# Niagara Region
# and
# City of Hamilton

## Final Draft Report on Comparative Emission Study

**June 2005**

**MacViro File: 5225**

5225

April 26, 2005

Mr. Drew Berketo
Acting Manager, Waste Policy and Planning
Public Works Department, Niagara Region
2201 St. David's Road
P.O. Box 1042
Thorold, ON L2V 4T7

and

Ms. Pat Parker
Manager of Solid Waste Planning
City of Hamilton
Solid Waste Management Division
71 Main Street West
Hamilton, ON L8E 4W8

**Re: Final Draft Comparative Emissions Study**

Dear Mr. Berketo & Ms. Parker:

MacViro Consultants Inc. is pleased to provide this final draft report. It presents the air emissions from an energy-from-waste (EFW) facility, which could be based on either gasification or combustion technology. The air emissions from such a potential facility are presented in relation to the air emissions from other Ontario sources of air pollution including; industrial sources, and electrical power generation.

The final draft report has been peer reviewed by Canadian ORTECH Environmental and their subconsultants: H.G. Rigo & Associates and Kelleher Environmental. Their recommendations have been incorporated into this final draft report.

We look forward to discussing this final draft report with the various interested parties and to preparing a final version of this report following the extended discussion of this draft.

Yours truly,
**MacViro Consultants Inc**.

Nenad Knezev, P.Eng.
Practice Leader
Air Emissions/Environmental Approvals

DOM/bmv

Enclosure

# Table of Contents

## List of Tables



## Appendices

# 1. Introduction

## 1.1 Background

Niagara Region and the City of Hamilton, as well as municipalities within the Greater Toronto Area (GTA), are involved in planning processes to select preferred approaches for managing the residual waste that will remain after the aggressive recycling and organics diversion programs have been implemented by these municipalities. Diversion targets in the order of 60 percent have been established for these various diversion programs (e.g., blue box, grey box and green bin programs plus other at-source recycling/diversion initiatives). The challenge is "what to do with the garbage that remains".

Presently, this residual waste is disposed of in landfills. Niagara Region and the City of Hamilton dispose of their waste in landfill sites within their respective municipalities. The City of Toronto and several of the other GTA municipalities export their waste to landfill sites in Michigan and other locations outside their municipal boundaries.

None of these current landfill facilities provide a good long-term solution for the disposal of the residual waste.

In broad terms, the options for the long-term disposal of residuals include either developing new landfill capacity or developing new physical, biological or thermal processes to significantly reduce the amount of future landfill disposal capacity required. Thermal processes, including gasification and combustion of waste, offer the potential of minimizing future landfill requirements and provide the added benefit of recovering the maximum amount of valuable energy from the waste.

## 1.2 Purpose of Report

When considering thermally based energy-from-waste (EFW) facilities, concerns are often expressed regarding the magnitude and nature of the air emissions from these facilities. Given the concerns commonly expressed about the air emissions from EFW facilities and a lack of readily available data on EFW facility emissions in Ontario, compared to that available for landfill operations, the purposes of this report are to:

- Identify what the air emissions from a modern thermal facility will be and to express the emissions in a manner that can be understood by members of the public; and
- Put these emissions into perspective by comparing them to other existing and accepted sources of air emissions.

It is hoped that by providing this information, an informed consideration of the role of thermal facilities in managing residual solid wastes will take place.

## 1.3 Overview of Report

The report explores a number of areas regarding EFW emissions outlined in the following sections.

**Section 2 – Annual EFW Emissions –** the annual emissions from an EFW facility processing 200,000 tonnes per year of post-diversion Residual Municipal Solid Waste (RMSW) is documented. This is the typical size of a facility required to meet the post diversion needs of Niagara Region and the City of Hamilton. The following emissions are presented as the pollutants typically of public concern:

- Greenhouse Gases (re: global warming);
- Acid Gases (re: acid rain);
- Smog Precursors (re. smog & bad air quality);
- Combustion Gases; and
- Trace Air Contaminants (e.g. heavy metals and dioxin/furans).

**Section 3 – Comparison of EFW Emissions to Other Common Air Emissions Sources** – the emissions from a 200,000 tonne per year EFW facility are put into perspective by considering them in relation to other existing Ontario sources of the same pollutants and other every day sources of those emissions such as cars, trucks, home heating furnaces and wood stoves/fireplaces.

**Section 4 – Comparison of EFW Emissions to Other Fossil Fuel Electricity Sources –** the emissions from an EFW facility are compared with those from other fossil fuel fired electrical energy sources. These sources include a current coal fired generating plant and several types of natural gas fired generating plants. Comparisons are provided on a per unit of energy produced (i.e. kilowatt hour) basis and on a total facility net electrical output basis (i.e. emissions from a coal fired or gas fired electricity generating facility that would produce the same quantity of electricity as a 200,000 tonne per year EFW facility).

**Section 5 – Reducing EFW Emissions –** the outlook and potential mechanisms for future reductions in the emissions from EFW facilities are considered.

**Section 6 – Additional Research and Studies –** the options for additional research and studies to further understand the implications of EFW facilities are identified.

A comparison of the net emissions from an EFW facility and other waste management system components (e.g. landfill sites and recycling facilities) will be undertaken as part of the Niagara-Hamilton WastePlan Environmental Assessment's evaluation of system alternatives. This comparison of net emissions will be made using the Integrated Solid Waste Management Model developed by the Corporations Supporting Recycling (CSR), the Environment and Plastics Industry Council (EPIC) and Environment Canada. This model uses a comprehensive life cycle assessment to estimate the environmental impacts from various waste management approaches.

The draft report has been peer reviewed by Canadian ORTECH Environmental Inc. and their subconsultants H.G. Rigo and Associates and Kelleher Environmental. Their recommendations have been incorporated into this report.

## 1.4 Glossary

A glossary of terms and abbreviations that are expected to be frequently used over the course of the Niagara-Hamilton WastePlan EA study is included in Appendix A. This glossary also includes information on units of measure and other information that will assist in the review of this report. The glossary will be continually updated over the course of the study.

# 2. Emissions from Thermal Facilities

Municipal waste processing facilities using thermal technologies, such as combustion and gasification, convert residual municipal solid waste (RMSW) into gaseous, liquid and solid conversion products with a simultaneous or subsequent release of heat energy. Air emissions released from thermal processing facilities arise from the compounds present in the waste stream, and are formed as a normal part of the combustion process like oxides of nitrogen, carbon dioxide and carbon monoxide. The Ontario Ministry of the Environment (MOE) has addressed air emissions from thermal facilities in Ontario Guideline A-7. All new publicly or privately-owned thermal systems (i.e. combustion and or gasification) designed to process municipal waste, as well as all existing thermal facilities that undergo expansion or modification, must comply with this Guideline. The requirements specified in Guideline A-7 are in addition to the requirements already listed in Ontario Regulation 346, including compliance with the Point of Impingement (POI) standards.

## 2.1 Guideline A-7

Guideline A-7 *Combustion and Air Pollution Control Requirements for New Municipal Waste Incinerators* was last updated in 2002. The guideline reflects the installation of state-of-the-art air pollution control systems, sets air emission limits for particulate matter, acid gases, metals and dioxins/furans and establishes requirements for the control, monitoring and performance testing of systems. Guideline A-7 is applied through conditions on Certificates of Approval in accordance with the requirements of the *Environmental Protection Act*, Part V, Section 27, and Part II, Section 9.

Emissions criteria specified in Guideline A-7 are very stringent. In all cases, the set limits are below those that would be established based solely on protection of human health and the environment (Reg. 346 POI Limits). They are comparable with the latest regulations governing comparable emissions from facilities in both the United States and Europe.

Table B-1, in Appendix B, provides a comparison of the maximum allowable concentration of various pollutants under:

- Ontario MOE Guideline A-7;
- Canadian Council of Ministers of the Environment (CCME) Guidelines (i.e. Canada's National Standard);
- US EPA New Incinerator Limits (i.e. the current US National Standard); and
- The European Union, New Incinerator Unit, Regulation (i.e., the current European Standard).

## 2.2 Combustion Technologies

### 2.2.1 Single-Stage Combustion Process

Single-stage combustion technology is well established. Waste is typically received in an enclosed tipping area and dumped into a receiving pit. The feed crane operator inspects waste in the pit and any large unacceptable materials are removed. The RMSW is then fed via a grapple crane into the feed chute, which guides it into combustion chamber.

