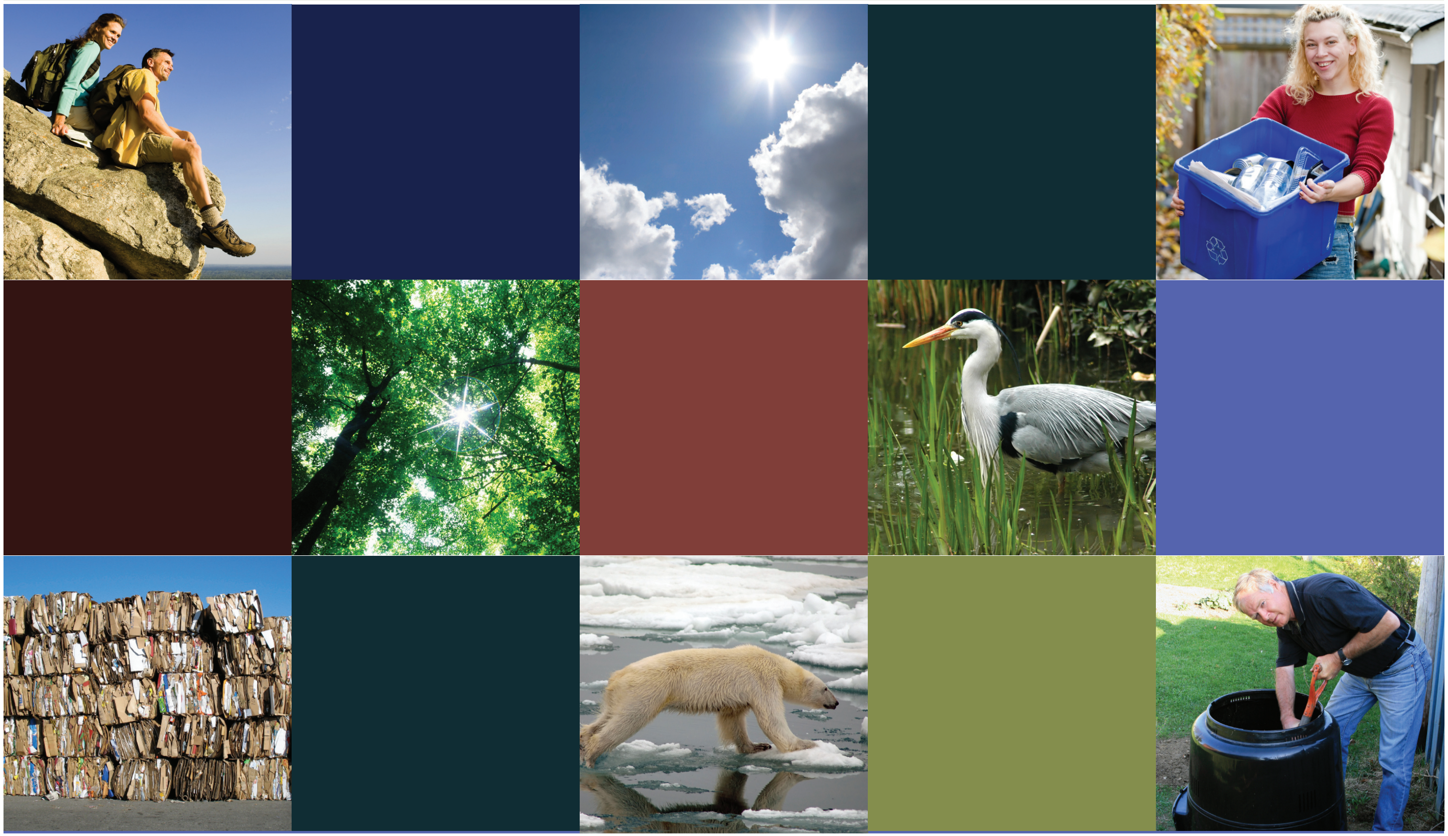
Environmental Life Cycle Assessment of Waste Management Strategies with a Zero Waste Objective

Study of the Solid Waste Management System in Metro Vancouver, British Columbia

June 2009



Sound Resource Management

Prepared by:
Sound Resource Management Group, Inc.,
Olympia, WA

Prepared for:
Belkorp Environmental Services Inc.,
Vancouver, BC

EXECUTIVE SUMMARY

Introduction

An increasingly complex set of environmental, economic and social pressures is driving change in the solid waste management industry in North America. These pressures include:

- The impact of Climate Change and the increasing awareness of the role of "waste" and "wasting" in the production of greenhouse gas emissions;
- Diminishing world fossil fuel energy supplies;
- Increasing limitations of government to prevent and control the volume and toxicity of products in the waste stream and a growing need to shift responsibility to the product manufacturer; and
- A growing public desire to set ambitious waste prevention and diversion goals thereby minimizing the need for waste disposal facilities in the long term.

Pressures such as these are driving change in public and private strategic planning for solid waste diversion and disposal systems. Notably, conventional approaches and mixes of municipal waste management facilities and services no longer sufficiently address broader public concerns and ambitions for environmental sustainability and zero waste. However, determining preferable strategic directions in this complex and changing industry is very challenging.

With these challenges in mind, Belkorp Environmental Services Inc. (BESI) commissioned Sound Resource Management Group (Olympia, WA) to conduct a comprehensive life cycle analysis (LCA) study of solid waste management in the Metro Vancouver region of British Columbia. The intent of the study was to provide BESI with guidance in developing a long term waste management business strategy based on adopting a zero waste objective.

BESI's interest in seeking such guidance arises from the company's experience and current involvement in the recycling and disposal industries in the region, and the Metro Vancouver regional government's adoption of a zero waste philosophy in a revised long-term 'Waste Management Plan'. Wastech Services Ltd., a subsidiary of BESI, handles municipal solid waste under contract to the regional government, operating four waste transfer stations and the Cache Creek landfill. Wastech also operates a cardboard baling facility, a wood waste recycling facility and recycling depots at each of the transfer stations.

Objectives of the Study

The primary objectives of this study were to provide BESI with an assessment of the environmental impacts associated with the existing solid waste management system in the Metro Vancouver region, and guidance on a future strategy that could incorporate a zero waste objective.

To meet these objectives, the study applied a life cycle analysis (LCA) approach to the assessment of two scenarios for managing municipal (MSW) and demolition, landclearing and construction (DLC) solid wastes generated in the region. These consisted of the Base Case (status quo) as of 2008, and a Zero Waste scenario in which waste diversion was taken from the current 53% to 83% between 2010 and 2029. To develop the Zero Waste scenario, plausible waste diversion strategies and projections were identified, with particular attention to what may be realistic in the first five to ten years of the long term scenario.

Life cycle analysis as applied to solid waste management systems is a technique for assessing cradle-to-grave environmental impacts associated with production, use, and discard of products and materials in our society. The methodology used in this study takes into consideration a broad range of environmental impact factors. These have been consolidated under three major categories:

1. **Climate Change** (e.g., greenhouse gases such as carbon dioxide, methane, nitrous oxide and chlorofluorocarbons),
2. **Human Health** (e.g., pollutants causing cancer, respiratory ailments and toxicity such as particulate matter, nitrogen oxide, sulphur oxide, mercury, lead, and benzene), and
3. **Ecosystem Toxicity** (e.g., pollutants harmful to wildlife and wildlife habitats such as DDT, lead, mercury, zinc, and polyvinyl chloride).

Key Findings

Recycling & Composting

Overall, the findings of this study show that recycling and composting are far better approaches than waste disposal at mitigating the life cycle environmental impacts associated with products and materials in the waste stream. Recycling and composting are the only waste management options that were found to prevent detrimental impacts in all three categories: Climate Change, Human Health and Ecosystem Toxicity.

The potential benefits were found to be even greater in terms of recycling and composting MSW as compared to DLC waste. In fact, recycling and composting MSW reduces more Climate Change impacts, more Human Health impacts, and more Ecosystem Toxicity impacts per tonne of waste than any other management method.

It was also shown that the environmental benefits increase significantly with the increasing diversion of wastes to recycling and composting under the Zero Waste scenario. For example, under the Zero Waste scenario, by 2029:

- Total tonnes of climate changing greenhouse gas (GHG) emissions prevented from being released to the atmosphere annually through recycling and composting would more than double, from 1.9 million tonnes eCO2 in 2008 to 4.3 million tonnes eCO2 in 2029. For perspective, a reduction of 1.9 million tonnes eCO2 in 2008 is equivalent to preventing emissions from nearly 500,000 private vehicles in Metro Vancouver in one year, or reducing current annual GHG emissions from cars in the region by approximately 35%.
- The total Human Health impact reductions associated with recycling and composting were estimated to be nearly 2.5 times greater than those saved in 2008. These reductions would be more than enough to offset impacts produced by all other waste management methods.
- Recycling and composting resulted in twice as many Ecosystem Toxicity impact reductions compared to 2008.

Given the clear superiority of recycling and composting from an environmental perspective, strategic planning for the implementation of a zero waste objective should focus on developing recycling and composting-based programs and business opportunities. As the MSW system currently has a significantly lower waste diversion rate than does the DLC system, and it holds the potential for significantly greater environmental benefits on a per tonne basis, diverting products and materials in the MSW waste stream should be a priority.

The findings point to the need for a zero waste strategy that prioritizes the diversion of all organic waste to composting systems, maximizes the effectiveness of existing recycling programs and initiatives, and moves rapidly forward with the development of new diversion efforts such as Extended Producer Responsibility (EPR) initiatives.

Industrial Fuel Applications

The findings show that diverting source separated wastes (i.e., wood, used lubricating oil, scrap tires) to industrial fuel applications results in significant Climate Change (GHG) impact reductions while at the same time producing significant levels of Human Health and Ecosystem Toxicity impacts. These impacts are primarily attributable to the large volume of wood waste in the wastes diverted to industrial fuel end uses under the Base Case and Zero Waste scenarios. In contrast, the LCA study showed that sending wood to recycling (pulp or board manufacturing) reduces impacts in all three categories.

The initial conclusion to be drawn from these findings is that for wood waste, in terms of environmental protection, the priority should be given to finding reuse and recycling markets for these materials.

It is important to state that the findings regarding Human Health and Ecosystem Toxicity impacts of waste wood combustion in industrial boilers are subject to considerable uncertainty in the scientific community, particularly with respect to the US EPA emissions profiles for industrial boilers used in this study. The application of more stringent environmental controls, with improvements in the industrial boiler technologies, will positively alter the LCA results.

Disposal Options

The study findings show that disposal options (landfilling and waste-to-energy) are unfavourable compared to recycling where environmental impacts are concerned. These findings also show that disposing MSW in landfills is more favourable than waste-to-energy in all three environmental impact areas, particularly once organics are removed from the waste stream.

Given these findings, disposal options should be seen only as interim solutions necessary to bridge the gap between the present situation and a zero waste objective achieved within a 20 - 30 year time horizon. Under these conditions, disposal options should be assessed in terms of their flexibility and whether they will facilitate or hinder the achievement of the zero waste objective.

Limitations and Additional Research

This study focused specifically on the life cycle environmental impacts associated with the Base Case and Zero Waste scenarios defined within. It did not take into consideration financial, economic or social impacts associated with various waste management methods or strategies. As such, the findings and conclusions drawn from this research are limited to the environmental aspects of strategic planning.

Additional research and analysis is required to develop an integrated assessment of the financial, economic and social aspects of these scenarios. Among other things, such research should address the potential local economic benefits arising in the context of developing reuse, recycling, composting and EPR take-back programs under a zero waste strategy.

With respect to modeling the configuration of waste disposal facilities, this study modeled a Base Case consisting of the existing MSW and DLC waste disposal systems in Metro Vancouver, including the Vancouver and Cache Creek landfills, the Burnaby Waste-to-Energy (WTE) facility, and DLC landfills in the region. In terms of modeling a future disposal system in the region under the Zero Waste scenario, it was beyond the scope of the study to identify an optimal or preferred system. Instead, for comparative purposes, the study estimated emissions of pollutants per tonne of waste disposed under the Zero Waste scenario using the same set of facilities and relative allocation of residual waste flows as currently exists.

The study also provided a set of MSW disposal system sensitivity analyses for the year 2029 at 83% diversion in order to gain insight into the total potential emissions from MSW disposal under three alternative waste flow allocations. Numerous alternative waste flow allocations for MSW disposal could be modeled. The options selected consisted of allocating 100% of MSW residuals to the Vancouver landfill, the Cache Creek landfill and the Burnaby WTE facility, respectively. These options were considered sufficient for the purpose of gaining insight into total potential emissions from MSW facilities in the absence of a regional plan for a future system. The findings for these analyses showed that the Vancouver and Cache Creek landfill options would prevent release of 140,000 to 174,500 tonnes of greenhouse gas emissions, 1,100 to 3,900 tonnes of Human Health related emissions, and more than 50 tonnes each of Ecosystem Toxicity related emissions. In contrast, the Burnaby WTE facility would produce 231,700 tonnes of greenhouse gases, 56,600 tonnes of Human Health related emissions and 800 tonnes of Ecosystem Toxicity emissions. The findings for these analyses confirmed the overall conclusions of the report.

With respect to the Climate Change related impacts of disposal options, the study took into consideration the issues of whether and how to account for greenhouse gas emissions from the biogenic fraction of the waste stream. In particular, in this study, landfills are given credit for storage of non- or slowly-degrading biogenic materials such as wood and paper. Sensitivity analyses on the global warming potential (GWP) of methane were also run to compare the effects of 25-year versus 100-year GWP assumptions on emissions estimates for waste management options. The findings for these analyses confirmed the overall conclusions of the report.

While this study modeled a wide range of potential pollutants, it did not model dioxin and furan emissions associated with the Burnaby WTE facility or other waste management facilities or programs. There were two reasons for this: (1) publicly available information on these emissions for the Burnaby WTE facility is unclear regarding speciation of dioxins and furans that may have been measured in emissions tests at the Burnaby WTE facility. Different dioxins and furans have widely different environmental impacts; (2) in some cases there is a lack of information on dioxin and furan emissions for other waste management methods or activities modeled in the study. Because dioxin and furan weigh heavily in the calculation of Human Health and Ecosystem Toxicity impacts, it was considered misleading to include them for only some and not all facilities and processes.

An additional limitation is that the characterization and extent of the environmental impacts of emissions associated with heavy metals such as lead, cadmium and mercury is a matter of debate in the scientific community, particularly with respect to the Human Health and Ecosystem Toxicity impacts. Accordingly, the estimated potential impacts of these pollutants associated with sending wood waste to industrial boilers, and residual MSW to the Burnaby WTE facility, are considered to be uncertain.

Acknowledgements

This report and the life cycle analyses (LCAs) the report details have benefited immensely from the efforts of a number of people.

Russ Black and Ted Rattray (Belkorp Environmental Services Inc., Vancouver, BC) sponsored this project and provided strategic direction along the way.

