for 'quantity of waste composted' (Input Screen B - item 2). The 'total tonnes composted' that were entered on Input Screen B - item 2, will automatically appear on

Input Screen G: COMPOSTING

the top of the screen as waste sent for composting.

- Breakdown: A breakdown in tonnes of the materials sent for composting is required. The material categories considered are: paper, food waste, and yard waste.
- Composition of yard waste: In this item, yard waste is required to be further broken down into tonnes of leaves, grass and yard materials (brush). If these data are not readily available to the user, the assumption can be made that leaves make up 40% of total yard waste and grass and brush makes up 30% each. Where a grass ban is in effect, the split can be assumed to be 60% leaves and 40% brush.
- Distance residue transported: The distance that the compost residues are transported for disposal should be entered here in kilometres.
- Energy consumption: The user can specify whether windrow or in-vessel composting is practiced. The model requires information on the amount of energy used to process the specified amount of waste (in terms of electricity and diesel consumption) at the composting facility.

INPUT SCREEN G2 - ANAEROBIC DIGESTION

Input Screen G2 will only appear if the user has either selected 'Run AD only' on Input Screen A or has entered a number greater than zero for 'quantity sent as source separated or as mixed (co-mingled) wastes to anaerobic digestion' (Input Screen B - Item 3). In either case the amounts selected for AD (tonnes) will automatically appear on the top of the 'input screen G2.

In addition:

- Sent as: A selection is to be made between source separated organic or co-mingled MSW.
- Breakdown: Breakdown in tonnes of materials sent for AD is required. The material categories considered are paper, food waste, yard waste, ferrous metals, aluminum, glass, plastics, other organics.
- Composition of Paper: In this item paper is required to be further broken down into tonnes of newspaper, OCC/OBB, telephone directories, office and mixed paper.
- Composition of yard waste: In this item yard waste is required to be broken down further into tonnes of leaves, grass and yard materials.

Input Screen G2: Anaerobic Digestion (AD)

The screenshot shows the 'Life Cycle Model - Input Screen G2' window. It contains the following fields and sections:

- Waste sent for AD:** 21 tonnes
- Sent as:** Source separated organic, Co-mingled MSW
- Breakdown:**
 - Paper: 0 tonnes
 - Food waste: 0 tonnes
 - Yard waste: 0 tonnes
 - Ferrous Metals: 0 tonnes
 - Aluminum: 0 tonnes
 - Glass: 0 tonnes
 - Plastics: 0 tonnes
 - Other Organics: 0 tonnes
- Composition of paper:**
 - Newspaper: 0 tonnes
 - OCC/OBB: 0 tonnes
 - Telephone Directories: 0 tonnes
 - Office: 0 tonnes
 - Mixed Paper: 0 tonnes
- Composition of yard waste:**
 - Leaves: 0 tonnes
 - Grass: 0 tonnes
 - Yard materials: 0 tonnes

INPUT SCREEN G3

Input Screen G3 will only appear if a number greater than zero appeared

for 'waste sent for AD' (Input Screen G2 – Anaerobic Digestion).

Input Screen G3: Anaerobic Digestion Process

The screenshot shows the 'Life Cycle Model - Input Screen G3' window. It contains the following fields and sections:

- Residue from process:** 19 %
- Additional Process Water:** 500 liters/tonne
- Composition of Biogas Produced:**
 - CO₂: 45 %
 - CH₄: 55 %
- Click here to define values for: Moisture Content, Biogas Yield and Contaminants**
- Recovery of secondary materials:**
 - Metals: Steel 0 %, Aluminum 0 %
 - Glass: 0 %
 - Plastics: 0 %
- Efficiency of Energy Production:**
 - Production of electricity
 - Production of steam
 - Production of steam and electricity (co-generation)
 - Efficiency of Energy Production: 20 %
- Amount of additional energy consumed:** 0 GJ/tonne of input waste
- Facility energy consumption:** 22 % of energy produced

percent residue can be selected by the user or the model provides a default value of 19% – a value typified for the wet process.