The combustion chamber is usually equipped with a grate system which mechanically moves the RMSW and introduces air in a controlled manner. The material passes through the stages of drying, ignition, combustion and burn out as it travels down the grate. More air is added at various points in the chamber and above the fire at each stage of the process. Flue gases generated inside the combustion chamber pass upward into a burnout zone, where the temperature is maintained at approximately 1000 degrees Celsius. Ash is discharged from the bottom of the grate into a water-filled trough where it is quenched. This bottom ash may be further processed to recover metals for recycling. The bottom ash is non-hazardous and is generally disposed in a sanitary landfill. This ash can be used for landfill cover, and in some jurisdictions, is further processed for use as aggregate in road construction applications.

Urea, or other ammonia-based solutions, is commonly injected into the post-combustion flue gases for reduction of nitrogen oxide ($NO_x$) emissions in a process commonly known as a selective non-catalytic reduction (SNCR).

The flue gases pass through a boiler and economizer. Steam is generated and used for heat and/or to generate electricity using a steam turbine.

The exhaust gases pass through an air pollution control system that generally includes:

- Lime slurry scrubber or dry lime spray dryer to control acid gases ($SO_x$, HCl);
- Powdered activated carbon (PAC) injection system to control mercury and dioxins/furans; and
- A fabric filter (also known as a bag house) to remove particulate matter including gases captured by the lime and PAC.

The cleaned exhaust gases are discharged to the atmosphere via a stack. The solid material removed by the air pollution control system (fly ash) is classified as a hazardous waste due to the presence of the metals removed from the exhaust gases. It must be either treated to render it non-hazardous or disposed of in a secure landfill.

### 2.2.2 Two-Stage Gasification & Combustion Process

Two-stage units are generally modular units that have much less individual capacity than single-stage units. Facilities are constructed by assembling a number of modules on-site. A plant sized to meet the needs of the study area would consist of a number of modular gasification/combustion units operating in parallel.

As these units are smaller, waste may be received on a flat tipping floor, rather than in a pit. Waste is often loaded into the primary combustion chamber with a front-end loader. The waste is usually gasified in a starved-air condition, which leads to the formation of a combustible gas mixture and ash. The combustible gas mixture passes into a secondary chamber where it is fired with auxiliary fuel (if required) to complete combustion and to achieve a gas temperature of approximately 1000 degrees Celsius. The hot gases are cooled in boilers and the steam produced can be used for electricity production and/or heating.

Because of their size, coupled with their combustion configuration, these technologies employ a slightly different set of pollution control technologies for acid gases and oxides of nitrogen. The air pollution control system for these technologies generally includes:

- Wet lime slurry scrubbers or dry lime spray dryer scrubbers to control acid gases (SOx, HCl);
- PAC system to control mercury and dioxins/furans;
- A fabric filter (also know as a bag house) to remove particulate matter; and
- Selective catalytic reactor (SCR) to control oxides of nitrogen ($NO_x$) since the temperature zones needed for the SNCR reaction to proceed, are frequently inaccessible.

The bottom ash from two-stage combustion units may contain more unburned carbon than single-stage combustion units. In other respects, the bottom ash and air pollution control system residues from this technology are similar to those produced by larger single-stage combustion units.

## 2.3 Gasification Technologies

### 2.3.1 Residual Municipal Solid Waste (RMSW) Gasification

One type of RMSW gasification technology involves first compressing the RMSW into cubes, and inserting them into a heated gas-tight channel leading to the gasifiers. As the cubes move through the input channel, the material is dried and volatile compounds are driven off as the material heats up. The cubes are eventually introduced into the main gasification chamber with less than stoichiometric air, operating at approximately 1200 degrees Celsius. A synthetic gas containing primarily hydrogen, carbon monoxide, and carbon dioxide is produced. The syngas is quenched and washed using scrubbers prior to use. It can either be cleaned up for use elsewhere or converted into steam and electricity on-site using conventional diesel or gas turbine based combined cycle technology. The molten residue stream from the gasifier is quenched in a water bath and can be separated to vitrified aggregate and metal pellets.

Wastewater from the facility requires treatment prior to discharge. Since the syngas is cleaned prior to its combustion, a separate air pollution control system is generally not required for the combustion gases in order to meet air emission standards.

### 2.3.2 Alternative Fuel Gasification and Combustion

This type of technology involves front-end processing of the input RMSW stream in order to produce an alternative fuel which is RMSW shredded to reduce its size and separated to remove non-combustible materials which will not gasify. The alternative fuel is gasified in a gasification chamber, and the synthetic gas is then cleaned and combusted in a gas engine, gas turbine, or steam/hot water boiler.

Front-end processing of RMSW, prior to gasification, to produce an alternative fuel may include the following:

- Shredding to open the bags and produce a material with a more uniform size;
- Magnetic and eddy current separators to remove ferrous and non-ferrous (mostly aluminum and brass) metals;
- Screens to remove small sized organic materials and fines (dirt and stones along with glass chips);

- Material drying via aerobic composting; and
- Air classification to separate light combustible materials (e.g. paper and plastic) from heavy non-combustible materials (e.g. glass).

The alternative fuel is loaded into the gasifier chambers and heated to a little less than 1000 degrees Celsius. A residual char is produced that might be processed for beneficial use if the residual metals can be removed or will require landfill disposal. Like all RMSW gasification units, synthetic gas is first quenched which reduces the amount of available energy and then washed with scrubbers prior to use. Wastewater requires treatment prior to discharge.

The alternative fuel could also be combusted in an approved utility boiler or a cement kiln, provided the facility was equipped with the required air pollution control equipment that produced emissions in compliance with either the requirements of Guideline A-7 or with site specific emission limits established by MOE.

## 2.4 Air Emissions Information

The data provided by potential vendors to Niagara Region in 2003 as part of their Long-Term Disposal Study were studied and the median values were compared to Ontario Guideline A-7. Data was received from the following manufacturers:

**Combustion Technologies**

- Barlow Projects Inc.
- Bear Necessities Waste & Food Inc.
- Montenay Inc.
- Wheelabrator Technologies Inc.
- Integrated Municipal Services Inc.

**Gasification Technologies**

- Interstate Waste Technologies Inc.
- Brightstar Environmental
- E.S. Fox/MCW/Enerkem
- State Group Industrial Ltd/Ecomaster

The median concentrations from the emissions data provided by the combustion and gasification technology suppliers are summarized in Table 2-1. Additional information is provided in Appendix C.

**Table 2-1 Summary of Emissions Data – Median Concentrations**

| Process | | | Median of Combustion Technologies | Median of Gasification Technologies |
|---|---|---|---|---|
| **Ontario A-7 Parameter** | **A-7 Limit** | **Units (1)** | | |
| Total Particulate Matter (TPM) | 17 | mg/Rm$^3$ @ 11% $O_2$ | 6.9 | 5.0 |
| Cadmium (Cd) | 14 | µg/Rm$^3$ @ 11% $O_2$ | 4.9 | 8.8 |
| Lead (Pb) | 142 | µg/Rm$^3$ @ 11% $O_2$ | 44.5 | 57.5 |
| Mercury (Hg) | 20 | µg/Rm$^3$ @ 11% $O_2$ | 10.0 | 9.6 |
| Dioxin/Furan PCDD/F TEQ | 0.08 | ng/Rm$^3$ @ 11% $O_2$ | 0.02 | 0.03 |
| Hydrogen Chloride (HCl) | 27 | mg/Rm$^3$ @ 11% $O_2$ | 10.0 | 4.2 |

| Process | | | Median of Combustion Technologies | Median of Gasification Technologies |
|---|---|---|---|---|
| **Ontario A-7 Parameter** | **A-7 Limit** | **Units (1)** | | |
| Sulphur Dioxide ($SO_2$) | 56 | $mg/Rm^3$ @ 11% $O_2$ | 10.8 | 18.2 |
| Nitrogen Oxides ($NO_x$) as $NO_2$ | 207 | $mg/Rm^3$ @ 11% $O_2$ | 185.7 | 149.0 |
| Organic Matter (as Methane) | 100 | ppmv undiluted | 1.1 | 12.0 |
| Carbon Monoxide (CO) | 49 | $mg/Rm^3$ @ 11% $O_2$ | 10.5 | 20.0 |

(1) mg – milligram; µg- microgram; ng- nanogram; ppmv- parts per million by volume; R- reference gas conditions(dry, 25°C, 101.3 kPa); TEQ- dioxin toxicity equivalent value compared to 2,3,7,8 tetrachlorodibenzo-p-dioxin.