Karen Asp (Project Manager, Belkorp Environmental Services Inc.) provided extensive research support, reviewed the LCA results, drafted and edited many portions of the report, led development of the zero waste diversion estimates, and shepherded the project through to the successful production of this final report.

Monica Kosmak (Writer and Independent Environmental Policy Analyst, Vancouver, BC) provided extensive advice on report structure and edited the report in its entirety, converted charts and tables into more understandable versions, and cross-checked facts and conclusions in the report to ensure they reflected the latest LCA results.

Robert Craggs (Vice President – Solid Waste Practice, R. W. Beck, Inc., Minneapolis. MN) and associates at R.W. Beck provided research and technical support, particularly with respect to waste projection modeling, waste diversion systems in other regions, anaerobic digestion technologies, landfill gas emissions rates and potentials, and the impact of precipitation levels and groundwater levels on landfills.

Colleagues of Dr. Jeffrey Morris (Principal Investigator, Sound Resource Management Group, Inc., Olympia, WA) who provided leads and sources for LCA results and studies that proved critical in carrying out the LCA project that culminated in this report included: Dr. H. Scott Matthews (Director of Research for the Green Design Institute, Associate Professor of Civil and Environmental Engineering, and Associate Professor of Engineering and Public Policy at Carnegie Mellon University, Pittsburgh, PA), Clarissa Morawski (Principal, CM Consulting, Toronto, ON), Jan Allen (P.E., Concept Kinetics, Seattle, WA), and Michelle Morris (CSR Specialist, Sound Resource Management Group, Inc., Olympia, WA).

Any errors and omissions remain the responsibility of the Principal Investigator, Dr. Jeffrey Morris.

Contents

APPENDICES

Tables

Figures

Acronyms

Acronym	Term
BWTEF	Burnaby Waste-to-Energy facility
DLC	demolition, landclearing & construction (waste)
e2,4-D	equivalent 2,4-D
eCO2	equivalent carbon dioxide
EPR	extended producer responsibility
eToluene	equivalent toluene
GHG	greenhouse gas
Ind Fuel	industrial fuel
LCA	life cycle analysis
MSW	municipal solid waste
Rec/Comp	recycling/composting
CCLF	Cache Creek landfill
VLF (MSW)	Vancouver landfill (MSW tonnages only, not DLC)
DLC LFs	demolition, landclearing & construction waste landfills
GWP	global warming potential
NOx	nitrogen oxides
SOx	sulfur oxides
ICI	industrial, commercial & institutional
Res	residential
CCME	Canadian Council of Ministers of the Environment
LFGs	landfill gases
MEBCalc	Measuring the Environmental Benefits Calculator
US EPA	United States Environmental Protection Agency
TRACI	Tool for the Reduction and Assessment of Chemical and other environmental Impacts
CH4	methane
N20	nitrous oxide
CFCs	chlorofluorocarbons
IPCC	Intergovernmental Panel on Climate Change
WARM	WAste Reduction Model
US NIST	United States National Institute of Standards and Technology

Section 1: INTRODUCTION

1.1 Context and Drivers

An increasingly complex set of environmental, economic and social pressures is driving change in the solid waste management industry in North America. Some of these pressures include:

- Climate change – acknowledgement of the indisputable fact of global warming, and the increasing awareness of the role of "waste" and "wasting" in the production of greenhouse gas emissions.
- Energy supplies – awareness of diminishing supplies of inexpensive fossil fuels, and the turn to solid waste as a possible new source of energy.
- Producer responsibility – recognition of the limits of local governments to prevent and control the volume and toxicity of products in the waste stream, and the shift to producer responsibility approaches to stimulate green design, drive reuse and recycling, and reduce taxpayer burden.
- Zero waste - informed by innovative approaches like producer responsibility, public desire to set ambitious waste prevention and diversion goals thereby minimizing the need for waste disposal facilities in the long term.

Pressures such as these are driving change in public and private strategic planning for solid waste diversion and disposal systems. Notably, conventional approaches and mixes of municipal waste management facilities and services no longer sufficiently address broader public concerns and ambitions for environmental sustainability and zero waste. However, determining preferable strategic directions in this complex and changing industry is very challenging.

With these challenges in mind, Belkorp Environmental Services Inc. (BESI) commissioned Sound Resource Management Group (Olympia, WA) to conduct a comprehensive life cycle analysis (LCA) study of solid waste management in the Metro Vancouver region of British Columbia. The intent of the study was to provide BESI with guidance in developing a long term waste management business strategy based on adopting a zero waste objective.

BESI's interest in seeking such guidance arises from the company's experience and current involvement in the recycling and disposal industries in the region, and the Metro Vancouver regional government's adoption of a zero waste philosophy in a revised long-term 'Waste Management Plan'. Wastech Services Ltd., a subsidiary of BESI, handles municipal solid waste under contract to the regional government, operating four waste transfer stations and the Cache Creek landfill. Wastech also operates a cardboard baling facility, a wood waste recycling facility and recycling depots at each of the transfer stations.

1.2 Objectives

The primary objectives of this study were to provide BESI with an assessment of the environmental impacts associated with the existing solid waste management system in the Metro Vancouver region, and guidance on a future strategy that could incorporate a zero waste objective.

To meet these objectives, the study applied a life cycle analysis (LCA) approach to the assessment of two scenarios for managing municipal (MSW) and construction and demolition (DLC) solid wastes generated in the region. These consisted of the Base Case (status quo) as of 2008, and a Zero Waste scenario in which waste diversion was taken from the current 53% to 83% between 2010 and 2029. To develop the Zero Waste scenario, plausible waste diversion strategies and projections were identified, with particular attention to what may be realistic in the first five to ten years of the long term scenario.

Life cycle analysis as applied to solid waste management systems is a technique for assessing cradle-to-grave environmental impacts associated with production, use, and discard of products and materials in our society. The methodology used in this study takes into consideration a broad range of environmental impact factors. These have been consolidated under three major categories:

1. **Climate Change** (e.g., greenhouse gases such as carbon dioxide, methane, nitrous oxide and chlorofluorocarbons),
2. **Human Health** (e.g., pollutants causing cancer, respiratory ailments and toxicity such as particulate matter, nitrogen oxide, sulphur oxide, mercury, lead, and benzene), and
3. **Ecosystem Toxicity** (e.g., pollutants harmful to wildlife and wildlife habitats such as DDT, lead, mercury, zinc, and vinyl chloride).

1.3 Scope

The geographic scope of this study is the Metro Vancouver region of British Columbia, a largely urban metropolis with a population of 2.27 million in 2008. Formerly known as Greater Vancouver, the region consists of 21 municipalities, and one electoral area, with specific administrative functions and utility services provided by the regional government, Metro Vancouver (Greater Vancouver Regional District). Responsibilities for solid waste management in the region are shared between the municipalities and the regional government. Accordingly, throughout this study, the phrase "Metro Vancouver region" is used to refer to the geographic area, or 'wasteshed', in which solid waste (MSW and DLC) is managed.

This study focuses specifically on the life cycle environmental impacts associated with the Base Case and Zero Waste scenarios defined within. It does not take into consideration economic or social impacts associated with various waste management methods or strategies. As such, the findings and conclusions that may be drawn from this research are limited to the environmental aspects of strategic planning. Additional research and analysis is required to develop an integrated assessment.

Section 2: METHODOLOGY

2.1 Introduction

This study applies a life cycle analysis (LCA) approach to the assessment of two scenarios for managing municipal solid waste (MSW) and demolition, landclearing and construction waste (DLC) generated in the Metro Vancouver region of British Columbia. These consist of the Base Case (status quo) as of 2008, and a Zero Waste scenario. The study assesses both the diversion and the disposal options associated with these scenarios. It looks at solid waste flows in each scenario in terms of particular categories of products and materials (discards) occurring in the waste stream, such as cardboard, film plastic, food waste, wood, carpet and electronic equipment. It estimates the environmental emissions arising in the production and management of these products/materials during their life cycles, and evaluates those emissions in terms of three of the main environmental impacts they cause – Climate Change, harm to Human Health, and toxic impacts on ecosystems. This LCA approach, thus, allows for a comparison of the benefits and burdens of the waste management options associated with each scenario.

Specifically, the LCA for this study encompassed the following steps:

1. Developing system scenarios for the purposes of analysis, including estimates and projections for waste generation and diversion.
2. Developing pollutant emissions inventories over the life cycle for waste materials generated in the Metro Vancouver region and discarded into the region's MSW or DLC streams.
3. Evaluating the environmental effects of these pollutant emissions in terms of three major impacts: Climate Change, Human Health impairments and Ecosystem Toxicity.
4. Assessing the contribution of various options for managing end-of-life product discards in terms of their relative contributions to the three major impacts.

This section of the report presents the methodology used to undertake the LCA analysis.

2.2 Scenario Descriptions

Two scenarios were defined for the purpose of conducting the LCA analysis. These are referred to as the Base Case and Zero Waste scenarios. A waste projection model was developed in order to integrate the Base Case and Zero Waste scenario assumptions and projections for waste generation, diversion and disposal. The projections provided a quantitative basis for conducting the LCA analysis. The following sections provide an overview of the scenario assumptions and summary information on the projections.

2.2.1 Waste Stream Assumptions

2.2.1.1 Waste Generators

The waste streams assessed in this study are generated by the following sectors, as described in the Greater Vancouver Regional District (GVRD) *Solid Waste Management 2004 Annual Report*:

- Residential (Res)
- Institutional, Commercial and Light Industrial (ICI)
- Demolition, Landclearing and Construction (DLC)

For the purposes of this study, the residential and ICI waste streams are grouped under the heading Municipal Solid Waste (MSW). The study does not include waste generated by the hazardous or heavy industrial waste sectors.

2.2.1.2 Waste Generation

In order to undertake this LCA study, baseline data on the quantities of MSW and DLC waste generated, diverted and disposed in the region were needed. As the most recent full set of data for this system was published in 2004,[1] a number of assumptions and calculations were made in order to establish a more recent baseline for the purpose of developing the scenarios:

- Total system generation (diversion plus disposal) for the MSW and DLC sectors was estimated based on

aggregated information presented in the Metro Vancouver *Strategy for Updating the Solid Waste Management Plan* (February 2008; Revised March 2008). In particular, total tonnages and diversion rates by sector for 2006 are presented in aggregated form in figures 2 and 5 of the *Strategy* document. Using this information, baseline estimates of the total quantities of waste generated, diverted and disposed for the year 2006 were developed as shown in **Table 2.1.**
- As the *Strategy for Updating the Solid Waste Management Plan* presented 2006 data, the year 2006 was used as a baseline for developing the Base Case Scenario.
- An estimate of quantities of waste diverted by product/material type was needed in order to conduct the LCA. As noted above, the GVRD Solid Waste Management 2004 Annual Report provided the most recent, publicly available, data of this nature for the MSW and DLC waste streams in the Metro Vancouver region. Therefore, the diversion data in that report was used to establish a preliminary diversion baseline by material type for 2006. It was supplemented with more current information where available. For example, more recent diversion estimates for Extended Producer Responsibility programs were available in annual reports and studies published on the BC Ministry of Environment web site.[2]
- A breakdown of waste disposed by product/material types was developed based on waste composition data for the MSW and DLC waste streams in Metro Vancouver.[3]

Based on these assumptions, the quantities of waste generated, diverted and disposed were estimated by material type for 2006. The estimates were based on best available information and are believed to constitute a reasonable representation of the overall quantities of waste recycled and disposed in the system as of 2006. The 2006 estimates were used as the basis for projecting the 2008 Base Case, discussed below. **Tables 2.2, 2.3** and **2.4** provide summaries of these estimates as used in the 2008 scenario.

Table 2.1 Estimated Waste Generation in Metro Vancouver Region (2006)

	MSW (tonnes)			DLC (tonnes)	Total (tonnes)
	Res	ICI	Subtotal		
Diverted	395,000	520,000	915,000	830,000	1,745,000
Disposed	475,000	800,000	1,275,000	335,000	1,610,000
Total Generated	**870,000**	**1,320,000**	**2,190,000**	**1,165,000**	**3,355,000**
Diversion Rate	**45%**	**39%**	**42%**	**71%**	**52%**

Table 2.2 Base Case – Projected Waste Generation, Diversion and Disposal (MSW & DLC) (2008)

	Generation (tonnes)	Diversion (tonnes)	Disposal (tonnes)	Diversion Rate
MSW	2,266,900	973,400	1,293,500	42.9%
DLC	1,202,600	856,800	345,800	71.2%
Total Waste	**3,469,500**	**1,830,200**	**1,639,300**	**52.8%**

Table 2.3 Base Case – Projected Waste Generation, Diversion, Disposal (MSW) (2008)

Material Category	Generation (tonnes)	Diversion (tonnes)	Disposal (tonnes)	Diversion Rate
Paper & Paperboard	724,800	422,100	302,700	58%
Plastics	197,700	21,400	176,200	11%
Organics (Compostable)	701,900	270,700	431,100	39%
Organics (Non-compostable)	109,800	17,000	92,800	15%
Metals	120,700	76,100	44,600	63%
Glass	172,000	134,000	37,900	78%
Inorganic Building Materials	99,600	0	99,600	0%
Electronics	35,600	5,700	29,900	16%
Household Hazardous	34,300	25,900	8,400	76%
Household Hygienic	40,000	0	40,000	0%
Bulky Objects	22,700	0	22,700	0%
Fines/Misc.	7,900	400	7,500	5%
Total MSW	**2,266,900**	**973,400**	**1,293,500**	**43%**

Table 2.4 Base Case – Projected Waste Generation, Diversion, Disposal (DLC) (2008)

Material Category	Generation (tonnes)	Diversion (tonnes)	Disposal (tonnes)	Diversion Rate
Paper & Paperboard	3,200	0	3,200	0%
Plastics	26,200	0	26,200	0%
Organics (Compostable)	260,400	145,900	114,500	56%
Organics (Non-compostable)	116,700	48,600	68,000	42%
Metals	21,300	12,200	9,200	57%
Glass	100	0	100	0%
Inorganic Building Materials	763,200	650,200	113,100	85%
Bulky Objects	100	0	100	0%
Fines/Misc.	11,400	0	11,400	0%
Total DLC Waste	**1,202,600**	**856,800**	**345,800**	**71%**

2.2.2 Base Case Scenario Description

The purpose of the Base Case LCA analysis is to provide insight into the relative environmental impacts of the various methods (i.e., diversion and disposal) currently used in the region for managing solid waste. The base case analysis also provides a reference point for comparing the environmental impacts of the status quo to the Zero Waste scenario. The Zero Waste scenario is discussed in Section 2.2.3.

2.2.2.3 Base Case Waste Generation Assumptions

The base case for this study was defined as the existing MSW and DLC waste management systems in the Metro Vancouver region, with waste generation and diversion rates assumed to be generally consistent with the 2006 baseline. The base year was assumed to be 2008, the year this study was implemented.