2. **Additional Process Water:** The user may enter a specific quantity or the default value of 500 litres/tonne of waste for process water.
3. **Composition of Biogas Produced:** Unless otherwise specified by a user, the composition will be based upon 45% CO₂ and 55% CH₄ which are provided as default (typical values).
4. **Recovery of Secondary Materials:** The user may indicate the per cent recovery of secondary materials if present including metals, glass and plastics.
5. **Production of Energy:** The user is required to indicate whether the energy recovered is in the form of electricity, steam or both (co-generation).
6. **Efficiency of Energy Production:** The efficiency of on-site electricity production is expressed as a percentage of the total energy produced can be

determined by the user. Alternatively, default values can be used including 20% for electricity, 70% for steam and 75% for co-generation.

7. **Amount of Additional Energy:** If energy is needed to operate the facility beyond that which can be produced on-site, the user can enter the amount of additional energy consumed in GJ/tonne of input waste. Typically this amount would be zero, but in cases where energy is required a default value of 123 GJ/tonne of input waste is supplied.
8. **Facility Energy Consumption:** The electricity consumption as a percentage of the total energy produced on-site is 22% for a wet process. The value can be replaced by the user.
9. **Moisture Content, Biogas Yield and Contaminants:** Values may be entered into the appropriate cells on the next screen and this will appear when the bar containing these parameters is activated. Selecting the default values button will install default values, otherwise a user can supply specific values.

Enter defaults for Organics (%)		Moisture in %	Biogas Yield in m3/kg
Paper	Newspaper	35 %	0.06073 m3/kg
	OCC/OBB	35 %	0.12449 m3/kg
	Telephone Directories	35 %	0.06073 m3/kg
	Office Paper	35 %	0.17762 m3/kg
	Mixed Paper	35 %	0.11175 m3/kg
Food Waste		70 %	0.11344 m3/kg
Yard Waste	Leaves	40 %	0.02309 m3/kg
	Grass	80 %	0.03421 m3/kg
	Yard Materials	15 %	0.06691 m3/kg
Other Organics		40 %	0.1006 m3/kg

The input screen will only appear if the user has clicked onto the 'Click here to define values for: Moisture Content, Biogas Yield and Contaminants' bar in Input Screen G3.

1. **Moisture Content:** The user may select to use the default values for each of the components listed of a waste stream or may enter alternative percentage estimates.

2. **Biogas Yield:** The user may select to use the default values for each of the waste components expressed as m³/kg of waste type or may enter alternative values.

3. **Contaminant Values for Water Discharged to Sewer:** The default values supplied may be replaced by user specified values.

Input Screen H: LAND APPLICATION

INPUT SCREEN H - LAND APPLICATION

Input Screen H will only appear if the user has entered a number greater than zero for 'quantity of waste land applied' (Input Screen B - item 4).

The 'total quantity of waste land applied' entered on Input Screen B will automatically appear on the top of the screen.

1. **Composition of yard waste:** a breakdown of the total yard waste, land applied into tonnes of leaves and tonnes of yard material (brush).
2. **Energy consumption:** the electricity and diesel consumed annually for yard waste chipping operations.

INPUT SCREEN I - ENERGY FROM WASTE

Input Screen I will only appear if the user has entered a number greater than zero for 'total quantity of waste to EFW' (Input Screen B - item 5).

1. **Quantity of waste to EFW:** the 'total quantity of waste to EFW' entered on Screen B (item 5) will automatically appear on the top of the screen.
2. The user is required to indicate whether the energy recovered is in the form of electricity, steam or both (as in the case of cogeneration).
3. **Energy recovery efficiency:** The user is required to specify the efficiency of energy recovery

Input Screen I: ENERGY FROM WASTE

Contaminant	Rate	Unit
dioxins	0.14	nanograms / reference cubic metre
lead	142	micrograms / reference cubic metre
mercury	54	micrograms / reference cubic metre
cadmium	14	micrograms / reference cubic metre
NOx	207	milligrams / reference cubic metre
SOx	56	milligrams / reference cubic metre
THC	65	milligrams / reference cubic metre
HCl	27	milligrams / reference cubic metre
particulate matter	17	milligrams / reference cubic metre

achieved at the facility. The energy efficiency is defined as the energy recovered divided by the total energy content of the waste as received at the facility. Default values are provided.