Air emissions from both combustion and gasification are below the required levels of Ontario Guideline A-7. Between the two overall technology types, neither process has lower air emissions for all parameters. Based on the received emissions test data, it appears that combustion technologies have a higher median emission concentration for particulate matter, hydrogen chloride, nitrogen oxides and mercury, while gasification technologies show a higher median emission rate for sulphur dioxide, carbon monoxide, cadmium, lead, organic matter and dioxins and furans. However, these trends are specific for the data presented and may vary depending on the source waste and the type of technology utilized.

While Table 2-1 presents median emissions, Table 2-2 illustrates the range of emissions information provided by the various vendors.

**Table 2-2 Summary of Emissions Data – Concentration Ranges**

| Process | | | Combustion Technologies | | Gasification Technologies | |
|---|---|---|---|---|---|---|
| Ontario A-7 Parameter | A-7 Limit | Units | Minimum | Maximum | Minimum | Maximum |
| Total Particulate Matter (TPM) | 17 | $mg/Rm^3$ @ 11% $O_2$ | 3.1 | 10.0 | 3.3 | 7.6 |
| Cadmium (Cd) | 14 | $\mu g/Rm^3$ @ 11% $O_2$ | 0.2 | 7.0 | 3.8 | 11.0 |
| Lead (Pb) | 142 | $\mu g/Rm^3$ @ 11% $O_2$ | 3.7 | 83.0 | 6.0 | 100.0 |
| Mercury (Hg) | 20 | $\mu g/Rm^3$ @ 11% $O_2$ | 0.8 | 18.5 | 3.0 | 20.0 |
| Dioxin/Furan PCDD/F TEQ | 0.08 | $ng/Rm^3$ @ 11% $O_2$ | 0.01 | 0.04 | 0.003 | 0.04 |
| Hydrogen Chloride (HCl) | 27 | $mg/Rm^3$ @ 11% $O_2$ | 2.5 | 10.2 | 1.0 | 12.0 |
| Sulphur Dioxide ($SO_2$) | 56 | $mg/Rm^3$ @ 11% $O_2$ | 0.5 | 33.0 | 2.0 | 50.0 |
| Nitrogen Oxides ($NO_x$) as $NO_2$ | 207 | $mg/Rm^3$ @ 11% $O_2$ | 122.1 | 207.0 | 58.0 | 200.0 |

| Process | | | Combustion Technologies | | Gasification Technologies | |
|---|---|---|---|---|---|---|
| Organic Matter (as Methane) | 100 | ppmv undiluted | 1.0 | 1.1 | 4.0 | 15.0 |
| Carbon Monoxide (CO) | 49 | mg/Rm$^3$ @ 11% $O_2$ | 2.1 | 15.0 | 5.0 | 49.0 |

Note: Vendors did not provide information on $N_2O$ emission concentrations. Based on test data from similar facilities, $N_2O$ concentrations are negligible for the proposed combustion technologies.

The vendor submittals show that for all parameters, the maximum air emissions levels from both combustion and gasification technologies meet Ontario Guideline A-7. The emission data that vendors provided from their facilities, operating throughout the world, were based on the facility being designed to meet local criteria. This local criterion is different than Ontario Guideline A-7. However, facilities can easily be designed to meet A-7 with readily available technologies. Therefore, in the case of nitrogen oxides in Table 2-2, the maximum value from the vendor has been substituted with the A-7 limit with the expectation that the technology would be designed to meet A-7. From the range of values, it can be seen that the two broad process categories have similar ranges for most parameters. This is further evidence that on a concentration basis, the two technology types have similar emissions.

The air emissions from either combustion or gasification technologies would also have to meet MOE Reg 346 Point of Impingement (POI) objectives. Calculations or assessment of the ability of the facility to meet Reg 346 criteria was not assessed, in detail, in this study, as such calculations are site specific. However, based on available information from similar combustion facilities, with a conservative assumption of a relatively short stack (50m), the maximum ground level concentration is expected to be in the range of 0.003% to 5% of Reg 346, depending on the contaminant (well below the specified limits).

The above information is organized and presented in the format set out in Guideline A-7. In order to better understand the nature and magnitude of these emissions, the information on flue gas concentrations has been combined with additional information on mass balances and flue gas flow rates provided by the various technology vendors to develop an estimate of the total annual emissions from a thermal processing facility processing 200,000 tonnes per year (TPY) of post diversion RMSW.

The information on the various pollutants has been grouped under the following categories:

- Greenhouse Gases;
- Acid Gases;
- Smog Precursors;
- Combustion Gases; and
- Trace Air Contaminants

The estimated annual emissions from a 200,000 tonne per year EFW facility utilizing combustion technology are presented in Table 2-3. As with the previously presented concentration information, the values presented in Table 2-3 are the typical values from the information data submitted by the various technology vendors listed at the beginning of this section multiplied by the calculated amount of gas that would be emitted from a facility burning 200,000 TPY (approximately 600 tonnes per day) of post diversion RMSW.

Combustion technologies are more commonly used to process RMSW than gasification technologies. As well, there was limited data on gasification technologies from vendors.

Therefore, the combustion data is used for comparison purposes. In the remainder of this report, the median combustion emissions will be referred to as the Estimated Total Annual Emissions from a 200,000 tonne per year EFW Facility. For more information on the given combustion and gasification data given from vendors, refer to Appendix C.

**Table 2-3 Estimated Annual Emissions from a 200,000 tonne per year EFW Facility**

| | Median Combustion Technologies kg/y |
|---|---|
| **Greenhouse Gases** | |
| Carbon Dioxide ($CO_2$) | 159,774,500 |
| Organic Matter (as $CH_4$) | 600 |
| Organic Matter (as $CO_2$ equivalent) | 12,593 |
| Nitrous Oxide ($N_2O$) | negligible |
| Nitrous Oxide (as $CO_2$ equivalent) | negligible |
| Total $CO_2$ Equivalent | 159,787,093 |
| **Acid Gases** | |
| Nitrogen Oxides $NO_x$ and $NO_2$ | 185,400 |
| Sulphur Dioxide | 8,480 |
| Hydrogen Chloride | 9,720 |
| **Smog Precursors** | |
| Nitrogen Oxides ($NO_x$) as $NO_2$ | 185,400 |
| Total Particulate Matter | 4,920 |
| Particulate Matter ≤ 2.5 µm] | 4,920 |
| **Combustion Gases** | |
| Carbon Monoxide | 10,220 |
| **Trace Air Contaminants** | |
| Cadmium | 4.86 |
| Lead | 49.8 |
| Mercury | 7.9 |
| Dioxins/Furans (TEQ) | 3.84E-5 |

# 3. Emissions of Pollutants of Concern from Other Sources

This section provides a perspective on the annual emissions from a 200,000 tonne per year energy-from-waste (EFW) facility in relation to other Ontario sources of emissions from energy facilities, transportation, and domestic activities such as driving cars and heating homes. This perspective is provided by presenting total Ontario wide emissions of the individual pollutants together with information on the major sources of these pollutants. This information is then compared with the emissions from a 200,000 tonne per year state-of-the-art EFW facility.

A 200,000 tonne per year facility is the order of magnitude size required to process the post diversion RMSW from Niagara Region and the City of Hamilton. The emissions from this hypothetical facility are based on the medians of the emissions from approximately 5 combustion technologies whose vendors submitted detailed emissions data to Niagara Region in 2003 as part of their Long Term Disposal Study. These five facilities are typical with other facilities around the world and are consistent with general literature. All of the emissions data considered meets the limits set out in Ontario Guideline A-7 and are considered to be reasonable estimates of the emissions that would result from a state-of-the-art EFW facility.

The emissions considered include greenhouse gases, acid gases, smog precursors, combustion gases and trace air contaminants. The particular pollutants considered were selected, based on the air pollutants typically of concern to the public and also those addressed in Ontario Guideline A-7.

The emissions data from Ontario sources was obtained from the Environment Canada Greenhouse Gas database and the Environmental Canada National Pollutant Release Inventory (NPRI) 2002 database. The NPRI database does not include data from mobile sources (such as cars and trucks) or households (such as residential fireplaces and wood-burning stoves). This data is based on information reported from industries and have not been independently verified.

Emissions data for automobiles and natural gas combustion was obtained from United States – Environmental Protection Agency (US-EPA) AP-42, *Compilation of Air Pollutant Emission Factors*, Volume 1. Emissions data for diesel trucks was obtained from the Corporations Supporting Recycling (CSR) and the Environment and Plastics Industry Council (EPIC) Integrated Solid Waste Model last modified on March 2004.