Tables 2.2, 2.3 and **2.4** present the waste generation, diversion and disposal projections used in the Base Case scenario. These projections were derived from the 2006 baseline waste generation assumptions discussed in Section 2.2.1.2. It was assumed that waste generation grew at the same rate as population growth, as estimated and projected by BC Stats.[4] The effect of changes in Gross Domestic Product (GDP) between 2006 and 2008 were not accounted for in this projection. The projections were adjusted to take into account the start up of the new EPR program for electronic equipment.

2.2.2.4 Base Case Waste Management Methods

In this study, "waste management methods" refers to the ways in which a product or material that enters the waste stream is processed or treated. A range of waste management methods are used to manage MSW and DLC waste in the Metro Vancouver region currently. For the purposes of this LCA study, these are generally described as follows. Additional information about the assumptions used is presented in **Appendices A** and **B.**

Waste Diversion

- **Reuse.** The term 'reuse' is used in this study to refer to the reutilization of a product or material in its current form for the same or a similar purpose. Two reuse initiatives were accounted for in this study, including the Product Care paint reuse program and the Brewers Distributors Ltd. domestic beer bottle reuse system. The Base Case scenario did not account for the various reuse activities that occur in the broader economy, such as yard sales, thrift stores, and used building supply stores.
- **Recycling.** The term 'recycling' is used in this study to refer to the processing of a product or material for use in the manufacture of a new product of the same type (i.e., bottle glass recycled into glass bottles) or of a different type (bottle glass recycled into sandblasting material or construction aggregate). There is a wide range of recycling programs and activities in the Metro Vancouver region. For example:
    - Municipalities typically provide collection services for single family and multi-family dwellings and/or drop off depots. Products typically handled (with some variations) include newspaper, mixed paper, cardboard, containers (glass, plastic, metal), plastic film, lead acid batteries, and scrap metal including appliances.
    - Regional transfer stations accept for recycling products and materials such as mixed paper, cardboard, containers, lead acid batteries, scrap metal including appliances, propane tanks and gypsum wallboard.
    - Private ICI initiatives divert large volumes of cardboard, as well as other materials such as mixed paper and scrap metal.
    - Extended Producer Responsibility programs delivered in the region recycle packaging (e.g., glass, plastic, aluminum, metal, cardboard, mixed paper) and products such as lubricating oil, paint and tires.
    - DLC initiatives divert concrete, asphalt, metal, plastic, gypsum wallboard and some wood to recycling.
- **Composting.** In this study, the term 'composting' refers to the processing of organic wastes (food, yard, soiled tissue, etc) in aerobic or anaerobic systems. The vast majority of organic waste currently processed in the Metro Vancouver region is yard waste, which is collected in municipal programs and/or dropped off at public depots or private composting facilities.
- **Industrial Fuel.** In this study, the term 'industrial fuel' refers to the existing practice of utilizing source separated wastes as fuels in industrial operations. Wood waste is primarily being used as fuel in cement and pulp and paper facilities. A portion of scrap tires collected in the Tire Stewardship BC program is being used as fuel in local cement kilns. Used lubricating oil and flammable liquids collected in EPR programs are also being diverted to industrial fuel uses.

For the purposes of this study, reuse, recycling and composting are typically grouped together under the heading "recycling/composting". Industrial fuel is typically shown as a separate waste management method.

Waste Disposal

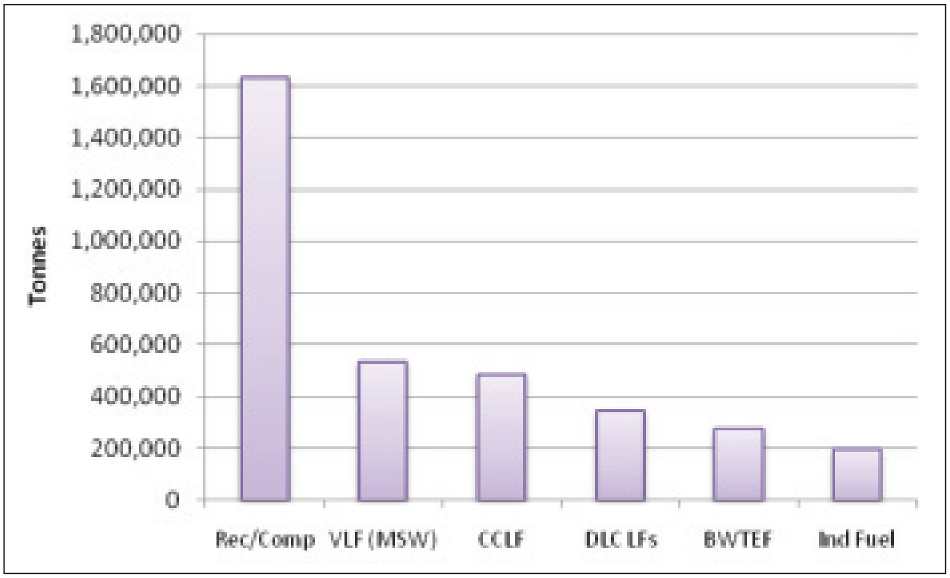
- **Waste-to-Energy.** In this study, waste-to-energy (WTE) refers specifically to the Burnaby waste-to-energy facility. The Burnaby WTE facility uses a mass burn technology to incinerate MSW, producing steam that is used to generate marketable electricity, as well as being sold to a neighbouring industrial plant. This facility receives approximately 21% of MSW disposed in the region.
- **Landfills.** In this study, the term 'landfills' refers specifically to the existing MSW and DLC landfills that receive these types of wastes from the Metro Vancouver region.
  - MSW Landfills
    - The Vancouver landfill receives approximately 41% of MSW disposed in the region. At the Vancouver landfill, landfill gases (LFGs) are captured and combusted to generate electricity and, to a lesser extent, for beneficial hot water heating purposes.
    - The Cache Creek landfill (CCLF) receives approximately 38% of MSW disposed in the region. MSW is long-hauled (with back-haul of wood chips) to this facility, where LFGs are captured and flared.
  - DLC Landfills
    - Private DLC landfill. DLC waste is hauled to a dedicated construction and demolition debris landfill in the region. There is no collection of landfill gases from disposed DLC discards at the dedicated DLC landfill.
    - Vancouver landfill. DLC waste is also disposed at the Vancouver landfill for the purpose of establishing the base of the landfill, and for site contouring uses. In this study, the DLC component of the Vancouver landfill is grouped with the private DLC landfill under the heading 'DLC landfills'.
    - Some DLC waste may be hauled out of the region but this was not accounted for in this study due to lack of data.

Figure 2.1 shows the disposition of MSW and DLC waste generated in the region in 2008 by waste management method. In this figure, 'recycle' includes reuse, recycling and composting. VLF (MSW) refers to the MSW fraction of waste received at the Vancouver landfill. DLC LFs includes DLC discharged at the Vancouver landfill as well as at a private DLC landfill in the region.

2.2.3 Zero Waste Scenario Description

The study defined a long term Zero Waste scenario for the Metro Vancouver region for the purpose of analyzing the associated lifecycle environmental impacts

Figure 2.1 Base Case – Estimated Disposition of Waste in Metro Vancouver (MSW & DLC)



(burdens and benefits) that would arise in the process of pursuing this future objective. Zero waste in this context was understood to mean progressively increasing the types and quantities of waste diverted, particularly through reuse, recycling, composting and EPR, thereby minimizing the need for disposal facilities in the long term.

A 20-year timeframe was selected in order to estimate the benefits of a zero waste approach. This timeframe was selected because it is a typical long term planning horizon in the waste management industry. It should not be construed as a limit to the potential for continued progress toward a zero waste objective. The 20-year timeframe was broken down into five-year increments (2014, 2019, 2024, and 2029) to facilitate the development of plausible diversion strategies and to allow for life cycle analysis of interim points with progressively higher diversion rates in the Zero Waste scenario.

2.2.3.5 Waste Generation Projections

Table 2.5 presents a summary of waste generation projections used in the Zero Waste scenario.

For the Zero Waste scenario, waste generation for MSW and DLC streams was projected to 2029 using the 2008 Base Case as a baseline for estimating per capita waste generation. It was assumed that waste generation for both these streams grew at the same rate as population growth, as projected by BC Stats.[5]

2.2.3.6 Waste Management Methods

Waste Diversion

For the purposes of this LCA study, plausible zero waste diversion strategies were identified by waste stream (MSW and DLC) and by product/material category for the 20-year planning timeframe. Based on this effort, waste diversion rates were projected for each five year increment in the 20-year scenario. Summary results for the projections are presented in **Table 2.6**.

The identification of zero waste diversion strategies was based on a number of considerations regarding the planning context, as well as research undertaken for this study. Notably:

- Current plans and initiatives to increase diversion in the region in the next five years were considered, such as proposed regional plans to:[6]
    - Increase the effectiveness of existing recycling programs through initiatives such as improved enforcement of materials bans.
    - Improve diversion in the ICI sector through implementation of recycling bylaw requirements.
    - Increase diversion of wood waste through modifications to demolitions and building permit processes, and support for DLC recycling facilities.
    - Increase paper and paperboard diversion through enhanced disposal bans, recycling bylaw requirements.
    - Target food waste diversion through provision of processing facilities.
    - Increase plastics waste diversion through support for EPR initiatives.
- Provincial and national objectives and support for Extended Producer Responsibility were considered:
    - British Columbia has EPR programs for products and packaging such as computers, TVs, used oil, paint and beverage containers. The Province has identified a list of potential candidates for mandatory EPR programs in the future, such as additional packaging, additional electronic and electrical equipment, furniture, carpet, textiles, and construction-related products.[7]
    - The Canadian Council of Ministers of the Environment (CCME) has made EPR a priority for coordinated action among provinces. The CCME recently issued a discussion paper on a Canada-wide action plan for EPR. This plan identifies packaging, printed materials, compact fluorescent lights, electronic and electrical equipment, household hazardous waste, automotive products, construction and demolition materials, furniture, textiles and carpet, and appliances as products for EPR programs.[8]
    - Numerous voluntary or private EPR programs are evident currently, such as the London Drugs packaging take-back initiative and the Sleep Country mattress recycling program. It was assumed that more of these types of initiatives would emerge as companies adopt zero waste and corporate social responsibility objectives in their efforts to remain competitive and ahead of regulatory requirements.
- Research was conducted regarding relevant diversion programs and zero waste planning initiatives in other cities and metropolitan regions. Several communities were found to have implemented zero waste planning

Table 2.5 Zero Waste Scenario – Projected Waste Generation (MSW & DLC)

	2014 (tonnes)	2019 (tonnes)	2024 (tonnes)	2029 (tonnes)
Paper & Paperboard	804,000	867,000	926,500	980,300
Plastics	247,400	266,600	284,900	301,500
Organics (Compostable)	1,063,200	1,146,000	1,224,700	1,295,800
Organics (Non-compostable)	250,200	269,700	288,200	304,900
Metals	156,900	169,200	180,800	191,300
Glass	190,100	204,900	219,000	231,700
Inorganic Building Materials	953,300	1,027,600	1,098,200	1,161,900
Electronic Waste	39,300	42,400	45,300	47,900
Household Hazardous	37,900	40,900	43,700	46,200
Household Hygienic	44,200	47,700	50,900	53,900
Bulky Objects	25,200	27,200	29,000	30,700
Fines/Misc	21,300	23,000	24,500	26,000
Total MSW & DLC	**3,833,400**	**4,132,000**	**4,415,900**	**4,672,200**

Table 2.6 Zero Waste Scenario – Projected Diversion Rates (MSW & DLC)

Material Category	Estimated 2008 Diversion Rate	Projected 2014 Diversion Rate	Projected 2019 Diversion Rate	Projected 2024 Diversion Rate	Projected 2029 Diversion Rate
Paper & Paperboard	58%	66%	75%	80%	85%
Plastics	10%	20%	50%	60%	80%
Organics (Compostable)	42%	60%	72%	77%	83%
Organics (Non-compostable)	29%	39%	48%	50%	51%
Metals	62%	71%	80%	85%	90%
Glass	78%	80%	85%	90%	90%
Inorganic Building Materials	75%	80%	84%	87%	90%
Electronics	16%	50%	65%	75%	90%
Household Hazardous	76%	80%	90%	95%	95%
Household Hygienic	0%	0%	10%	30%	50%
Bulky Objects	0%	8%	25%	51%	68%
Fines/Misc.	2%	2%	4%	4%	4%
Total MSW & DLC	**53%**	**63%**	**72%**	**77%**	**83%**

initiatives in the last three to five years, such as Seattle and Los Angeles. Particular attention was paid to programs and plans in the City of Seattle and Greater Portland, as these communities share similarities with the Metro Vancouver region in terms of their populations, climate, commitment to waste diversion, and their position as the major employment and population centres in their specific geographic regions. This research aided in the identification of plausible diversion strategies for the purposes of this LCA analysis, particularly for the first five to ten years of the Zero Waste scenario. **Appendix C** provides a summary of the research.

Given these considerations, a mix of strategies was identified for the projections, such as:

- Mandatory EPR programs (new or expanded) for products such as: packaging, printed paper, electronic equipment, furniture, textiles, carpet, gypsum wallboard, roofing shingles.
- Organics collection and processing, targeting food, tissue paper, soiled paper.
- Mandatory recycling requirements (bylaws) for the ICI sector to increase reduction/diversion of products and materials such as paper, packaging, metal and hazardous wastes. This would include products managed in EPR programs.
- Mandatory recycling requirements (permit process related) for the DLC sector to increase diversion of wood, metal, plastic, cardboard, and other materials.
- Disposal bans and enhanced enforcement to support EPR, municipal recycling and composting programs.
- Financial incentives, zoning and licensing adjustments to support development of resource recovery parks, DLC processing facilities and regional recycling markets.
- Enhanced education and social marketing outreach to targeted sectors.

Waste Disposal

Modeling the disposal system under the Zero Waste scenario required consideration of two overall sets of variables: the changing volume and composition of waste disposed, and the disposal facility configuration used to manage these waste streams in the future.

The composition of residual waste is expected to change under the Zero Waste scenario as more and new kinds of products and materials (e.g., food waste, carpets and furniture) are diverted. These changes can affect the environmental performance of various disposal system options. For example, removing food waste lowers the potential methane emissions from landfills. The composition of waste disposed in each Zero Waste scenario profile year (2014, 2019, 2024 and 2029) was modeled in this LCA study. An important assumption related to this is that while the composition of waste disposed changed under the Zero Waste scenario, the composition of waste did not vary by disposal facility. The composition of waste for each scenario profile year was held constant on a per tonne basis such that MSW disposal facilities would each receive the same mix of residual MSW; DCL facilities would each receive the same mix of residual DLC waste.

The volume of waste disposed is dependent on the assumptions driving increasing diversion. As waste diversion rises from 53% to 83% of waste generated, disposal decreases from 47% in 2008 to 17% in 2029. As shown in **Table 2.7,** the volume of MSW disposed is projected to drop to 545,300 tonnes in 2029. Combined MSW and DLC tonnage disposed is projected to drop by 50% to 803,900 tonnes in 2029. These tonnage projections were modeled in this LCA study. The allocation of tonnage to particular facilities is discussed below.