4. Energy consumption: the electricity and natural gas consumption per tonne of waste received at the EFW facility should be entered. This information can be obtained from the facility's utility bills and waste receipts
5. Ash: The user is asked whether he/she knows the quantity of ash that is or would be generated by

the energy from waste facility. If the user selects 'no', the model will automatically estimate the quantity of fly and bottom ash from the composition of the waste flowing to the EFW and the quantities of reagents that are added to air pollution control equipment of modern EFW plants. If the user selects 'yes', the total quantity of bottom ash and fly ash generated by the amount of waste from which energy is recovered must be entered in the appropriate boxes.

6. Distance fly ash transported: fly ash produced by EFW facilities is typically considered to be

hazardous waste. It is therefore either sent to a hazardous waste landfill or to a user of fly ash such as a manufacturer of cement.

7. Distance bottom ash transported: bottom ash produced by EFW facilities is typically considered non-hazardous. It is therefore usually sent to a municipal waste landfill.
8. Input Air Emission Data: selecting the 'input air emission data' button brings up the subsidiary screen "Emission Rates for Air Contaminants from EFW" which allows the user to view and change the defaults for EFW emission concentrations

used by the model. The defaults are based on the assumption that the EFW is operating at the emission standards stipulated in the Ontario Ministry of Environment and Energy's Guideline A-7 for new incinerators combusting municipal solid waste.

INPUT SCREEN J - LANDFILLING

Input Screen J will always appear since even for a system where all collected waste is sent to an EFW plant, it is assumed that residues from composting, the reprocessing of recovered materials and ash are sent to a landfill. The user is required to enter the following data on this

Input Screen J: LANDFILLING

screen:

1. Gas recovery: the user is required to indicate whether or not the landfill within the modeled system has a gas recovery system.
2. Energy recovery: the user is required to indicate whether energy is being recovered from the collected landfill gas by selecting the appropriate button on the screen.
3. Annual precipitation: The user is required to enter the average annual precipitation. The model uses this factor to estimate the amount of leachate produced by the waste.
4. Energy consumption: the diesel electricity and natural gas consumed per tonne of waste received for landfilling operations should be entered.
5. Landfill sequestration: users may select between yes or no for landfill sequestration or the
 - ◊◊◊ Leachate collection efficiency: The user is required to enter the leachate collection efficiency achieved at the landfill. The leachate collection efficiency will depend upon whether a landfill has a liner and whether leachate is collected. Defaults are provided.

storing of carbon in a modern landfill. It has been demonstrated by experiment and shown by direct observation that not all organic materials deposited in a landfill degrade at the same rate. Some materials such as newspaper, which has a high content of lignin, are quite resistant to the process of anaerobic digestion. (Excavations of old landfills have turned up editions of newspapers that are decades old.) As a result of this resistance to degradation the quantity of methane and carbon dioxide released by the anaerobic process is less than that which would be expected from the amount of organic carbon deposited. The un-degraded carbon is thus sequestered and hence removed from the natural carbon cycle of CO₂.

6. Input Screen J is the last screen in the model. If the user is satisfied with the data entered, the user should select the 'Finish' button at the bottom of Input Screen J to indicate that data entry is complete. The model will then ask the user to provide a name for the file, which is then saved as a "data interchange file" (dif). Finally the model will then process the data and produce an output file.

SAMPLE RUN

The model allows the user to evaluate the life cycle impacts of the existing waste management system and the incremental impacts of a proposed change to the system.

The model generates four output worksheets in a new Excel workbook:

- ◊◊◊ An input table which summarizes all the input data for that run.
- ◊◊◊ A summary output table that shows the total life cycle burdens by waste management practice as in Table 3.
- ◊◊◊ A detailed output table, which provides a further break down of the burdens from each waste management process into collection burdens, processing burdens and waste management facility burdens.
- ◊◊◊ A table expressing the life cycle inventory results (in the summary output table) in terms of impact equivalents discussed in a later section.
- ◊◊◊ As with any Excel file, the user can either print and/or save the output workbook.