The annual kilometres driven for both automobiles and trucks were obtained from the *Transportation in Canada, 2003 Annual Report* from Transport Canada. The average quantity of natural gas consumed by residences was taken from the Ontario Energy Board – Enbridge Gas Distribution Inc.

Appendix D provides more detailed information from these databases on the various sources of emissions.

## 3.1 Greenhouse Gas Emissions

Greenhouse gas emissions are the pollutants that contribute to global warming.

Table 3-1 presents information on greenhouse gas emissions in Ontario in 2002. These emissions are composed primarily of carbon dioxide ($CO_2$) and nitrous oxide ($N_2O$) from combustion of fossil fuels, and methane ($CH_4$) from various sources. The greenhouse gas effect of methane and nitrous oxide is approximately 21 and 310 times greater than carbon dioxide, respectively. The global warming potential for methane and nitrous oxide was taken from Environment Canada, 2002 Greenhouse Gas Emission Summary. In order to provide a meaningful comparison, the methane and nitrous oxide emissions have been converted to an equivalent amount of carbon dioxide and then added to the carbon dioxide quantities to yield the total greenhouse gas emissions expressed as equivalent tonnes of $CO_2$.

**Table 3-1 Greenhouse Gas Emissions**

| Source | Tonnes of $CO_2$ Equivalent |
|---|---|
| Total Annual Ontario Emissions (1) | 202,000,000 |
| Stationary Combustion Sources | 102,000,000 |
| Transportation Combustion Sources | 62,200,000 |
| Non combustion Industrial and Agricultural Sources | 22,700,000 |
| Waste Management Activities | 8,100,000 |
| Other Sources | 7,000,000 |
| | |
| Estimated total annual emissions from a 200,000 tpy EFW facility | 159,787 |
| | |
| Emissions from EFW facility as a percentage of total Ontario emissions | 0.08% |
| Emissions from EFW facility as a percentage of Ontario wide waste management activities | 2.0% |

(1) Source: Environment Canada Greenhouse Gas Database (2002 Data)

Table 3-1 presents the estimated annual Ontario wide emissions of greenhouse gases in 2002 of 202 million tonnes, together with the breakdown of this total into:

- Emissions from stationary combustion sources such as home heating furnaces and fossil fuel fired electricity generating stations represented 50% of the total Ontario carbon dioxide equivalent emissions;
- Emissions from transportation sources such as cars, trucks, and aeroplanes represented 31% of the total Ontario carbon dioxide equivalent emissions;
- Emissions from non combustion industrial and agricultural sources represented 11% of the total Ontario carbon dioxide equivalent emissions; and
- Emissions from waste management activities including those from landfills represented 4% of the total Ontario carbon dioxide equivalent emissions.

Additional details on these sources of greenhouse gas emissions are provided in Appendix D in Table 1.

Table 3-1 also presents the emissions from a 200,000 tonne per year EFW facility as less than 0.08% of the total Ontario wide greenhouse gas emissions and less than 2.0% of the emissions from waste management activities in Ontario.

The annual greenhouse gas emissions from an EFW facility thermally processing 200,000 tonnes per year of post diversion RMSW is estimated to equal 159,787 tonnes of $CO_2$ equivalent per year. This quantity of carbon dioxide is equivalent to the quantity released from approximately:

- 34,961 automobiles each travelling 17,600 km per year; or
- 1,593 diesel trucks each travelling 91,200 km per year; or
- 27,741 homes heated with natural gas fired residential furnaces.

In summary, although 159,787 tonnes is a significant quantity of carbon dioxide, it is an extremely small quantity in relation to the total Ontario wide emissions of greenhouse gases. It is also small in relation to the greenhouse gas emissions generated by the residents of Niagara Region and the City of Hamilton in driving their cars and heating their homes.

## 3.2 Acid Gas Emissions

Acid gas emissions contribute to the formation of "acid rain". These acid gas emissions include nitrogen oxides ($NO_x$), sulphur oxides and hydrogen chloride. Table 3-2 illustrates the emissions of nitrogen oxides (expressed as $NO_2$), sulphur dioxide and hydrogen chloride from a 200,000 tonne per year EFW facility in relation to:

- total annual Ontario emissions of these pollutants;
- the emissions from the top 10 sources of these pollutants; and
- the emissions from Ontario's largest single source of these pollutants.

Additional details on these sources of acid gas emissions are provided in Appendix D in Tables 2, 3 and 4.

This table also illustrates where the emissions from a 200,000 tonne per year EFW facility would rank in relation to the other individual sources of these pollutants. An EFW facility of this size would be the 87th largest emitter of nitrogen oxides in Ontario, (i.e., 86 other sources would emit more).

**Table 3-2 Acid Gas Emissions**

| | Nitogen Oxides $NO_x$ (2) (as $NO_2$) | Sulphur Dioxide (3) ($SO_2$) | Hydrogen Chloride (HCl) (4) |
|---|---|---|---|
| Total annual Ontario air emissions (1) in tonnes | 155,638 | 563,376 | 10,346 |
| Total annual Ontario air emissions from top ten sources (1) in tonnes | 84,066 | 464,709 | 9,829 |
| Total annual Ontario air emissions from largest single source (1) in tonnes | 38,203 | 235,907 | 6,749 |
| | | | |
| Estimated total annual emissions from a 200,000 tpy EFW facility in tonnes | 185 | 8.5 | 9.7 |
| | | | |
| Emissions from EFW facility as a percentage of | 0.1% | 0.002% | 0.09% |

| | Nitogen Oxides $NO_x$ (2) (as $NO_2$) | Sulphur Dioxide (3) ($SO_2$) | Hydrogen Chloride (HCl) (4) |
|---|---|---|---|
| total annual Ontario air emissions | | | |
| Emissions from EFW facility as a percentage of total annual air emissions from top ten Ontario sources | 0.2% | 0.002% | 0.1% |
| Emissions from EFW facility as a percentage of total annual air emissions from largest single source in Ontario | 0.5% | 0.004% | 0.1% |
| | | | |
| Ranking in relation to all Ontario facilities reporting to NPRI in 2002 | 87th | 104th | 27nd |

(1) Source: Environment Canada 2002 NPRI Database
(2) 366 facilities reported to the NPRI Database
(3) 230 facilities reported to the NPRI Database
(4) 180 facilities reported to the NPRI Database

#### Nitrogen Oxides

The annual nitrogen oxides emissions from an EFW facility thermally processing 200,000 tonnes per year of post diversion RMSW is estimated to equal 185 tonnes per year. This annual quantity of nitrogen oxides is equivalent to the quantity released from approximately:

- 12,126 automobiles each travelling 17,600 km per year; or
- 203 diesel trucks (e.g., 18 wheelers) each travelling 91,200 km per year; or
- 41,090 homes heated with natural gas fired residential furnaces.

#### Sulphur Dioxide

The annual sulphur dioxide emissions from an EFW facility thermally processing 200,000 tonnes per year of post diversion RMSW is estimated to equal 8.5 tonnes per year. This annual amount of sulphur dioxide is approximately equivalent to:

- 55 diesel trucks each travelling 91,200 km per year.

Automobiles and homes heated with natural gas emit negligible amounts of sulphur dioxide.

#### Hydrogen Chloride

An EFW facility thermally processing 200,000 tonnes of post diversion RMSW per year is estimated to emit approximately 9.7 tonnes of hydrogen chloride annually.

Automobiles, diesel trucks, and homes heated with natural gas emit negligible amounts of hydrogen chloride.

In summary, the emissions of pollutants causing acid rain from a 200,000 tonne per year EFW facility are very small in relation to other existing sources of acid gas emissions in Ontario.

## 3.3 Smog Precursors

A variety of pollutants, including nitrogen oxides (note that $NO_x$ is both an acid gas and a smog precursor), total particulate matter and fine particulate matter with particle size equal or less than 2.5 microns (PM2.5) contribute to the formation of smog. Table 3-3 illustrates the emissions of these three specified smog precursors from a 200,000 tonne per year EFW facility in relation to:

- total annual Ontario emissions of these pollutants;
- the emissions from the top 10 sources of these pollutants in Ontario; and
- the emissions from Ontario's largest single source of these pollutants.

Additional details on these sources of smog precursors are provided in Appendix D in Tables 2,5 and 6.

This table also illustrates where the emissions from a 200,000 tonne per year EFW facility would rank in relation to the other individual sources of these pollutants.