Table 2.7 Zero Waste Scenario – Disposal Projections (MSW & DLC)

Management System	2008 (tonnes)	2014 (tonnes)	2019 (tonnes)	2024 (tonnes)	2029 (tonnes)
MSW Disposal System	1,293,500	1,132,000	862,500	735,400	545,300
DLC Disposal System	345,900	301,700	285,300	266,600	258,700
Disposal Total	**1,639,300**	**1,433,700**	**1,147,700**	**1,002,000**	**803,900**
Disposal Rate	**47%**	**37%**	**28%**	**23%**	**17%**

The types and configuration of disposal facilities that may be in place in the Metro Vancouver region in the future to receive solid waste is uncertain, particularly with respect to the MSW system. It was beyond the scope of this study to identify the optimal disposal system. Instead, the objective of modeling the disposal system under the Zero Waste scenario was to identify the environmental impacts of the system under the changing waste composition and volume conditions, and to compare these to the Base Case. To undertake this, a hypothetical future disposal system configuration was identified, supplemented by three sensitivity analyses for MSW disposal.

It was determined that the hypothetical future disposal system would consist of the set of MSW and DLC disposal facilities existing under the Base Case, with the same relative waste volume allocations as the Base Case. Some of the facilities in this model would be subject to certain kinds of known or planned upgrades that would improve environmental performance, as well as to changes in the mix of future fuel offsets. For example, the Burnaby WTE facility is scheduled to receive air emissions upgrades that will significantly reduce emissions of NOx, SO2 and HCL.

The hypothetical model was used to calculate environmental impacts of facilities on a per tonne basis, which in turn provided the basis for comparison of each waste management facility to other management options in that year of the Zero Waste scenario and to the Base Case (as discussed in Section 4.2). The per tonne environmental impacts of disposal facilities are sensitive to facility operating parameters and related assumptions, such as NOx emissions controls or landfill gas collection efficiencies (see Appendix B). However, the per tonne impact calculations are not sensitive to the volume of waste received in a given year of the Zero Waste scenario because the composition of the waste was not differentiated between facilities.

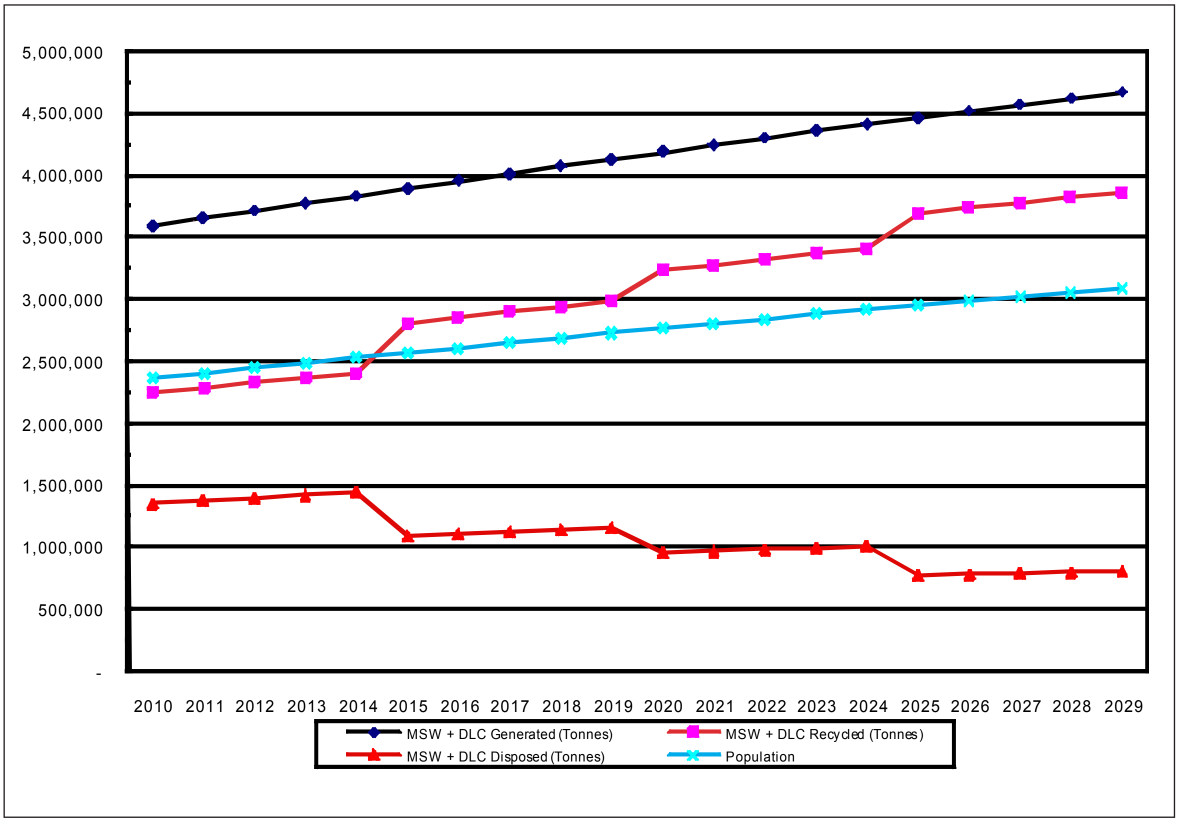
The volume of waste received at particular disposal facilities may affect the total potential emissions released to the environment under the Zero Waste scenario. As the allocation of the volume of waste between disposal facilities is altered, the total emissions produced or saved may change, more or less, depending on the environmental performance of each facility on a per tonne basis. To gain insight into this relationship, a set of three sensitivity analyses were run on the allocation of waste in the MSW disposal system at 2029 (83% diversion). While any number of allocation configurations could be applied, for this study it was assumed that 100% of residual MSW would be allocated to the Vancouver landfill, the Cache Creek landfill and the Burnaby WTE facility, respectively. These allocations did not take into consideration actual or planned facility capacities or financial costs as they were strictly intended to profile environmental impacts. No variation was assumed for the DLC system (i.e., same allocation as the 2008 Base Case). **Table 2.8** illustrates these assumptions. The results of this analysis are presented in Section 4.4.

Figure 2.2 presents a time series projection of generation, diversion and disposal of MSW and DLC over the 20-year period using the results of the modeling effort.

Table 2.8 Disposal System Sensitivity Analyses – Tonnes of Waste Disposed (2029)

Facility	Sensitivity 1 (tonnes)	Sensitivity 2 (tonnes)	Sensitivity 3 (tonnes)
Vancouver MSW LF	545,200	—	—
Cache Creek MSW LF	—	545,200	—
Burnaby MSW WTEF	—	—	545,200
DLC LFs	258,600	258,600	258,600
Total	**803,900**	**803,900**	**803,900**

Figure 2.2 Zero Waste Scenario – Projected Generation, Diversion & Disposal (MSW & DLC)



2.3 Life Cycle Analysis Methodology

2.3.1 General Scope of LCA

Life cycle analysis or assessment (LCA) is a technique for assessing the environmental inputs and outputs associated with products and processes. As the name implies, the LCA approach purposefully broadens the scope of an environmental impact assessment to include the materials and energy inputs and outputs that occur at each stage of the life cycle of the product or process.

Figure 2.3 portrays environmental flows across a product's life cycle in terms of energy and material inputs and energy and pollution outputs (to air, water and land). The typical product's life cycle involves:

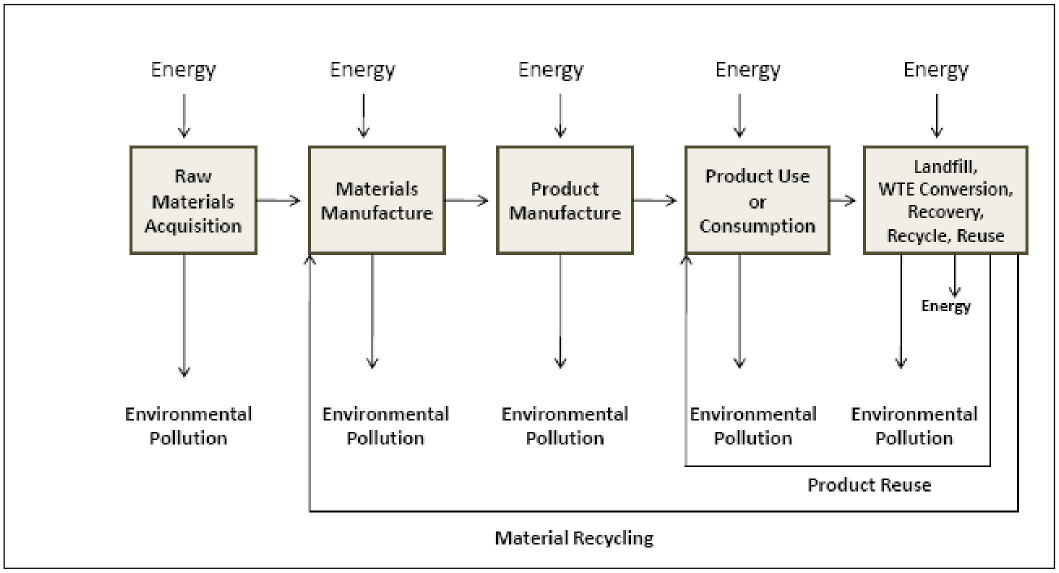
- extracting raw materials from nature's ecosystems,
- refining those virgin resources into industrial feedstocks,
- manufacturing the product from these feedstocks,
- using the product by its consumer, and
- disposition of the product discards by reuse, recycling, recovery or disposal.

The first three phases (extraction, refining and manufacturing) are often termed the *upstream phase* in the product life cycle. The last phase (reuse, recycling composting, waste-to-energy, landfill) is often termed the *downstream* or post-consumer phase.

The feedback loops in **Figure 2.3** show how recycling and composting bypass a portion of the upstream phase. This conserves the energy already embodied in products and reduces the waste and pollution that result when new goods and services are produced. Most of the environmental benefit of recycling and composting comes from pollution reductions when recycled materials replace raw materials and compost replaces petroleum-based fertilizers. The upstream environmental benefits and burdens of recycling and composting are taken into account in this study.[9]

The first step of this LCA was to define the Base Case and Zero Waste scenarios, particularly with respect to the products and materials occurring in the waste stream and the various ways in which each type of product or material, or portion thereof, was managed (e.g., recycling, landfilling, WTE). The next steps in the LCA involved developing pollutant emissions inventories and assessing the impacts of these pollutants over the product or material lifecycle. This assessment was based on how these products and materials are managed in the post-consumer phase as defined in the scenarios. For example, a small portion of clean wood waste is sent for recycling at pulp and paper mills. In the LCA assessment of this management method for wood waste, a range of emissions were identified associated with the production of recycled wood sent for pulp. As well, a range of emissions "offsets" or "credits" were also identified, such as GHG emissions prevented through avoided tree harvesting. The lifecycle emissions and lifecycle offsets were summed up to result in a net emissions

Figure 2.3 Product Life Cycle Phases



estimate for this particular way of managing clean wood waste. Other ways of managing wood waste, including using it as industrial fuel or disposing of it at landfills or the Burnaby WTE facility, were similarly assessed. A detailed example of the steps involved in assessing the lifecycle impacts of various waste management methods for wood waste is provided in **Appendix D**.

2.3.2 Developing Emissions Inventories with MEBCalc

To estimate many of the environmental emissions for Vancouver region discards management methods, Sound Resource Management's MEBCalc model (Measuring the Environmental Benefits Calculator) was used. This is a comprehensive recycling and composting environmental costs and benefits valuation model.[10] MEBCalc includes a "best-of" compendium of life cycle inventory data from a number of environmental life cycle inventory and assessment models, including:

- US EPA's WARM life cycle inventory spreadsheet calculator for GHG emissions and the associated report (EPA 2006).[11]
- US EPA's MSW Decision Support Tool and database.[12]
- Carnegie Mellon University Green Design Institute's Economic Input-Output Life Cycle Assessment model.[13]
- US National Institute of Standards and Technology's Building for Environmental and Economic Stability (BEES) model.[14]
- US EPA's TRACI model.[15]

MEBCalc estimates pollution reductions or increases that are caused by diverting material discards to recycling or composting. The model takes into account pollution emissions from collection vehicles, transportation of collected wastes to management facilities, recyclables processing facilities, composting facilities, disposal facilities, shipping of processed materials to end users, and product manufacturing facilities.

Emissions inventory estimates also rely on life cycle data from the Consumer Environmental Index (CEI) model developed for the Washington State Department of Ecology,[16] as well as from peer-reviewed journal articles including Morris (1996), Morris (2005), and Morris and Bagby (2008).

In addition, the study relied on:

- Life cycle inventories for DLC wood and carpet wastes developed recently for Seattle Public Utilities.[17]
- Franklin Associates report on environmental impacts of recycling glass into containers, fiberglass and aggregate.[18]
- R. W. Beck reports on conversion technologies and anaerobic digestion.[19]

The emissions inventories for the Vancouver region's current and projected future waste management facilities and systems also are based on:

- Description of current Burnaby WTE facility and Vancouver landfill disposal system characteristics, and projected future WTE and landfill disposal system characteristics as summarized and detailed in Sheltair (2008).
- Sulfur dioxide, nitrogen oxides, hydrogen chloride, particulate matter, carbon dioxide, and Class 1 through 3 metals emissions for the Burnaby MSW WTE facility, as detailed in Sheltair (2008). Dioxin and furan emissions, while presented in Sheltair (2008), were not included in this study in the calculations of environmental impacts for the Burnaby WTE facility or for other waste management methods.[20]
- Non-methane organic compounds (NMOC) and metals emissions factors for the Vancouver and Cache Creek MSW landfills, as estimated using US EPA's LandGEM (Landfill Gas Emissions Model–version 3.02) with site specific gas generation parameters reflecting local precipitation and organics composition of disposed MSW.[21]

Additional information on emissions data and assumptions for recycling, industrial fuels, and disposal facilities are shown in **Appendices A** and **B** of this report.

2.3.3 Estimating Impacts from Emissions Inventories

2.3.3.1 Overview

Life cycle assessment methodology connects emissions inventories covering hundreds of pollutants to a handful of environmental impacts. As such, it distills the overwhelming amount of information in emissions inventories down to a level of detail that is more manageable in terms of following complex trends and understanding relative environmental costs and benefits of options.