IMPACT EQUIVALENTS

Impact equivalents are conversion

Table 4: Impact Equivalents and Conversion Factors

Parameter	Impact Equivalent	Conversion Factor
Energy	Power to supply x homes for one year	34.22 GJ/home/year
Greenhouse Gases	Emissions from x vehicles for one year	3.5t CO ₂ /vehicle/year
Nitrogen Oxides	Emissions from x vehicles for one year	19.7kg NO _x /vehicle/year
Sulphur Oxides	Power to supply x homes for one year	6.2kg SO _x /home/year
Hydrogen Chloride	Power to supply x homes for one year	0.34kg/home/year
Particulate Matter	Power to supply x homes for one year	3.6kg/home/year
Volatile Organic Compounds	Emissions from x vehicles for one year	25.6kg/vehicle/year
Lead (Air)	Power to supply x homes for one year	0.3g/home/year
Mercury (Air)	Power to supply x homes for one year	0.05g/home/year
Cadmium (Air)	Power to supply x homes for one year	0.016g/home/year
Dioxins (TEQ) (Air)	Power to supply x homes for one year	0.058ug/home/year
Lead (Water)	Power to supply x homes for one year	8.5g/home/year
Mercury (Water)	Power to supply x homes for one year	2.1mg/home/year
Cadmium (Water)	Power to supply x homes for one year	0.07g/home/year
BOD	Sewage from x persons for one year	27.4kg/person/year

factors that allow users to convert the inventory results into every day equivalents. Impact equivalents have been developed for the majority of environmental parameters evaluated by the model. Wherever possible the impact equivalent for each of the pollutants has been selected such that it:

- a) Refers to every day activities that users can relate to; and,
- b) Is a significant source of the pollutant.

The energy consumed by the various waste management processes (as calculated by the model) is compared to

the amount of electricity used by the average Canadian home for a year. In the “Burden Equivalents” sheet of the output file, energy consumption is expressed in terms of the number of homes that would consume an equivalent amount of energy in the form of electricity per year.

Emissions of greenhouse gases, nitrogen oxides and volatile organic compounds are expressed in terms of the number of average Canadian passenger vehicles emitting an equivalent amount of these pollutants in a year.

Emissions of sulphur oxides, hydro-

gen chloride, particulate matter, and heavy metal air emissions are expressed in terms of the number of homes consuming the amount of electricity per year whose generation would produce an equivalent amount of these pollutants.

Emissions of biochemical demand (BOD) are compared with the quantity of BOD contained in the sewage from the average Canadian home and is expressed in terms of the number of homes producing an equivalent BOD load in a year.

The conversion factors used to calculate impact equivalents are shown in Table 4.

COMPARISON OF CASES

Two scenarios may be compared, one with the other, in a very simple fashion. The user returns to the first page (title page) and activates the button “Compare two saved scenarios”. A screen appears that lists all of the scenarios that have been saved. The user then selects the scenario he wishes to consider as “scenario one” by double clicking on it. A second screen then appears again listing all of the saved scenarios. The user selects the scenario desired to be “scenario two”.

The model proceeds to produce an output table that shows the differ-

ences between the two scenarios in quantitative terms as well as the differences expressed as “Burden Equivalents”. An example is shown in Table 5.

ASSISTANCE TO USERS OF THE MODEL

EPIC and CSR have engaged Professor M.E. Haight of the Faculty of Environmental Science of the University of Waterloo (Ontario) to manage the website for the model. In addition Professor Haight maintains the currency of the data used in the model, and has developed additional modules particularly that for “Anaerobic Digestion” that extend the usefulness of the model. Limited assistance to registered users is also available through the website. The website has been designated to be the sole source of upgraded versions of the model. As improvements are made registered users will be notified of these via e-mail and may access the new version as they wish.

The model is provided free of charge to municipalities and other interested parties through application. The application form is on the “Home Page” of the website that, as previously stated, may be accessed through www.csr.org, www.plastics.ca/epic or www.iwm-model.uwaterloo.ca