**Table 3-3 Smog Precursors**

| | Nitogen Oxides $NO_x$ (as $NO_2$) (2) | Total Particulate Matter (TPM) (3) | Particulate Matter Dia. ≤2.5 µm] (PM2.5) (4) |
|---|---|---|---|
| Total annual Ontario air emissions (1) in tonnes | 155,638 | 61,793 | 22,760 |
| Total annual Ontario air emissions from top ten sources (1) in tonnes | 84,066 | 30,061 | 11,148 |
| Total annual Ontario air emissions from largest single source (1) in tonnes | 38,204 | 7,768 | 2,546 |
| | | | |
| Estimated total annual emissions from a 200,000 tpy EFW facility in tonnes | 185 | 4.9 | 4.9 (5) |
| | | | |
| Emissions from EFW facility as a percentage of total annual Ontario air emissions | 0.1% | 0.008% | 0.02% |
| Emissions from EFW facility as a percentage of total annual air emissions from top ten Ontario sources | 0.2% | 0.02% | 0.04% |
| Emissions from EFW facility as a percentage of total annual air emissions from largest single source in Ontario | 0.5% | 0.06% | 0.2% |
| | | | |
| Ranking in relation to all Ontario facilities reporting to NPRI in 2002 | 87th | 276th | 226th |

(1) Source: Environment Canada 2002 NPRI Database
(2) 366 facilities reported to the NPRI Database
(3) 451 facilities reported to the NPRI Database
(4) 920 facilities reported to the NPRI Database
(5) Based on the proposed combustion and air pollution control equipment, it is assumed that all particulate matter will be PM2.5

#### Nitrogen Oxides

The annual nitrogen oxides emissions from an EFW facility thermally processing 200,000 tonnes per year of post diversion RMSW is estimated to equal 185 tonnes per year. This annual quantity of nitrogen oxides is equivalent to the quantity released from approximately:

- 12,126 automobiles each travelling 17,600 km per year (for $NO_x$); or
- 203 diesel trucks (e.g., 18 wheelers) each travelling 91,200 km per year (for $NO_x$); or
- 41,090 homes heated with natural gas fired residential furnaces (for $NO_x$).

#### Total Particulate Matter (TPM)

The annual total particulate matter emissions from an EFW facility thermally processing 200,000 tonnes per year of post diversion RMSW is estimated to equal 4.9 tonnes per year. This quantity of TPM is equivalent to the quantity released from approximately:

- 39 diesel trucks (18 wheelers) each travelling 91,200 km per year; or
- 53,947 homes heated with natural gas fired residential furnaces; or,
- 28,439 fires in a residential fireplace, each burning 10 kg of wood per fire.

Automobiles emit negligible amounts of particulate matter.

#### Particulate Matter less than 2.5 microns (PM2.5)

Since particulate emissions from an EFW facility are typically PM2.5 (as larger particle sizes are usually removed by the air pollution control systems), for comparative purposes, it is assumed that all particulate matter will be PM2.5 (as mentioned in Table 3-3).

Therefore, the PM2.5 emissions from an EFW facility thermally processing 200,000 tonnes per year of post diversion RMSW are estimated to equal 4.9 tonnes per year, the same amount as TPM for such a facility. This quantity of PM2.5 is equivalent to the quantity released from approximately:

- 53,947 homes heated with natural gas fired residential furnaces.

The diesel trucks comparison data presented for particulate matter is for particulates less than 10 microns (PM10) in diameter. PM10 also includes particles less than 2.5 microns, but the exact proportion of PM10 to PM2.5 is unknown. As there is no data available for solely PM2.5 emissions from diesel trucks and residential fireplaces, a comparison has not been undertaken.

In summary, the emissions of smog causing contaminants from a 200,000 tonne per year EFW facility is very small in relation to other existing sources of smog precursors in Ontario.

## 3.4 Combustion Gases

Incomplete combustion processes leads to the formation of carbon monoxide. Table 3-4 illustrates the emissions of carbon monoxide from a 200,000 tonne per year EFW facility in relation to:

- total annual Ontario emissions of this pollutant;
- the emissions from the top 10 sources of carbon monoxide in Ontario; and

- the emissions from Ontario's largest single source of carbon monoxide.

Additional details on these sources of carbon monoxide are provided in Appendix D in Table 7.

This table also illustrates where the emission from a 200,000 tonne per year EFW facility would rank in relation to the other individual sources of this pollutant.

**Table 3-4 Combustion Gases**

| | Carbon Monoxide (CO) (2) |
|---|---|
| Total annual Ontario air emissions (1) in tonnes | 156,820 |
| Total annual Ontario air emissions from top ten sources (1) in tonnes | 72,085 |
| Total annual Ontario air emissions from largest single source (1) in tonnes | 18,227 |
| | |
| Estimated total annual emissions from a 200,000 tpy EFW facility in tonnes | 10.2 |
| | |
| Emissions from EFW facility as a percentage of total annual Ontario air emissions | 0.007% |
| Emissions from EFW facility as a percentage of total annual air emissions from top ten Ontario sources | 0.01% |
| Emissions from EFW facility as a percentage of total annual air emissions from largest single source in Ontario | 0.06% |
| | |
| Ranking in relation to all Ontario facilities reporting to NPRI in 2002 | 290th |

(1) Source: Environment Canada 2002 NPRI Database
(2) 406 facilities reported to the NPRI Database

The annual carbon monoxide emissions from an EFW facility thermally processing 200,000 tonnes per year of post diversion RMSW are estimated to equal 10.2 tonnes per year. This quantity of carbon monoxide is equivalent to the quantity released from approximately:

- 44 automobiles each travelling 17,600 km per year; or
- 5,323 homes heated with natural gas fired residential furnaces.

Diesel trucks emit negligible amounts of carbon monoxide.

In summary, the emissions of carbon monoxide from a 200,000 tonne per year EFW facility are very small in relation to other existing sources of combustion gases.

## 3.5 Trace Air Contaminants

A number of pollutants, in sufficiently high concentrations, can cause toxic effects. These pollutants include heavy metals (cadmium, lead and mercury) and organic pollutants such as dioxins/furans. Tables 3-5 and 3-6 illustrate the emissions of these trace air contaminants from a 200,000 tonne per year EFW facility in relation to:

- total annual Ontario emissions of these pollutants;

- the emissions from the top 10 sources of these pollutants in Ontario; and
- the emissions from Ontario's largest single source of these pollutants.

Additional details on these sources of trace air emissions are provided in Appendix D in Tables 8, 9, 10 and 11.

These tables also illustrate where the emissions from a 200,000 tonne per year EFW facility would rank in relation to the other individual sources of these pollutants.

**Table 3-5 Trace Air Contaminants – Heavy Metals**

| | Cadmium (Cd) (2) | Lead (Pb) (3) | Mercury (Hg) (4) |
|---|---|---|---|
| Total annual Ontario air emissions (1) in kg | 8,474 | 203,672 | 1,474 |
| Total annual Ontario air emissions from top ten sources (1) in kg | 7,982 | 177,538 | 951 |
| Total annual Ontario air emissions from largest single source (1) in kg | 4,984 | 77,283 | 242 |
| | | | |
| Estimated total annual emissions from a 200,000 tpy EFW facility in kg | 4.9 | 50 | 7.9 |
| | | | |
| Emissions from EFW facility as a percentage of total annual Ontario air emissions | 0.06% | 0.02% | 0.5% |
| Emissions from EFW facility as a percentage of total annual air emissions from top ten Ontario sources | 0.06% | 0.03% | 0.8% |
| Emissions from EFW facility as a percentage of total annual air emissions from largest single source in Ontario | 0.1% | 0.06% | 3.3% |
| | | | |
| Ranking in relation to all Ontario facilities reporting to NPRI in 2002 | 48th | 74th | 34th |

(1) Source: Environment Canada 2002 NPRI Database
(2) 113 facilities reported to the NPRI Database
(3) 296 facilities reported to the NPRI Database
(4) 122 facilities reported to the NPRI Database

### Cadmium

The annual cadmium emissions from an EFW facility thermally processing 200,000 tonnes per year of post diversion RMSW are estimated to equal 4.9 kg per year. This quantity of cadmium is equivalent to the quantity released from approximately:

- 33,655 residences heated with distillate No. 2 fuel oil; or
- 2,664 diesel trucks each travelling 91,200 km per year.

Automobiles and homes heated with natural gas release negligible amounts of cadmium.