The trade-off is that we have to sort through complex pollutant aggregation and weighting methodologies. A "best-of" consensus methodology is in development by the United Nations Environment Program and the Society of Environmental Toxicology and Chemistry.[22]

Until that study is released, pollutant emissions aggregation relies on the methodologies used by the Intergovernmental Panel on Climate Change (IPCC), US EPA's TRACI (Tool for the Reduction and Assessment of Chemical and other environmental Impacts) model and the Lawrence Berkeley National Laboratory's CalTOX model.[23,24]

The case of greenhouse gases provides an example of how complex emissions inventories are grouped into impact categories for the purposes of LCA analysis. Greenhouse gases, including carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), chlorofluorocarbons (CFCs) and other pollutants, cause global warming that can lead to Climate Change. The United Nations Intergovernmental Panel on Climate Change (IPCC) has conducted and reviewed scientific data to determine the strength of each pollutant relative to carbon dioxide in causing global warming. For example, over a hundred year time frame a current release of a given amount by weight of methane or nitrous oxide is 25 times or 298 times, respectively, more harmful to the climate than a current release of the same weight of CO2.[25] Based on these global warming potential factors we can aggregate the emissions of all GHG pollutants into a single indicator quantity for global warming potential (GWP). This quantity is CO2 equivalents (herein denoted eCO2).[26]

Similar scientific efforts enable us to express the quantity of pollutant releases in terms of a single indicator quantity for other categories of environmental damage. Each category encompasses a particular type of potential environmental impact.

The impact categories used in an LCA may include, among others:[27]

- Global warming
- Acidification
- Eutrophication
- Human Health – respiratory diseases caused by criteria air pollutants
- Human Health – cancers
- Human Health – non-cancers
- Ecosystem Toxicity
- Ozone depletion
- Smog formation
- Habitat alteration
- Resource depletion
- Water consumption

2.3.3.2 Selection of Impact Categories for this Study

Five environmental *impact categories* were selected to analyze the impacts of waste management options for the Metro Vancouver region waste stream:

1. **Climate Change:** greenhouse gases that cause global warming and Climate Change.
2. **Human Health:**
   - *Respiratory diseases:* particulates that cause lung disease.
   - *Cancers:* carcinogenic substances.
   - *Non-cancers:* toxic, non-carcinogenic substances.
3. **Ecosystem Toxicity:** pollutants that are toxic to plants and animals.

These categories were chosen because they capture many of the global and local, as well as human and non-human, repercussions of waste management methods. In addition, there are readily available sources of emissions data on many of the toxic and carcinogenic substances and pollutants that cause these particular public health and ecological problems. The other impact categories listed in Section 2.3.3.1 were outside the scope of this study.

The Human Health impact categories were subsequently aggregated into a single category in order to make the results of the study more straight forward for readers. The process of reducing these three impact categories to a single category required selecting a single indicator pollutant. This step is discussed further in the following section.

2.3.3.3 Selection of Pollutant Indicators for this Study

In LCA methodology, pollutant emissions associated with each impact category are commonly reduced to one *indicator pollutant,* as discussed in Section 2.3.3.1. By aggregating many pollutants into one equivalent indicator, it is easier to compare and analyze trends for hundreds of pollutants. Life cycle impact assessment practitioners have selected standard indicators for each impact category based on these indicator substances having environmental impacts that are relatively well-characterized and understood. They thus provide a recognizable standard against which to measure the relative effects of other pollutants in terms of each particular environmental impact.

To make it easier to compare the LCA results for Human Health to the results for Climate Change and Ecosystem Toxicity, we aggregated the three Human Health impacts into a single Human Health impact indicator by expressing the indicators for the three Human Health categories in terms of just one of them: eToluene.

Converting ePM2.5, the indicator for respiratory diseases, and eBenzene, the indicator for cancers, to eToluene, the indicator for human non-cancer health impacts, is a two-part process:

1. A monetary cost was estimated for each of the three indicator substances for the Human Health impacts.[28] The monetary health cost estimates for the three indicator substances are based on the Human Health scientific literature's estimates of the health costs of exposure to particulates, carcinogens, or toxics. Specifically, these costs are:
    - US $11.02/kilogram PM2.5
    - US $3.34/kilogram benzene
    - US $0.13/kilogram toluene
2. The three Human Health impacts were then re-expressed in terms of toluene equivalents (eToluene), the human toxics indicator.

Table 2.9 shows the pollutant indicators for the impact categories used in this study. Human Health has been reduced to one category as discussed above. As shown, a pollutant may fall into more than one category. This is not double counting. A single substance, such as chloroform, may be a greenhouse gas, toxic to humans, and a toxic to ecosystems. As such, it will have different environmental impacts which must be taken into account in the different categories for environmental impacts.

2.3.4 Applying Emissions Categories to Scenarios

Once the LCA impact indicator quantities are calculated for each material handled by each management method and disposal facility, it is relatively straight forward to calculate the overall environmental impacts of emissions based on the composition of waste materials handled under each method, and the quantities of wastes handled at each particular disposal facility and by diversion methods. Thus, the selected impact categories were applied to the emissions generated by wastes flowing to each management method and disposal facility based on the waste stream projections discussed in Section 2.2 as allocated to each management method and disposal facility. This resulted in the generation of estimates of kilograms of climate changing, Human Health impairing and ecosystem toxifying pollutants per tonne of waste handled by each management method and waste disposal facility. The results are presented in Sections 3 and 4 of this report.

Table 2.9 Impact Categories and Pollutant Indicators Used in this Study

Impact Categories	Pollutant Indicator	Examples of Pollutants Factored into Indicator
Climate Change	Carbon dioxide equivalents (eCO2)	Carbon dioxide (CO2) Methane (CH4) Nitrous oxide (N2O) Chlorofluorocarbons (CFCs) Plus numerous other pollutants
Human Health	Toluene equivalents (eToluene)	Particulate Matter 2.5 NOx, SOx Mercury, lead, cadmium Toluene, benzene Plus scores of other pollutants
Ecosystem Toxicity	2,4-D herbicide equivalents (e2,4-D)	DDT Lead, mercury, zinc Vinyl chloride Plus scores of other pollutants

2.3.5 Further Information on LCA Approach

This report would be exceedingly voluminous were we to include all the details and calculations for the life cycle analysis for all methods currently used and projected for future use to manage each MSW and DLC waste material generated in the Metro Vancouver region during the years 2008 through 2029. At the same time, it is important that this report provide transparency for the life cycle analysis. To this end, in addition to **Appendices A, B** and **C** as noted above, additional information is provided in the following appendices:

Appendix D (LCA Example – Clean Wood Waste Management) discusses the calculations for the analysis of greenhouse gas emissions for the seven different methods of handling wood wastes that are currently used in the Metro Vancouver region. As such, it provides a detailed example of the LCA methodology used for the various types of products and materials assessed.

Appendix E (Sensitivity Analysis for Global Warming Potential of Methane Gas) discusses a sensitivity analysis for the global warming potential multipliers that should be used for calculating potential Climate Change impacts if one is more concerned about Climate Change during the next 25 years compared with the 100-year convention typically used in life cycle analysis of carbon emissions. This sensitivity analysis illuminates the importance of the characterization factors used for aggregating pollutants into environmental impact categories. The information in this appendix is also important in that it shows that the conventional 100-year time frame for climate impacts does understate the impacts of landfills somewhat compared with a shorter time frame. However, the shorter time frame does not change the relative rankings for waste management methods reported in the main body of the report that result when using the 100-year convention in the life cycle analysis of GHG emissions.

Appendix E also provides a combined sensitivity analysis showing the impact of a 25-year time horizon combined with a 90% capture rate for landfill gases (as opposed to the 75% capture rate used in the LCA calculations shown in the main body of this report). This sensitivity analysis shows the further reductions in greenhouse gases achievable when landfills attain the capture rates currently being achieved in modern landfills.

Section 3: LCA RESULTS FOR BASE CASE SCENARIO

3.1 Introduction

This section presents LCA results for the Base Case scenario for managing MSW and DLC discards in Metro Vancouver. Results are presented in terms of total potential and per tonne emissions for each of the three environmental impact categories: Climate Change (eCO2), Human Health (eToluene) and Ecosystem Toxicity (e2,4-D).

'Total potential emissions' refers to the total net tonnes of emissions prevented or produced by each waste management method in the Base Case scenario. The results per management option are also summed up, resulting in a 'net system emissions' total. When reviewing the total emissions results for each waste management method, it is important to bear in mind that the total emissions are, in part, relative to the quantity of waste flowing to these methods. By fluctuating the volume of waste received by a waste management option, the total emissions will similarly fluctuate. Total emissions are also a function of various constant factors associated with the life cycle environmental impacts of waste management options and facilities. These are expressed in the 'emissions per tonne' estimates discussed below. The total emissions results provide insight into the overall scale of environmental benefits and burdens associated with each method.

'Emissions per tonne' refers to the kilograms of emissions prevented or produced per tonne of waste flowing to each waste management option in the Base Case scenario. Emissions per tonne are calculated by dividing total emissions by total tonnes of waste flowing to a waste management method. They are sensitive to changes in program or facility operating parameters and related assumptions, such as NOx emissions controls or landfill gas collection efficiencies, but they are not sensitive to alterations in waste volumes as long as waste composition assumptions are not altered. The per tonne results are also shown in terms of 'system average emissions', which are calculated by dividing the total net system emissions by the total waste generated in the Base Case year. The emissions per tonne results provide the basis for comparing waste management options to each other.

The results for recycling and composting have been aggregated into one category (recycling/composting), as have the results for industrial fuels. This is to facilitate comparison between the waste management methods in the Metro Vancouver solid waste system. However, for discussion purposes, per tonne results have also been presented for select disaggregated recyclables/compostables. With respect to disposal, results are reported for the four separate disposal facilities: DLC landfills, Vancouver landfill, Cache Creek landfill, and the Burnaby WTE facility.

Table 3.1 summarizes the potential emissions by waste management method for the combined MSW and DLC system, and for MSW and DLC separately. This is the data source for the summary graphs presented in this section, with the exception of the graphs for disaggregated recyclables.

*It should be noted that the emissions per tonne values calculated for each management method as shown in the last three columns in **Table 3.1** are not additive (i.e., emissions per tonne values for any two or more management methods cannot be added together to result in a net sum value for the combined methods). This is because they are each derived from the total tonnes of emissions and waste associated with each specific management method, as presented in the first four columns. Similarly, the emissions per tonne values shown separately for MSW and DLC cannot be summed to result in per tonne values for the combined system.*

Table 3.1 Potential Emissions (2008)

	Waste (tonnes)	Total Potential Emissions (tonnes)			Average Potential Emissions(1) per Tonne (kg/tonne waste)		
		Climate Change (eCO2)	Human Health (eToluene)	Ecosystem Toxicity (e2,4-D)	Climate Change (eCO2)	Human Health (eToluene)	Ecosystem Toxicity (e2,4-D)
MSW System (43% diversion)							
Recycling/Composting	957,300	(1,758,200)	(904,400)	(2,100)	(1,837)	(945)	(2)
Industrial Fuel	16,100	(13,300)	(4,500)	100	(828)	(276)	6
Vancouver MSW LF	532,800	(143,600)	58,700	<50	(270)	110	<0.5
Cache Creek MSW LF	483,600	(73,900)	2,800	<50	(153)	6	<0.5
Burnaby MSW WTEF	277,100	67,600	28,400	500	244	103	2
Net System(2)	2,266,900	(1,921,500)	(819,000)	(1,500)	(848)	(361)	(1)
DLC System (71% diversion)							
Recycling/Composting	676,900	(125,000)	(61,200)	(400)	(185)	(90)	(1)
Industrial Fuel	179,900	(264,900)	169,600	4,900	(1,473)	943	27
DLC LFs	345,800	(78,200)	900	<50	(226)	2	<0.5
Net System(2)	1,202,600	(468,200)	109,300	4,600	(389)	91	4
Combined MSW and DLC System (53% diversion)							
Recycling/Composting	1,634,200	(1,883,200)	(965,600)	(2,500)	(1,152)	(591)	(2)
Industrial Fuel	196,000	(278,300)	165,200	5,000	(1,420)	843	26
Vancouver MSW LF	532,800	(143,600)	58,700	<50	(270)	110	<0.5
Cache Creek MSW LF	483,600	(73,900)	2,800	<50	(153)	6	<0.5
Burnaby MSW WTEF	277,100	67,600	28,400	500	244	103	2
DLC LFs	345,800	(78,200)	900	<50	(226)	2	<0.5
Net System(2)	**3,469,500**	**(2,389,600)**	**(709,700)**	**3,000**	**(689)**	**(205)**	**1**

(1) Average Potential Emissions per Tonne: Total Potential Emissions divided by tonnes of waste.
(2) Net System: For Total Potential Emissions columns, the sum of total emissions by management method. (Numbers may not add due to rounding.) For Average Potential Emissions per Tonne, the Net System is determined by dividing the Net System Total Potential Emissions by tonnes of waste. (Average Potential Emissions for different waste management methods cannot be added.)

3.1.1 Climate Change Impacts of Recycling/Composting

Under the Base Case scenario, 1,634,000 tonnes of waste were diverted to recycling/composting, accounting for 47% of waste generated. In terms of total emissions, the findings show that as a result of these activities, 1,883,200 tonnes of GHG emissions were prevented from entering the atmosphere (**Table 3.1**). Recycling/composting accounts for nearly 80% of total GHG emissions reductions achieved under the Base Case scenario, as the total net system GHG emissions were reduced by 2,389,600 tonnes eCO2 under the Base Case.

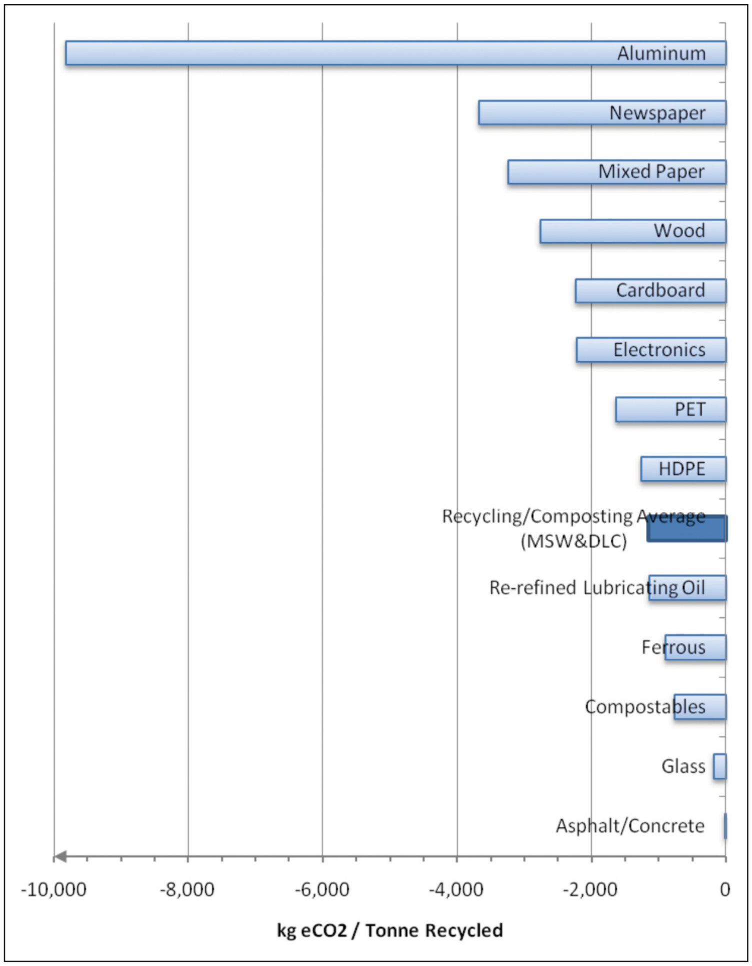
Table 3.2 and **Figure 3.1** shows the GHG reductions for select recyclables from both the MSW and DLC waste streams. The GHG savings range from a high of 9,827 kg eCO2 per tonne of aluminum cans diverted to use as feedstocks for new aluminum can manufacturing, to a low of 14 kg eCO2 per tonne of concrete, asphalt or glass diverted to use as construction aggregates.