Table 3: Environmental Inventory – MSW Management System

	Recycling	Composting	EFW	AD	Landfill	Total Waste Management System	Virgin Material Displacement Credit	Reprocessing of Recycled Materials	Net Life Cycle Inventory
Tonnes Managed (***)	14,673	3,953	0	19,533	53,543	91,702			
Energy Consumed (GJ)	8,627	356	0	581	6,827	16,390	-517,709	203,520	-297,798
Greenhouse Gases									
- CO2 (tonnes)	529	4	0	1,747	434	2,715	-12,929	2,581	-7,633
- CH4 + NOx (tonnes)	5	0.03	0	0	497	502	-17.5	0	484
- CO2 Equivalents (tonnes)	1,961	9	0	1,748	12,166	13,250	-13,297	2,581	2,535
Acid Gases									
- NOx (tonnes)	4.28	0.014	0	0.02	4.2	8.52	-97.3	48.5	-40.3
- SOx (tonnes)	1.08	0.004	0	0.13	0.96	2.16	-147	86.7	-58.1
- HCl (tonnes)	0.003	0	0	0.06	0.055	0.12	-330.9	1050.51	719.7
Smog Precursors									
- NOx (tonnes)	4.28	0.014	0	0	4.2	8.5	-97.3	48.5	-40.3
- PM (tonnes)	0.84	0.7	0	1.1	16.3	18.9	-50.8	28.7	-3.3
- VOCs (tonnes)	1.85	0.1	0	0.4	3.2	5.5	-90.3	52.8	-32
Heavy Metals & Organics									
- Air									
Pb (kg)	0.023	0	0	0	0.02	0	-4.48	2.46	-2
Hg (kg)	0.001	0	0	0	0.001	0	-0.02	0	-0.01
Cd (kg)	0.005	0	0	0	0.008	0.01	-0.02	0	0
Dioxins (TEQ) (g)	0.0001	0	0	0.004	0.001	0.005	n/a	0	0.005
- Water									
Pb (kg)	0.107	0.006	0	0.01	3.19	3.31	-22	19.4	0.7
Hg (kg)	0.0001	0.00001	0	0	0.075	0.075	0	0	0.077
Cd (kg)	0.009	0	0	0	4.48	4.49	-0.4	0.31	4.419
BOD (kg)	0.66	0.001	0	0	34,808	34,809	-26,566	30,995	39,238
Dioxins (TEQ) (g)	n/a	n/a	n/a	0	0.00035	0.0003	n/a	n/a	0.00035
Residual Waste (tonnes)	734	198	0	211	53,543	54,685	-3,587	2,464	53,562

Table 5: Comparison of Two Scenarios (Net Life Cycle Inventory)

	Scenario 1 Food to AD	Scenario 2 Base Case	Change in Burden	Net Change	Annual Burden Equivalents
Energy Consumed (GJ)	-297,798	-297,898	≈	100	Electricity for 0 homes
Greenhouse Gases					
CO2 (t)	-7,633	-9,362			
CH4 (t)	484	1,051			
CO2 Equivalents (t)	2,535	12,713	≈	10,179	Emissions from 2,700 cars
Acid Gases					
Nox (t)	-40.3	-39.66	≈	0.6	Emissions from 0 cars
Sox (t)	-58.14	-58.21	≈	0.1	Electricity for 0 homes
HCl (t)	719.75	719.75	≈	0.0	Electricity for 0 homes
Smog Precursors					
Nox (t)	-40.3	-39.66	≈	0.6	Emissions from 0 cars
PM (t)	-3.3	1.1	≈	4.4	Electricity for 1,000 homes
VOCs (t)	-32.0	-30.57	≈	1.4	Emissions from 0 cars
Heavy Metals & Organics					
Air					
Pb (kg)	-2.0	-1.97	≈	0.00	Electricity for 0 homes for one year
Hg (kg)	0.0	-0.01	≈	0.00	Electricity for 0 homes for one year
Cd (kg)	0.00	0.00	≈	0.00	Electricity for 200 homes for one year
PCDD/F (TEQ) g	0.00	0.00	≈	0.00	
Water					
Pb (kg)	0.70	1.76	≈	1.1	Electricity for 100 homes for one year
Hg (kg)	0.0769	0.102	≈	0.026	Electricity for 9,800 homes for one year
Cd (kg)	4.42	5.95	≈	1.54	Electricity for 17,100 homes for one year
BOD (kg)	39,238	51,179	≈	11,941	Sewage from 436 homes
PCDD/F (TEQ) g	3.48E-04	4.7E-04	≈	0.000119	
Total Residual Waste (tonnes)	53,562	72,884	≈	19,322	