### Lead

The annual lead emissions from an EFW facility thermally processing 200,000 tonnes per year of post diversion RMSW are estimated to equal 50 kg per year. This quantity of lead is equivalent to the quantity released from approximately:

- 114,955 residences heated with distillate No. 2 fuel oil; or
- 9,071 diesel trucks each travelling 91,200 km per year.

Automobiles and homes heated with natural gas release negligible amounts of lead.

### Mercury

The annual mercury emissions from an EFW facility thermally processing 200,000 tonnes per year of post diversion RMSW are estimated to equal 7.9 kg per year. This quantity of mercury is equivalent to the quantity released from approximately:

- 54,707 residences heated with distillate No. 2 fuel oil; or
- 4,331 diesel trucks each travelling 91,200 km per year.

Automobiles, diesel trucks and homes heated with natural gas release negligible amounts of mercury.

**Table 3-6 Trace Air Contaminants – Organic Pollutants**

| | Dioxins/Furans (2) |
|---|---|
| Total annual Ontario air emissions (1) in g TEQ | 23 |
| Total annual Ontario air emissions from top ten sources (1) in g TEQ | 21 |
| Total annual Ontario air emissions from largest single source (1) in g TEQ | 10 |
| | |
| Estimated total annual emissions from a 200,000 tpy EFW facility in g TEQ | 0.04 |
| | |
| Emissions from EFW facility as a percentage of total annual Ontario air emissions | 0.2% |
| Emissions from EFW facility as a percentage of total annual air emissions from top ten Ontario sources | 0.2% |
| Emissions from EFW facility as a percentage of total annual air emissions from largest single source in Ontario | 0.4% |
| | |
| Ranking in relation to all Ontario facilities reporting to NPRI in 2002 | 26th |

(1) Source: Environment Canada 2002 NPRI Database
(2) 81 facilities reported to the NPRI Database

The annual dioxin/furan emissions from an EFW facility thermally processing 200,000 tonnes per year of post diversion RMSW are estimated to equal 0.04 grams (TEQ) per year. This quantity of dioxins/furans is equivalent to the quantity released from approximately:

- 1,684 diesel trucks each travelling 91,200 km per year; or
- the open burning, in an uncontrolled fashion, of approximately 192 tonnes of waste.

Automobiles emit negligible amounts of dioxins/furans.

Air pollution control equipment for EFW facilities can be updated in existing facilities as new technologies develop. For example, in 2001 the Algonquin Power EFW facility (formerly KMS Peel Inc.) dioxin emissions were 0.243g TEQ, based on NPRI data. Since then, air pollution control equipment has been installed in the existing EFW facility and the dioxin emissions in 2002 and 2003 were reduced to below the NPRI reporting threshold (based on 2002 and preliminary 2003 NPRI data) each year.

Some preliminary research indicates that dioxins/furans emissions from EFW facilities have now been reduced to such low levels that more direct emissions of these contaminants result from recycling the contents of the blue box than combusting the RMSW. This preliminary research indicates that a 200,000 tonne per year EFW facility would generate as much dioxins/furans as recycling 33,391 tonnes of ferrous material or 1,811 tonnes of aluminum. Further research will be undertaken as part of the comparison of net emissions from waste management system components as part of the Niagara-Hamilton WastePlan EA.

In summary, the emissions of these heavy metal and organic pollutants from a 200,000 tonne per year EFW facility are very small in relation to other existing sources of these trace air contaminants.

# 4. Emissions from Other Energy Sources

This section provides a perspective on the emissions from an EFW facility in relation to the stack emissions from other thermal electricity generating facilities. This perspective is provided by considering three types of commonly used thermal power plants: a current coal fired power plant, an efficient combined cycle natural gas fired power plant and a steam turbine natural gas fired power plant.

The relevant emissions are presented first on a per kilowatt-hour (kWh) basis. Specifically if a consumer of electricity chooses to switch on a light, or turns on an electric heater and consumes one kWh of electricity, what package of pollutants would be emitted to the atmosphere if the kWh of electricity was produced by:

- an EFW facility
- a coal fired power plant
- a combined cycle natural gas fired power plant (gas turbine/generator, steam boiler and steam turbine/generator)
- a steam turbine natural gas fired power plant (steam boiler and steam turbine/generator)

An alternative perspective is provided by considering the annual emissions and electrical output from a 200,000 tonne per year EFW facility in relation to coal and natural gas fired power plants producing the same amount of electricity as the EFW facility.

The considered emissions include greenhouse gases, acid gases, smog precursors, combustion gases and trace air contaminants. Appendix E provides detailed information on emissions from each type of energy source described.

## 4.1 Coal Fired Power Generating Plant

Coal fired power plants combust coal to generate heat. The heat is used to boil water and generate steam. The steam passes through a steam turbine, which spins a generator to produce electricity.

Annual stack emissions data was obtained from various sources including The Ontario Ministry of the Environment (MOE) OnAir Regulation 127 database for a large Ontario Power Generation (OPG) facility and average NPRI emission rate numbers. Based on the information collected, it was possible to generate emission factors with units of grams of pollutant released per kilowatt-hour of net electricity produced.

It should be noted that the emissions taken from the OPG facility were stack emissions only and did not include fugitive, storage, or road dust emissions.

## 4.1. Combined Cycle Natural Gas Fired Power Generating Plant

Combined cycle natural gas fired power plants generate electricity using a combination of gas and steam cycles. Natural gas is burned in a turbine to turn a generator and create electricity. The hot exhaust gases exiting the gas turbine are used to heat water and create steam. The steam is then used to turn a steam turbine, which turns a generator to create additional electricity. The benefit of combined cycle natural gas fired power plants is the higher overall efficiency achieved compared to power plants generating electricity from only a gas cycle or a steam cycle. Based on the newest combined cycle technology available, the overall plant efficiency can be as high as 60% compared to 30% for only a gas fired power plant.

Emission data was obtained from US EPA AP-42, Section 3.1, *Stationary Gas Turbines*. Emission factors in AP-42 are, in most cases, average contaminant emission rates relative to a source type and configuration and are often based on source tests performed at one or more facilities within an industry. For this report, emission factors were used for lean-premixed natural gas-fired turbines, and uncontrolled emissions from natural gas-fired turbines. Emission factors were generated with units of grams of pollutant released per kilowatt-hour of energy produced calculated on a net power production basis.

## 4.2. Steam Turbine Natural Gas Fired Power Generating Plant

Steam turbine natural gas fired power plants combust natural gas to generate heat. The heat is used to boil water and generate steam. The steam passes through a steam turbine, which spins a generator to produce electricity.

Emission data was obtained from US EPA AP-42, Section 1.4, *Natural Gas Combustion*. Emission factors in AP-42 are, in most cases, average contaminant emission rates relative to a source type and configuration and are often based on source tests performed at one or more facilities within an industry. For this report, emission factors were used for boilers larger than 100 million Btu/h with low $NO_x$ burners. Emission factors were generated with units of grams of pollutant released per kilowatt-hour of energy produced calculated on a net power production basis.

## 4.3. Emission Factor Comparison (g/kWh Basis)

Refer to Table 4-1 for a comparison of greenhouse gas, acid gases, smog precursors, combustion gases and trace air contaminant emission factors per kilowatt-hour (kWh) basis for an average EFW facility processing 200,000 tonnes per year of RMSW, a coal fired power plant, a combined cycle natural gas fired power plant and a steam turbine natural gas fired power plant.