As shown in **Figure 3.2**, for the MSW system one tonne of recycling or composting reduces GHG

Table 3.2 Greenhouse Gas Emissions – Select Recyclables (2008)

Product / Material	kg eCO2 / Tonne Recycled or Composted
Aluminum	(9,827)
Newspaper	(3,666)
Mixed Paper	(3,236)
Wood	(2,753)
Cardboard	(2,236)
Electronics	(2,220)
PET	(1,638)
HDPE	(1,258)
Re-refined Lubricating Oil	(1,133)
Recycling/Composting Average (MSW & DLC)	**(1,152)**
Ferrous	(900)
Compostables	(757)
Glass	(181)
Asphalt/Concrete	(14)

Figure 3.1 Greenhouse Gas Emissions per Tonne – Select Recyclables (2008)



emissions by 1,837 kg of eCO2. DLC recyclables reduce GHGs by 185 kg eCO2/tonne waste. As such, MSW recycling/composting results in ten times more eCO2 reductions per tonne than DLC recycling. The lower value for GHG reductions associated with DLC recycling is due to the predominance of concrete/asphalt/masonry recycling in this sector. As it is assumed that these materials are primarily processed into aggregate, the associated GHG emissions reductions are only 14 kg per tonne of waste.

Figure 3.2 shows that, for the combined MSW & DLC system, diverting one tonne of discards to recycling or composting reduces GHGs by 1,152 kg of carbon dioxide equivalents (eCO2). This per tonne result for the combined system is lower than the per tonne benefit associated with MSW recycling due to the averaging that occurs when the total MSW and total DLC GHG emissions for recycling are combined and divided by the total tonnes (see **Table 3.1**).

3.1.2 Climate Change Impacts of Industrial Fuel

Under the Base Case scenario, an estimated 196,000 tonnes of waste were diverted to industrial fuel end uses, accounting for 6% of waste generated. Of this amount, 92% was clean wood from DLC sources, and 8% was used lubricating oil and rubber (scrap tires) from MSW sources (i.e., EPR programs).[29] In terms of total emissions, the findings show that as a result of these activities, 278,300 tonnes of GHG emissions were prevented from entering the atmosphere.

As shown in **Figure 3.3**, in the DLC system, sending wood to industrial fuel reduces GHG emissions by 1,473 kg tonnes eCO2 per tonne waste, while in the MSW system, sending used oil and rubber to industrial fuel reduces GHG emissions by 828 kg per tonne waste on average. In the combined MSW & DLC system, each tonne of industrial fuel reduces GHG emissions by 1,420 kg eCO2. This per tonne result for the combined system is lower than the per tonne benefit associated with the DLC system due to the averaging that occurs when the total MSW and total DLC GHG emissions for industrial fuels are combined and divided by the total tonnes (see **Table 3.1**).

Like MSW recyclables, the variation between the DLC and MSW industrial fuels is partly due to waste composition. The average tonne of DLC industrial fuel in 2008 consists of wood waste. The average tonne of MSW industrial fuel in 2008 contains a mix of lubricating oil (79%) and rubber (21%). The following are some additional observations and considerations regarding these results:

- As discussed in Appendix D, processing, chipping (or size reduction), and hauling operations to provide wood waste chips for combustion in industrial boilers generate 7,000 kg eCO2 per million megajoules (MJ), including the non-CO2 greenhouse gases released during combustion of wood. In contrast, coal production and combustion generates 125,000 kg of carbon dioxide equivalents per million MJ. Natural gas production and combustion generates 60,000 eCO2 per million MJ.
- Based on the assumption that 50% of waste wood fuel offsets coal, and 50% offsets natural gas, wood fuel reduces GHG emissions by 1,500 kg eCO2 per tonne

Figure 3.2 Greenhouse Gas Emissions per Tonne – Recycling/Composting (2008)

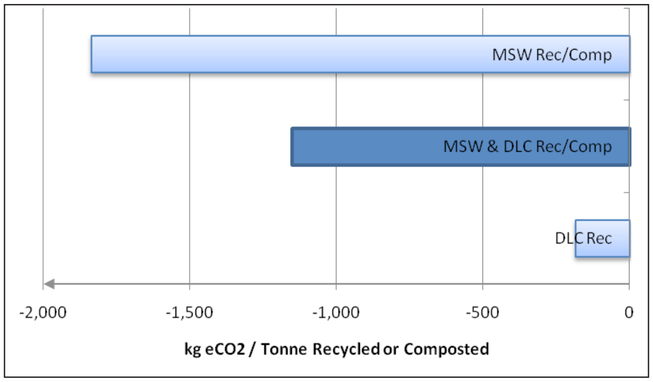
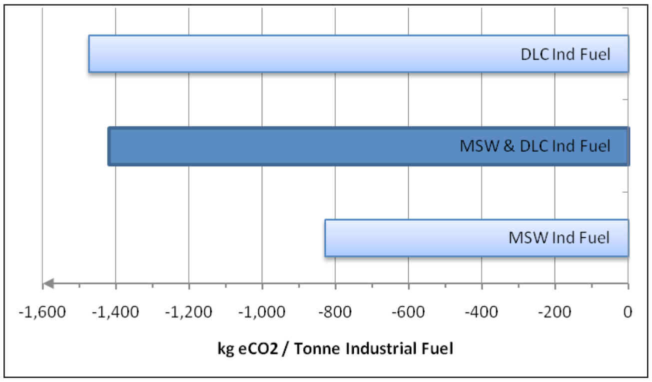


Figure 3.3 Greenhouse Gas Emissions per Tonne – Industrial Fuel (2008)



of waste in the Base Case. Due to wood combustion's carbon dioxide emissions usually being classified as biogenic rather than anthropogenic, substitution of wood wastes for coal reduces GHG emissions by more than 2,000 kg eCO2 per tonne of wood. Substituting one tonne of wood waste for natural gas reduces GHG emissions by more than 900 kg eCO2, less than for coal substitution because natural gas is a more GHG efficient source of energy than coal.

- Combusting lubricating oil in industrial facilities reduces GHG emissions by 1,300 kg eCO2 per tonne of oil. This is because oil produces substantially fewer GHG emissions per megajoule than does coal, and only a few more GHGs than natural gas. At the assumed 50/50 split between coal and natural gas in industrial use, replacing these industrial fuels with lubricating oil reduces GHG emissions. If natural gas was the only offset fuel, then the results would show a net GHG emissions impact rather than a benefit because natural gas is a cleaner fuel than used oil.
- Based on the estimate that rubber used as an industrial fuel will replace coal and natural gas on a 50/50 basis, as wood and used lubricating oil do, one tonne of rubber fuel emits 800 kg eCO2 in the Base Case. Rubber combustion releases anthropogenic CO2 to the atmosphere due to the petroleum and natural gas materials from which synthetic rubber is compounded. As a result, diversion of rubber to industrial fuel as a substitute for coal releases as much fossil CO2 as coal – 125,000 kg eCO2 per million MJ. Substituting rubber for natural gas actually increases GHG emissions by 1,600 kg eCO2 per tonne of rubber diverted to industrial combustion.

3.1.3 Climate Change Impacts of Disposal

Under the Base Case scenario, 1,639,300 tonnes of waste (47% of waste generated) is disposed in MSW and DLC landfills and at the Burnaby WTEF.

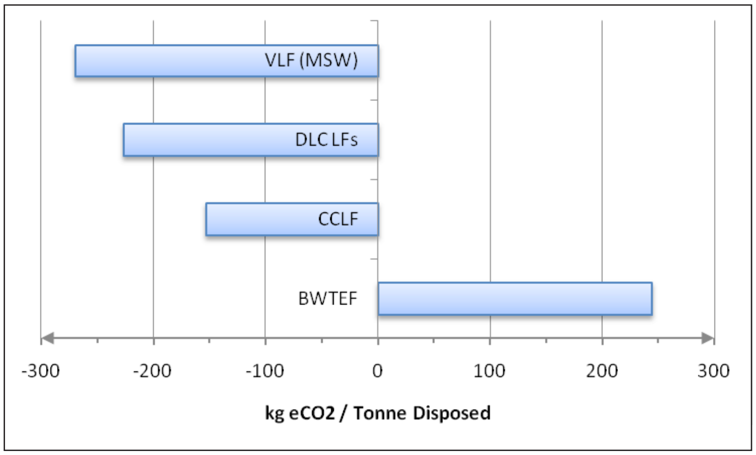
Landfilling, which accounts for 39% of waste generated, resulted in net GHG emissions reductions of nearly 295,800 tonnes eCO2 or 12% of net system savings of GHGs. The breakdown of total emissions impacts reductions for landfills, shown in **Table 3.1**, is as follows:

- Vancouver landfill (MSW): 143,600 tonnes eCO2 reduced for 532,800 tonnes MSW disposed (15% of waste generated).
- Cache Creek landfill (MSW): 73,900 tonnes eCO2 reduced for the 483,600 tonnes MSW disposed (14% of waste generated).
- DLC landfills: 78,200 tonnes eCO2 reduced for the 345,800 tonnes DLC waste disposed (10% of waste generated).

On a per tonne basis, all three landfills reduce eCO2 emissions (**Figure 3.4**). The Vancouver MSW landfill reduces the most GHGs (270 kg eCO2/tonne waste), followed by the DLC landfills (226 kg eCO2/tonne waste) and the Cache Creek MSW landfill (153 kg eCO2/tonne waste). The reduction of GHGs from landfilling is due to the storage of carbon in materials that degrade slowly in a landfill and to the effective capture of much of the methane generated by anaerobic decomposition of both slow and fast degrading organic materials.

The primary reason for the difference between the Vancouver and Cache Creek MSW landfills in terms of GHG emissions reductions is that the Vancouver landfill

Figure 3.4 Greenhouse Gas Emissions per Tonne – Disposal (2008)



has an energy recovery system whereas the Cache Creek landfill does not. As such, the Vancouver landfill is given an offset of reduced natural gas consumption for electricity generation. Otherwise, the assumptions used were identical for both facilities in the 2008 Base Case scenario: capture of 75% of generated methane, same waste composition and same amount of carbon for each waste material.

With respect to the Burnaby WTE facility, 67,600 tonnes of GHG emissions were produced for an estimated 277,100 tonnes of waste processed under the Base Case scenario (8% of waste generated). This works out to 244 kg eCO2 per tonne waste.

These findings are based on the following assumptions and considerations:

MSW Landfills

- Landfill gas capture rate: Capture and neutralization (via flaring or combustion for energy recovery) of at least 75% of the lifetime methane generated in the MSW landfills. Lifetime methane generation was calculated using the Landgem model. The model assumes a lifetime methane generation period of 140 years, starting from the Base Case scenario year (2008). The 75% lifetime capture rate was selected as it reflects actual gas capture rates in state-of-the art landfills. The current gas capture rates at Vancouver and Cache Creek landfills are 70% and 55%, respectively.[30] The efficiency of these systems was assumed to reach the standard of 75% by or before 2011. The lower capture rates in the intervening years are inconsequential relative to the total methane generation period of 140 years.
- Fuel offsets: Electricity generated from recovering landfill gas offsets GHG emissions from electricity produced in natural gas fired turbines. The availability of waste heat is assumed to offset natural gas used as a fuel for producing hot water for heating purposes. GHG emissions from natural gas per kWh generated are low relative to other fossil fuels, but high relative to renewable fuels and hydropower.
- Carbon storage: Wood, plastics, rubber and other slowly degrading or non-degradable wastes account for 50 percent of disposed MSW. For example, branches, lumber scraps, and other woody materials degrade slowly in a modern, dry-tomb MSW landfill. Thus, carbon stored in wood products and certain other organic materials such as yard debris does not completely degrade in modern landfills.[31]
- Proportion of food waste: Food waste, which is a rapidly degrading material with a substantial contribution to the methane generation potential of landfilled MSW, is estimated to account for over 22 percent of currently disposed MSW waste. If MSW disposal contained less food waste, say because food waste collection and composting programs removed much of it from the disposal stream, the GHG reductions as a result of landfilling would be even greater.

DLC Landfills

- GHG emissions reductions of 226 kg eCO2/tonne DLC waste may be surprising because the DLC landfills do not collect landfill gases. However, the methane generation rate in the DLC landfills is estimated to be 10% of that of MSW landfills. A substantial portion of DLC disposal is located below the water table. The above water-table portions of landfilled DLC are subjected to mostly aerobic conditions. Thus, DLC landfills store more carbon and generate much less methane than MSW landfills.[32]

Burnaby WTE Facility

- Results for the Burnaby WTE facility show that it emits 244 kg eCO2 per tonne of MSW, partly because plastics, rubber, and other products derived from fossil fuels comprise over 15 percent of the MSW disposal stream in the Base Case. These fossil carbon bound materials release anthropogenic CO2 when combusted for energy recovery.
- An additional factor in the result for the Burnaby WTE facility is that the availability of electricity from the facility is assumed to offset natural gas as the energy source for incremental electricity generation. The availability of waste heat amounting to 1.183GJ per tonne MSW also is assumed to offset natural gas used as a fuel for producing steam. The GHG emissions of natural gas are much lower per kWh and GJ generated than other fossil fuels. Thus, the electricity and steam generated by the Burnaby WTE facility does not yield as substantial a credit for GHG reductions as it would if the facility's electricity generation was displacing power from coal-fired electrical power generation and the steam was displacing coal heated hot water and steam. At the same time, the natural gas offset is quite substantial relative to the zero offset if electricity from the Burnaby WTE facility displaced power from a generation facility fueled by renewables and steam produced from renewables.[33]

3.1.4 Summary of Climate Change Impacts

As discussed in the previous sections, for the combined MSW and DLC system, industrial fuel saves the most GHGs, with emissions savings of 1,420 kg eCO2 per tonne of waste. Recycling/composting save the second most GHGs (reducing emissions by 1,152 tonnes eCO2 per tonne of waste). Landfilling also results in GHG emissions savings, which range from 153 kg to 270 kg eCO2 per tonne of waste. The Burnaby WTEF releases 244 kg eCO2 per tonne of waste.

Figures 3.5 and **3.6** show significant differences between the MSW and DLC systems. This is due to the different composition of MSW and DLC recyclables, as well as MSW and DLC industrial fuels, as discussed in sections 3.1.1 and 3.1.2. In the MSW system, recyclables reduce the most GHGs on a per tonne basis, followed by industrial fuel. In the DLC system, industrial fuels reduce the most GHGs on a per tonne basis.