**Table 4-1 Other Energy Sources – Emission Factor Comparison**

| Parameter | Emission Factors (in g/kWh) | | | |
|---|---|---|---|---|
| | EFW Facility | Coal Fired Power Plant (1) | Combined Cycle Natural Gas Fired Power Plant (2) | Steam Turbine Natural Gas Fired Power Plant (2) |
| **Greenhouse Gases** | | | | |
| Carbon Dioxide | 1,437 | 959 | 365 | 917 |
| Organic Matter (as $CH_4$) | 0.005 | No data | 0.03 | 0.02 |
| Organic Matter (as $CO_2$ equivalent) | 0.113 | No data | 0.6 | 0.37 |
| Nitrous Oxide ($N_20$) | negligible | 0.01 | 0.01 | 0.005 |

| Parameter | Emission Factors (in g/kWh) | | | |
|---|---|---|---|---|
| | EFW Facility | Coal Fired Power Plant (1) | Combined Cycle Natural Gas Fired Power Plant (2) | Steam Turbine Natural Gas Fired Power Plant (2) |
| Nitrous Oxide (as $CO_2$ equivalent) | negligible | 2.16 | 3.1 | 1.52 |
| Total $CO_2$ Equivalent | 1,437 | 961 | 368 | 919 |
| **Acid Gases** | | | | |
| Nitrogen Oxides ($NO_x$) as $NO_2$ | 1.7 | 1.7 | 0.3 | 1.1 |
| Sulphur Dioxide | 0.08 | 3.9 | 0.01 | 4.6E-3 |
| Hydrogen Chloride | 0.09 | 0.2 | No Data | No Data |
| **Smog Precursors** | | | | |
| Nitrogen Oxides ($NO_x$) as $NO_2$ | 1.7 | 1.7 | 0.3 | 1.1 |
| Total Particulate Matter | 0.04 | 0.3 | 0.006 | 0.02 |
| Particulate Matter ≤ 2.5 µm | 0.04 | 0.1 | 0.006 | 0.02 |
| **Combustion Gases** | | | | |
| Carbon Monoxide | 0.09 | 0.3 | 0.05 | 0.6 |
| **Trace Air Contaminants** | | | | |
| Cadmium | 4.4E-5 | No Data | No Data | 8.4E-6 |
| Lead | 4.5E-4 | 3.3E-5 | No Data | No Data |
| Mercury | 7.1E-5 | 1.4E-5 | No Data | 2.0E-6 |
| Dioxins/Furans (TEQ) | 3.5E-10 | 1.2E-9 | No Data | No Data |

(1) Ontario Ministry of the Environment – *OnAIr Annual Report 2002* <http://environetprod3.ene.gov.on.ca/OnAIR>

(2) United States Environmental Protection Agency – AP-42 Fifth Edition *Compilation of Air Emission Factors* Volume 1 <http://www.epa.gov/ttn/chief/ap42/>

Carbon dioxide equivalent emissions are higher per kilowatt-hour of electricity produced from the average EFW facility than for typical coal fired power plants, typical combined cycle natural gas fired power plants and typical steam turbine natural gas fired power plants.

Methane and nitrous oxide emissions are higher from typical combined cycle natural gas fired power plant than from the other energy sources. No data was available for methane emissions from coal fired power plants.

Nitrogen oxide emissions are similar from the average EFW facility and typical coal fired power plants and higher than typical combined cycle natural gas fired power plants and steam turbine natural gas fired power plants.

Sulphur dioxide emissions are highest from coal-fired power plants and lowest from steam turbine natural gas fired power plants. No data was available for hydrogen chloride emissions from steam turbine natural gas fired combustion however, hydrogen chloride emissions from typical coal fired power plants are higher than the emissions from the average EFW facility. Total Particulate Matter (TPM) and Particulate Matter 2.5 (equivalent diameter 2.5 µm, PM2.5) emissions are highest from coal-fired power plants and lowest from combined cycle natural gas fired power plants. It should be noted that TPM is greater than PM2.5 in comparison to other technology due to the different air pollution control equipment presently used by the OPG coal-fired power plant. Also, all particulate matter from the EFW plant and the natural gas fired power plants are assumed to be PM2.5.

Carbon monoxide emissions per kilowatt-hour of electricity produced are higher from steam turbine natural gas fired power plants than for the average EFW facility and coal plants. The lowest carbon monoxide emissions are from combined cycle natural gas fired power plants.

Heavy metal (cadmium, lead, and mercury) releases from typical coal fired power plants and natural gas fired power plants are less than the emissions per kilowatt-hour of electricity produced from average EFW facilities. Dioxin/furan emissions are higher from coal-fired power plants. No heavy metal or dioxin/furan emissions data was available for combined cycle natural gas fired power plants.

## 4.4. Annual Emission Comparison

An average EFW facility processing 200,000 tonnes per year of RMSW will generate approximately 14.1 MW of net electricity according to information provided by thermal technology vendors. This would serve the electricity needs of approximately 9,000 homes. Table 4-2 summarizes the annual emissions of greenhouse gases, acid gases, smog precursors, combustion gases and trace air emissions from a 200,000 tonnes per year EFW facility, a coal-fired power plant, a combined cycle natural gas fired power plant and a steam turbine natural gas fired power plant that each generate 14.1 MW of net electricity output.

**Table 4-2 Other Energy Sources – Annual Emissions**

| Parameter | Power Plants Generating 14.1 MW of Net Electricity | | | |
|---|---|---|---|---|
| | EFW Facility | Coal Fired Power Plant | Combined Cycle Natural Gas Fired Power Plant | Steam Turbine Natural Gas Fired Power Plant |
| | kg/y | kg/y | kg/y | kg/y |
| **Greenhouse Gases** | | | | |
| Carbon Dioxide ($CO_2$) | 159,775,000 | 106,618,783 | 40,550,011 | 101,921,386 |
| Organic Matter (as $CH_4$) | 600 | No Data | 3,170 | 1,953 |
| Organic Matter (as $CO_2$ equivalent) | 12,593 | No Data | 66,576 | 41,023 |
| Nitrous Oxide ($N_2O$) | negligible | 775 | 1,106 | 544 |
| Nitrous Oxide (as $CO_2$ equivalent) | negligible | 342,832 | 342,832 | 168,510 |
| Total $CO_2$ Equivalent | 159,787,093 | 106,859,166 | 40,959,419 | 102,130,920 |
| **Acid Gases** | | | | |
| Nitrogen Oxides ($NO_x$) as $NO_2$ | 185,400 | 190,628 | 36,495 | 118,908 |
| Sulphur Dioxide | 8,480 | 432,673 | 1,253 | 510 |
| Hydrogen Chloride | 9,720 | 33,677 | No Data | No Data |

| Parameter | Power Plants Generating 14.1 MW of Net Electricity | | | |
|---|---|---|---|---|
| | EFW Facility kg/y | Coal Fired Power Plant kg/y | Combined Cycle Natural Gas Fired Power Plant kg/y | Steam Turbine Natural Gas Fired Power Plant kg/y |
| **Smog Precursors** | | | | |
| Nitrogen Oxides ($NO_x$) as $NO_2$ | 185,400 | 190,628 | 36,495 | 118,908 |
| Total Particulate Matter | 4,920 | 37,303 | 700 | 1,614 |
| Particulate Matter < 2.5 µm | 4,920 | 10,818 | 700 | 1,614 |
| **Combustion Gases** | | | | |
| Carbon Monoxide | 10,200 | 32,764 | 5,530 | 71,345 |
| **Trace Air Contaminants** | | | | |
| Cadmium | 4.9 | No Data | No Data | 0.9 |
| Lead | 50 | 3.7 | No Data | No Data |
| Mercury | 7.9 | 1.6 | No Data | 0.2 |
| Dioxins/Furans (TEQ) | 3.8E-5 | 1.3E-4 | No Data | No Data |

An EFW facility processing 200,000 tonnes of RMSW per year and generating approximately 14.1 MW of net electricity will release 159,787,093 kg of carbon dioxide equivalent emissions to the atmosphere. Less carbon dioxide is released from coal fired, combined cycle natural gas fired and steam turbine natural gas fired power plants generating 14.1 MW of net electricity. Methane and nitrous oxide emissions are highest from typical combined cycle natural gas fired power plants, emitting 3,170 and 1,106 kg per year, respectively. No data was available for methane emissions from coal fired power plants.

With respect to acid gases, an average thermal EFW facility processing 200,000 tonnes per year of post diversion RMSW will release 185,400 kg of nitrogen oxides to the atmosphere compared to 190,628 kg/y, 36,495 kg/y and 118,908 kg/y for coal fired plants, combined cycle natural gas fired plants and steam turbine natural gas fired power plants, respectively. Significantly more sulphur dioxide and hydrogen chloride is released from coal fired power plants than the other energy sources generating 14.1 MW of electricity. No data was available for hydrogen chloride from a steam turbine natural gas fired plant.

A 14.1 MW coal fired power plant will release considerably more total particulate matter and particulate matter (2.5 µm) than an average 14.1 MW EFW facility, a combined cycle natural gas fired power plant and a steam turbine natural gas fired power plant.

A steam turbine natural gas fired power plant, generating 14.1 MW of electricity, will release 71,345 kg/y of carbon monoxide. This quantity is considerably more than the carbon monoxide emissions released from an average thermal EFW facility, coal fired power plants, and combined cycle natural gas power plants.

An average EFW facility, generating 14.1 MW of electricity, will release more cadmium, lead and mercury than coal fired power plants and natural gas fired power plants. No data was available for lead emissions from a steam turbine natural gas fired power plant or for cadmium, lead and mercury from a combined cycle natural gas fired power plant.

A coal fired power plant generating 14.1 MW of electricity, will release more dioxins/furans compared to an average EFW facility generating the same amount of electricity. No data was available for steam turbine natural gas and combined cycle natural gas fired power plants.

In summary, coal fired power plants release the most overall emissions, followed by the EFW facility, and then the steam turbine natural gas fired power plants. The combined cycle natural gas fired power plants release the least amount of emissions due to its' efficient energy conversion process.

# 5. Potential for Future Reduction of Emissions

An energy-from-waste (EFW) facility has the advantage that it can be modified and upgraded to incorporate improvements in technology. This differs from landfill disposal where once material has been buried, very little, other than liner repair or landfill mining can be done to reduce the releases to the environment from the facility.

The Algonquin Power (formerly KMS) EFW facility serving the Region of Peel provides a current example of this upgrade process. This facility was commissioned in 1992 with a "then" state-of-the-art pollution control system. In subsequent years, new technology became available and new emission standards, in the form of Guideline A-7, came into effect. In response to these developments, the facility's air pollution control system was improved and the emissions of most pollutants from the facility are now less than $1/10^{th}$ of what they were when the facility was built.

In the balance of this section, the potential for further reducing the emissions from an EFW facility is discussed.

## 5.1 Greenhouse Gas Emissions

Greenhouse gas emissions, in the form of carbon dioxide, are a basic by-product of our fossil fuel based civilization. As long as we have a fossil fuel-based economy, the key to reducing greenhouse gas emissions lies, in part, in improving the efficiency of our energy conversion processes. This is readily apparent by comparing the $CO_2$ emissions per kWh from a conventional coal fired power plant with those from an efficient combined cycle plant (refer to Table 4-1). The lower greenhouse gas emissions are due to the efficiency of the process not the fuel.

In the case of the 200,000 tonne per year EFW facility considered in this report, the overall efficiency of the waste to energy conversion process can be improved in several ways.

The quantities of emissions are based on the assumption that the RMSW (or syngas produced from the waste) is simply combusted to produce steam and the steam is used in a turbine to make electricity. The overall efficiency of this process could be improved if the waste heat is also used, as in a cogeneration (i.e., production and use of electricity and heat) facility. To obtain this efficiency, a facility that can use the heat must be within reasonable proximity of the facility.

The efficiency could also be improved if the syngas from an EFW gasifier were used in a combined cycle power plant as described in Section 5.2 rather than in a conventional boiler or engine. Since the energy conversion process in the combined cycle power plants are the most efficient, the amount of syngas used will be lower for the same power output, thus the total greenhouse gas emissions will be lower.

In addition to improving overall process efficiencies, the municipalities could also undertake other initiatives, such as energy conservation efforts, to yield reductions in greenhouse gas emissions to offset those produced by a potential facility.

## 5.2 Acid Gas Emissions

Acidic gases such as nitrogen oxides, hydrogen chloride and sulphur oxides are formed through the direct combination of nitrogen, chloride, sulphur and hydrogen present in the waste stream or fossil fuel and oxygen and nitrogen present in the air during exposure to the intense heat from any combustion process.

Optimization of combustion processes with staged combustion air injection and use of post-combustion air pollution control technologies are proven and commonly used techniques for the removal of acidic gases from gaseous products of combustion.

Today's air pollution control systems are capable of reducing emissions of acidic gases from the EFW facilities by over 90%.

Since the performance capabilities of the current state-of-the-art acid gas control systems used at the EFW facilities have been reached, any further reductions could be achieved either by reducing the presence of chlorides and sulphur in the waste stream or by developing new control techniques.

## 5.3 Smog Precursors

Both nitrogen oxides and fine particulate matter that are present in the products of combustion, contribute to the formation of smog.

In order to meet today's stringent regulatory requirements, a combination of staged combustion, a selective catalytic reduction (SCR) process, and fabric filter are commonly used techniques to control both nitrogen oxides and particulate matter emissions at thermal power plants and EFW facilities.

Although the majority of the particulates are removed from the exhaust gases and captured in the fabric filter, there are concerns that the small quantity of particles, that are less than 2.5 microns in size, are still emitted into the atmosphere.

The addition of secondary filters specially designed to capture fine particulates (PM2.5) after the conventional fabric filter is possible in the future if the impact from such facilities become significant in comparison to the other existing sources such as road dust, industrial processes and transportation.

## 5.4 Combustion Gases

Typically, the combustion process in the modern EFW facilities occurs under excess oxygen conditions and most of the carbon monoxide, as a product of incomplete combustion, is converted into carbon dioxide. Therefore, it is anticipated that there will not be any significant further reduction in the small amounts of carbon monoxide that results from the combustion of RMSW.

## 5.5 Trace Air Contaminants

Trace air contaminants include heavy metals (cadmium, lead and mercury) and dioxin/furans (polychlorinated hydrocarbons).

### 5.5.1 Heavy Metals

Heavy metals originate in the source waste stream. The pollution control system at an EFW facility captures most of these metals and allows them to be disposed of in a secure facility. In the case of a landfill, these metals are simply buried as part of the waste.

Great strides have been made, during the last 20 years, to reduce the amount of heavy metals released to the environment. In the future, improvements can be made by additional at-source reduction efforts. An example of this type of initiative is the Mercury Policy and Elimination Plan developed by the Niagara Region and the Association of Municipal Recycling Coordinators (AMRC) with funding associated from Environment Canada.

The development and implementation of these types of at-source reduction programs will lead to the further reduction of these trace contaminants.

### 5.5.2 Dioxins and Furans

Recent research has shown that these compounds are:

i) Not created in a syngas production process;

ii) Destroyed in a well-controlled high temperature combustion process; and

iii) Created in trace amounts through chemical reactions, which occur in the post combustion exhaust gases following the direct combustion of: waste, waste derived fuel, syngas produced from waste, or other hydrocarbons such as diesel fuel.

Further research also indicates that the quantity of dioxins and furans in the exhaust gas are not related to the quantity of chlorine (plastics) in the incoming waste stream.

State-of-the-art pollution control technology, in the form of carbon injection followed by bag house filtering, has led to the current low level of these emissions.

Possible future initiatives to further reduce the level of these emissions are expected to focus on the development of techniques that will reduce the formation of dioxins and furans rather than on the reduction of already formed dioxins and furans.

# 6. Additional Research and Studies

The preceding sections have presented the available information on air emissions from EFW facilities in comparison with other sources of air emissions. In the course of assembling this information, some additional research and study requirements have been identified. These recommended additional research activities are presented below, in the order of priority.

## 6.1 Modelling Cumulative Effects

This report has focused on the emissions from an EFW facility, sized to process the post diversion RMSW from Niagara and Hamilton. In addition to this potential facility, there is an existing EFW facility in Brampton serving the Region of Peel. Other municipalities within the GTA are also considering the development of thermal facilities for processing their RMSW.

The potential development of several facilities introduces the issue of cumulative effects and the impacts of these facilities on overall air quality.

The modelling of a significant smog event on north eastern North America has been performed and has been used to identify the effects of Ontario's coal fired power plants on both the broad North Eastern North America scale and the more local "Golden Horseshoe" scale.

This existing model could be modified to illustrate the cumulative effects of several EFW facilities on a significant smog event.

The cost of this modelling is estimated at approximately $60,000.

## 6.2 Ambient Air Testing For Dioxins and Furans

Dioxins and furans are pollutants of concern. Some test data indicates that these compounds may be present in the ambient air environment, particularly in areas in close proximity to major transportation corridors.

Therefore, it is recommended that additional testing for dioxins and furans in the ambient air be conducted at three locations, one in Niagara, one in Hamilton and one in Toronto. It is further recommended that three test samples be collected and analyzed at each test location.

The cost of such a test program, including three locations with three samples at each location, is estimated at $75,000.

## 6.3 Natural Gas Fuel Power Plant Testing

In the comparison of the emissions associated with electricity produced from an EFW facility with electricity produced from a natural gas fired generating plant, there is no data on the potential metals and dioxin/furan emissions from natural gas fired power plants.

Therefore, it is recommended that the potential heavy metals and dioxin and furan emissions from a natural gas fired power plant be tested.

The estimated cost of this test program, assuming the availability of suitable stack testing ports coupled with the collection and analysis of three samples, is $65,000.