Figure 3.5 Greenhouse Gas Emissions per Tonne – MSW (2008)

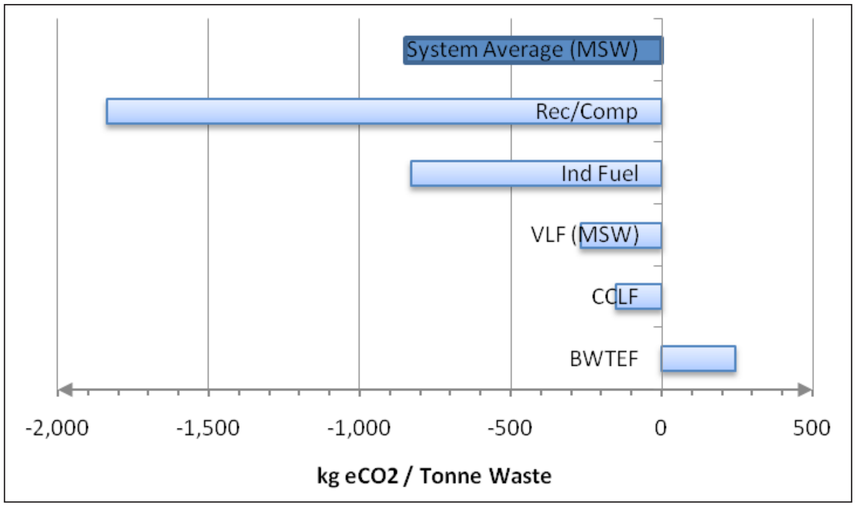
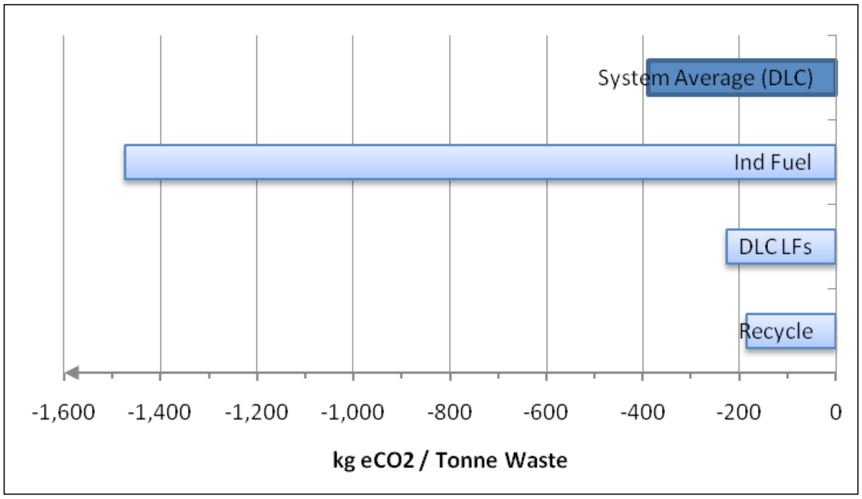


Figure 3.6 Greenhouse Gas Emissions per Tonne – DLC (2008)



3.2 Potential Human Health Impacts

3.2.1 Human Health Impacts of Recycling/Composting

In 2008, recycling/composting 1,634,200 tonnes of waste reduced a total of 965,600 tonnes of eToluene emissions, as shown in **Table 3.1**. In contrast, all other waste management options combined produced more than 256,000 tonnes of eToluene emissions.

Table 3.3 and **Figure 3.7** show that emission reductions for select recyclables range from 7,650 kg eToluene per tonne of aluminum to 8 kg eToluene for recycling wood into papermaking pulp.

Figure 3.8 shows that, for the combined MSW & DLC system, recycling reduces Human Health impacts by 591 kg eToluene per tonne of waste. One tonne of MSW recycling/composting reduces 945 kg of eToluene. One tonne of DLC recycling reduces 90 kg eToluene.

As with the Climate Change impact category, MSW recycling/composting reduces more eToluene than DLC recycling, partly because of waste composition. The average tonne of MSW recyclables contains more materials with greater eToluene savings (metals, plastic, paper, electronics). DLC recyclables such as wood have nearly neutral eToluene emissions (8 kg eToluene/tonne recycled), while ferrous metal recycling ranks low in its per tonne rate of reducing emissions harmful to humans. Based on available information, the Human Health benefits of recycling concrete and asphalt into construction aggregates could not be accurately estimated, but they are believed to be small. However, diverting these DLC recyclables is still beneficial compared to landfilling, which has net positive eToluene emissions, as described in Section 3.2.3.

Figure 3.7 Human Health Emissions per Tonne – Select Recyclables (2008)

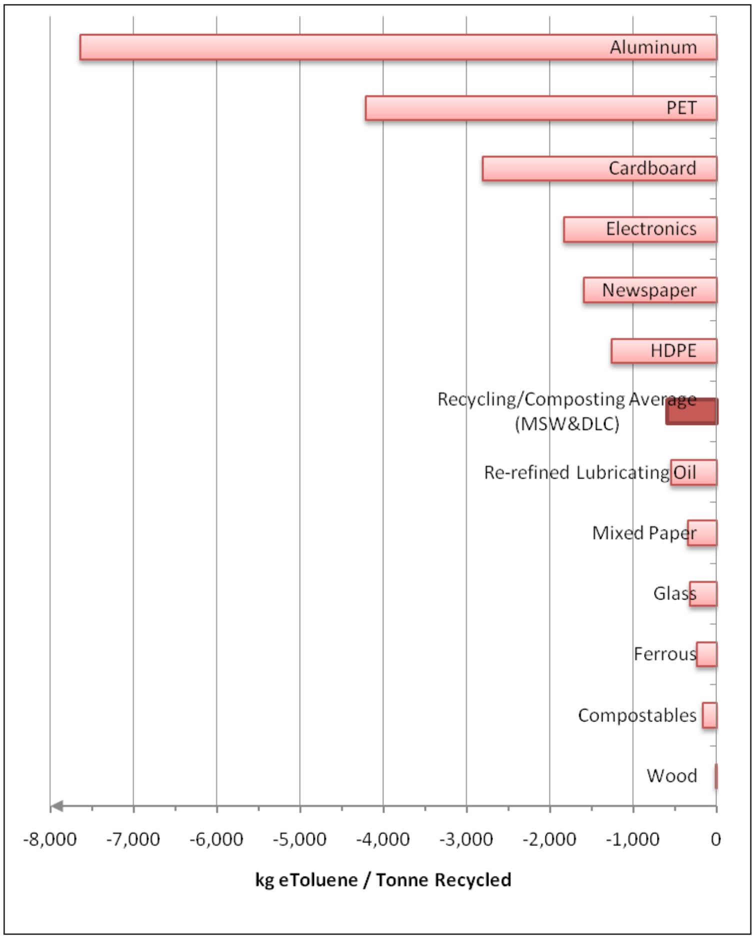


Table 3.3 Human Health Emissions per Tonne – Select Recyclables (2008)

Product / Material	kg eToluene / Tonne Recycled or Composted
Aluminum	(7,646)
PET	(4,212)
Cardboard	(2,802)
Electronics	(1,830)
Newspaper	(1,598)
HDPE	(1,262)
Recycling/Composting Average (MSW & DLC)	(591)
Re-refined Lubricating Oil	(549)
Mixed Paper	(341)
Glass	(316)
Ferrous	(239)
Compostables	(165)
Wood	(8)

3.2.2 Human Health Impacts of Industrial Fuel

Industrial fuels may reduce significant GHGs by offsetting coal and natural gas, but their combustion can emit pollutants that harm human health. In 2008, the 196,000 tonnes of waste used for industrial fuel resulted in total emissions impacts estimated at 165,200 tonnes eToluene. **Figure 3.9** shows these results on a per tonne basis. The variation between the DLC and MSW industrial fuels is partly due to waste composition. The average tonne of DLC industrial fuel is all wood. The average tonne of MSW industrial fuel contains a mix of lubricating oil and rubber.

The following are some observations and considerations regarding Human Health emissions associated with waste wood used in industrial fuel applications. These considerations are also relevant to the findings on Ecosystem Toxicity emissions from industrial fuel, presented in Section 3.3.2 below:

- According to US EPA data[34] on industrial boiler emissions, the negative human health and ecosystem impact potentials from wood combustion are the result of two factors. First, even clean (untreated and unpainted) wood tends to have higher emissions for many metals and volatile organic compounds than coal, and much more than natural gas. Second, certain pollutants that are emitted at a higher rate from wood combustion also happen to be the same pollutants that are estimated to have some of the most serious human health and/or ecosystem impacts: arsenic, benzene, copper, lead, phenols, styrene, toluene, and zinc. There are two important limitations with this analysis:
    - This assessment relied primarily on US EPA inventory data (AP-42) for industrial boiler emissions. Additional research was undertaken to identify the types of industrial boilers and air pollution control (APC) devices used to combust wood at mills and cement plants in BC in order to select the most relevant emissions factors for PM 10, NOx, SO2 and CO available from the AP-42 database. Notably, a PM 10 factor of 41 mg/m3 was applied to the combustion of wood waste in industrial boilers based on review of Beauchemin and Tempier (2008). Similar research was undertaken with respect to coal, which is the primary fuel used in cement kilns (see Appendix A for further information). However, the results of the human health and ecosystem toxicity findings would be more certain if detailed emissions profiles were available for industries using waste wood generated in Metro Vancouver to offset other fuel sources.
    - There is considerable debate among life cycle assessment practitioners as to the characterization of metals emissions (i.e., mercury, lead, cadmium), in particular in terms of their impacts on human health and ecosystems. Given this lack of consensus, one must conclude that there is considerable uncertainty in the estimates of potential impacts on human health and ecosystems from use of wood wastes as industrial fuel.

Figure 3.8 Human Health Emissions per Tonne – Recycling/Composting (2008)

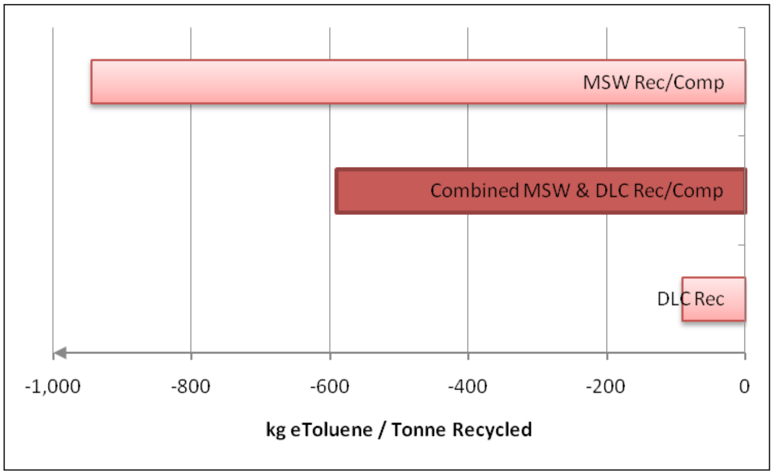


Figure 3.9 Human Health Emissions per Tonne – Industrial Fuel (2008)

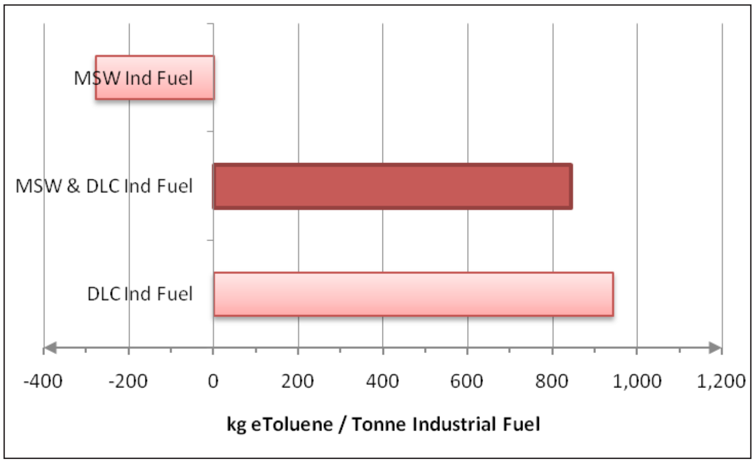
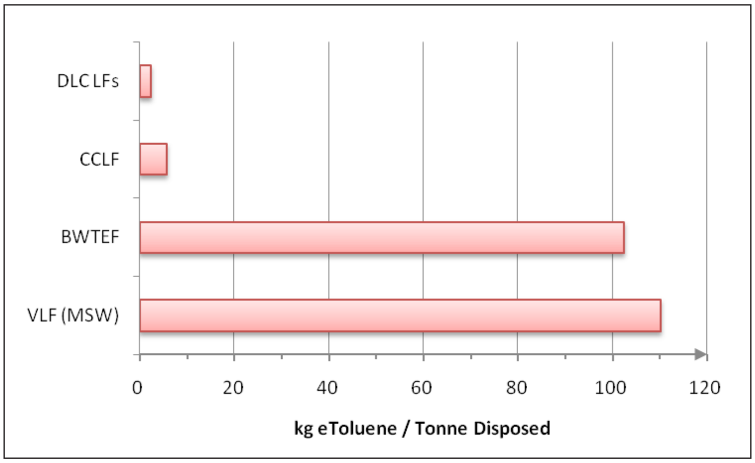


Figure 3.10 Human Health Emissions per Tonne – Disposal (2008)



With respect to the findings for oil and rubber:

- Combusting lubricating oil in industrial facilities reduces Human Health emissions by 410 kg eToluene per tonne of oil. This is in part because oil produces considerably fewer eToluene emissions than does coal, though more than natural gas. At the assumed 50/50 split between coal and natural gas in industrial use, replacing these industrial fuels with lubricating oil reduces eToluene emissions. If natural gas was the only offset fuel, then the results would show a net Human Health emissions impact rather than a benefit because natural gas is a cleaner fuel than oil.
- Based on the estimate that rubber used as an industrial fuel will replace coal and natural gas on a 50/50 basis, as wood and used lubricating oil do, one tonne of rubber fuel emits 210 kg eToluene in the Base Case. Based on the AP-42 data used in this assessment, rubber combustion releases marginally more Human Health related emissions than coal combustion and significantly more than natural gas combustion.

3.2.3 Human Health Impacts of Disposal

In 2008, total Human Health emissions impacts for disposal were estimated to be 90,800 tonnes eToluene for 1, 639,300 tonnes of waste disposed (**Table 3.1**). Specific results are as follows:

- Vancouver landfill (MSW): 58,700 tonnes eToluene produced for an estimated 532,800 tonnes MSW disposed (15% of waste generated).
- Cache Creek landfill (MSW): 2,800 tonnes eToluene produced for an estimated 483,600 tonnes MSW disposed (14% of waste generated).
- DLC landfills: 900 tonnes eToluene produced for an estimated 345,800 tonnes DLC waste disposed (10% of waste generated).
- BWTEF: 28,400 tonnes eToluene produced for an estimated 277,100 tonnes MSW disposed (8% of waste generated).

On a per tonne basis, **Figure 3.10** shows that the DLC and Cache Creek landfills released small quantities, 2 kg and 6 kg of eToluene per tonne of waste disposed, respectively.

The Burnaby WTE facility produced an estimated 103 kg of eToluene per tonne combusted. The Human Health impact for the Burnaby WTE facility is driven by air emissions of metals – primarily lead, antimony, nickel, arsenic and mercury, and, to a lesser extent, by air emissions of particulates and particulate precursors that have the potential to cause respiratory disease in humans. It is important to note here that dioxins and furans were not accounted for in this study due to limitations in available data for the Burnaby WTE facility and other waste management methods or facilities (see Section 2.3.2 for discussion of this limitation).

The Vancouver landfill released an estimated 110 kg of eToluene per tonne of waste. This result is primarily due to the estimated emissions of particulates and particulate precursors from the reciprocating engines used to generate electricity from captured landfill gases.[35] The Cache Creek and DLC landfills have significantly lower emissions because they do not have energy recovery systems in place.

3.2.4 Summary of Human Health Impacts

Table 3.1 showed that, for the combined MSW & DLC system, recycling/composting is the only waste management method that reduces eToluene emissions. Whether through incineration, landfill gas combustion in reciprocating engines, or wood waste combustion in industrial boilers, the findings show that using waste to generate energy has much higher potential Human Health impacts than disposal of MSW in a landfill that efficiently captures methane and flares it. Net releases (taking into account emissions reductions from the offset coal and natural gas fuels) when industrial boilers burn source separated MSW and DLC wastes amount to 843 kg eToluene per tonne of waste. The Burnaby WTE facility and Vancouver landfill emit more than 100 kg eToluene per tonne disposed. By contrast, estimated eToluene emissions at Cache Creek and the DLC landfills are less than 6 kg per tonne landfilled, about 1/20 of the other disposal facilities.

As with the Climate Change impact category, **Figures 3.11** and **3.12** show significant differences between the MSW and DLC systems. This is due to the different composition of MSW and DLC recyclables, as well as MSW and DLC industrial fuels, as discussed in sections 3.2.1 and 3.2.2.

Figure 3.11 Human Health Emissions per Tonne – MSW (2008)

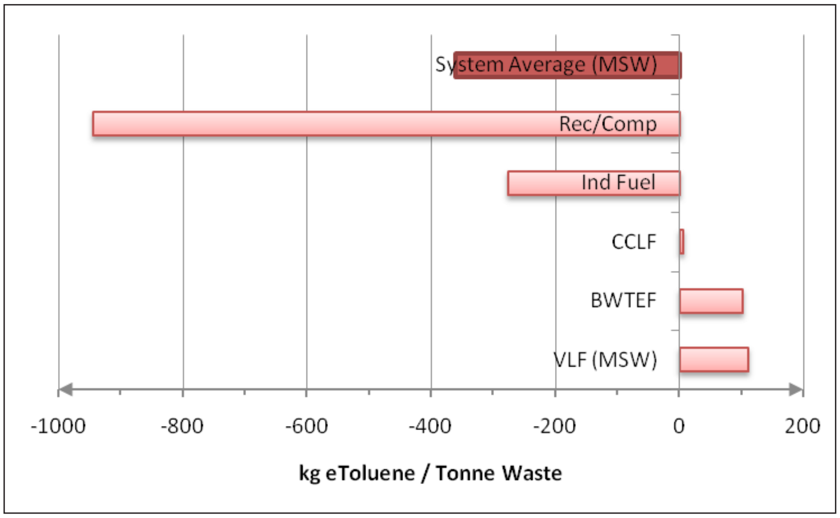
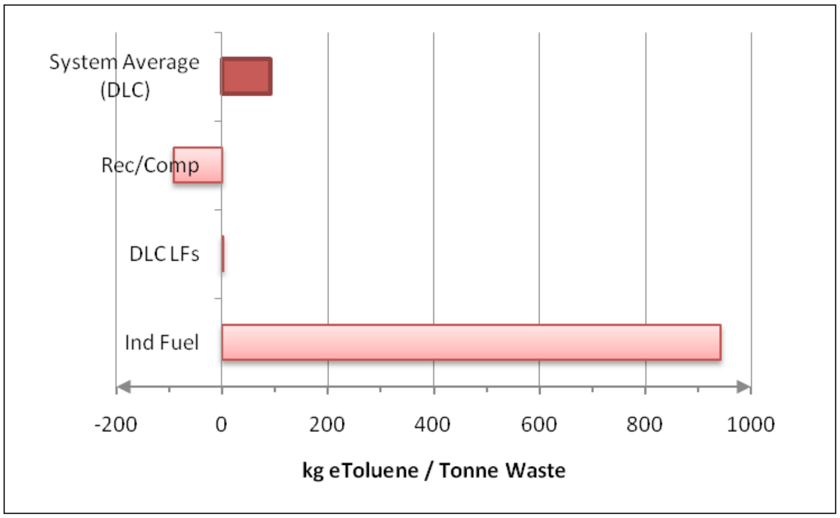


Figure 3.12 Human Health Emissions per Tonne – DLC (2008)



3.3 Potential Ecosystem Toxicity Impacts

3.3.1 Ecosystem Toxicity Impacts of Recycling/Composting

The 1,634,200 tonnes of waste recycled/composted in the combined MSW & DLC system under the Base Case scenario prevented the emission of 2,500 tonnes of herbicide 2,4-D equivalents (e2,4-D).

Table 3.4 and **Figure 3.13** show that emission reductions for select recyclables range from 39.18 kg e2,4-D per tonne of aluminum to 0.08 kg e2,4-D for recycling HDPE plastic. On average, this is about 2 kg of e2,4-D prevented per tonne recycled in the combined MSW & DLC system (**Figure 3.14**).

3.3.2 Ecosystem Toxicity Impacts of Industrial Fuel

In terms of total emissions impacts, diversion of 196,000 tonnes of wood, rubber tires and used lubricating oil to industrial fuel released 5,000 tonnes of e2,4-D to the environment – more than any other waste management method. This works out to 26 kg e-2,4-D produced per tonne of waste (**Figure 3.15**). All three types of fuels were found to produce emissions harmful to ecosystems. However, wood combustion has roughly three or four times more e2,4-D emissions than combustion of tires and used lubricating oil, assuming that the lubricating oil is from cars and trucks, not from oils used during shaping and grinding of metals or other industrial processes.

Figure 3.13 Ecosystem Toxicity Emissions per Tonne – Select Recyclables (2008)

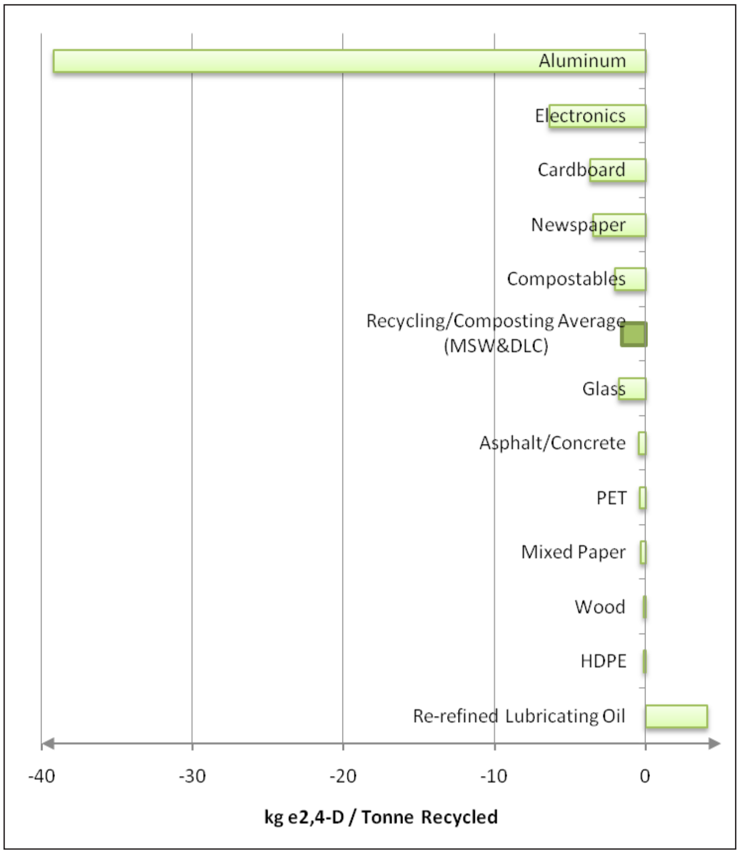


Table 3.4 Ecosystem Toxicity Emissions per Tonne – Select Recyclables (2008)

Product / Material	kg e2,4-D / Tonne Recycled or Composted
Aluminum	(39.18)
Electronics	(6.35)
Cardboard	(3.65)
Newspaper	(3.45)
Compostables	(2.02)
Recycling/Composting Average (MSW & DLC)	**(1.53)**
Glass	(1.73)
Asphalt/Concrete	(0.44)
PET	(0.35)
Mixed Paper	(0.29)
Wood	(0.10)
HDPE	(0.08)
Re-refined Lubricating Oil	4.10

3.3.3 Ecosystem Toxicity Impacts of Disposal

Disposal of MSW and DLC discards in landfills is estimated to have relatively low potential toxic impacts on ecosystems. Disposal of 532,800 tonnes of waste at the Vancouver landfill, 483,600 tonnes at the Cache Creek landfill, and 345,800 tonnes at the DLC landfills resulted in less than 50 tonnes e2,4-D in total emitted for each facility (total emissions impacts). This works out to less than 0.5 kg e-2,4-D per tonne disposed (**Figure 3.16**).

In terms of total emissions impacts associated with the Burnaby WTE facility, disposal of 277,100 tonnes of MSW at this facility resulted in the release of an estimated 500 tonnes e2,4-D under the Base Case scenario. This works out to 2 kg e2,4-D per tonne disposed. This result is mainly due to the estimated ecosystems toxicity caused by the atmospheric releases of copper, nickel and zinc from the Burnaby WTE facility. This result is somewhat uncertain due to the ongoing discussions and debate in the LCA scientific community over the relative Ecosystem Toxicity impacts from releases to air or water of various heavy metals.

Figure 3.14 Ecosystem Toxicity Emissions per Tonne – Recycling/Composting (2008)

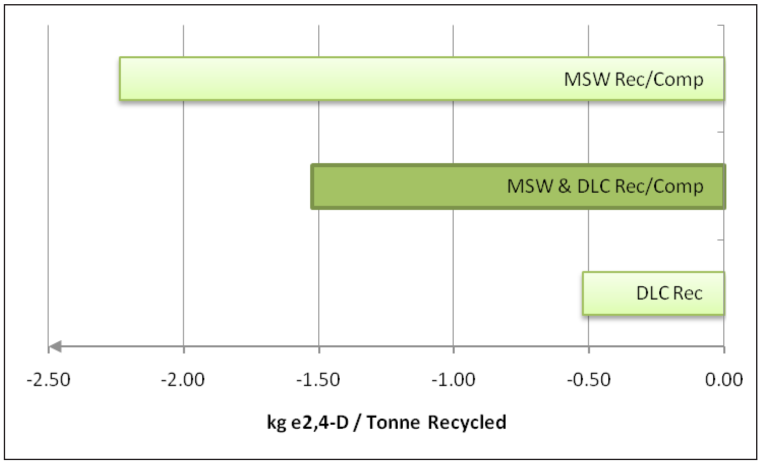


Figure 3.15 Ecosystem Toxicity Emissions per Tonne – Industrial Fuel (2008)

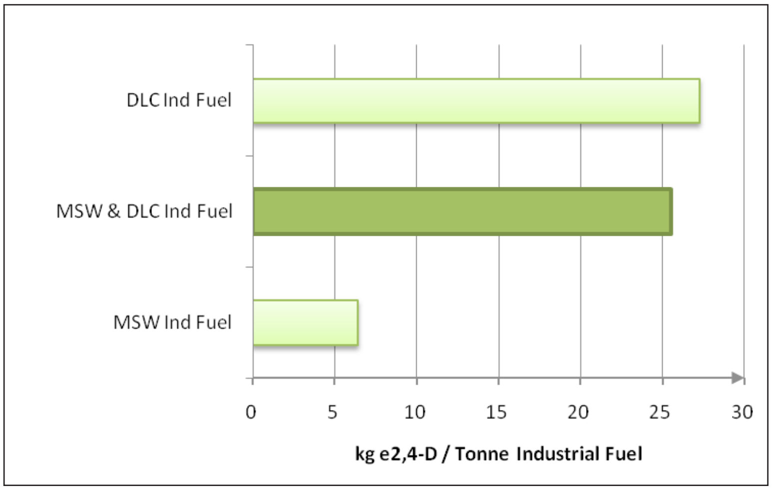
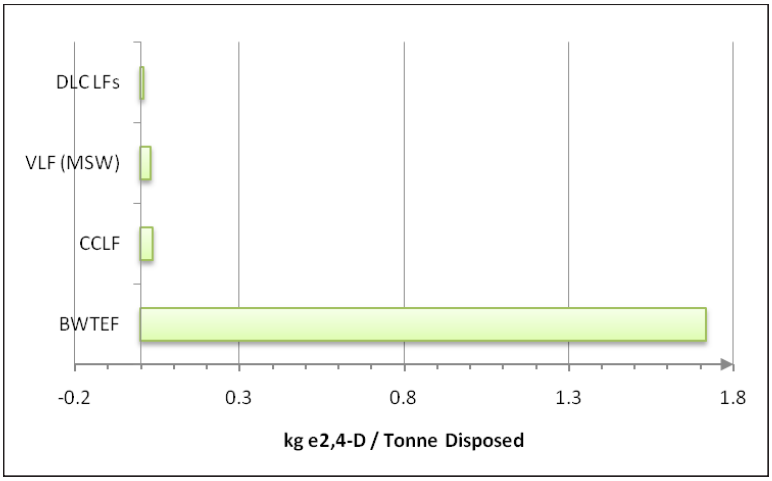


Figure 3.16 Ecosystem Toxicity Emissions per Tonne – Disposal (2008)



3.3.4 Summary of Ecosystem Toxicity Impacts

Recycling/composting is the only waste management method that prevents e2,4-D emissions from entering the environment. **Table 3.1** showed that on a per tonne basis, industrial fuel emits significantly more e2,4-D than any other waste management option.

As with the Climate Change and Human Health impact categories, **Figures 3.17** and **3.18** show significant differences between the MSW and DLC systems. This is due to the different composition of MSW and DLC recyclables, as well as MSW and DLC industrial fuels, as discussed in sections 3.3.1 and 3.3.2.

Figure 3.17 Ecosystem Toxicity Emissions per Tonne – MSW (2008)

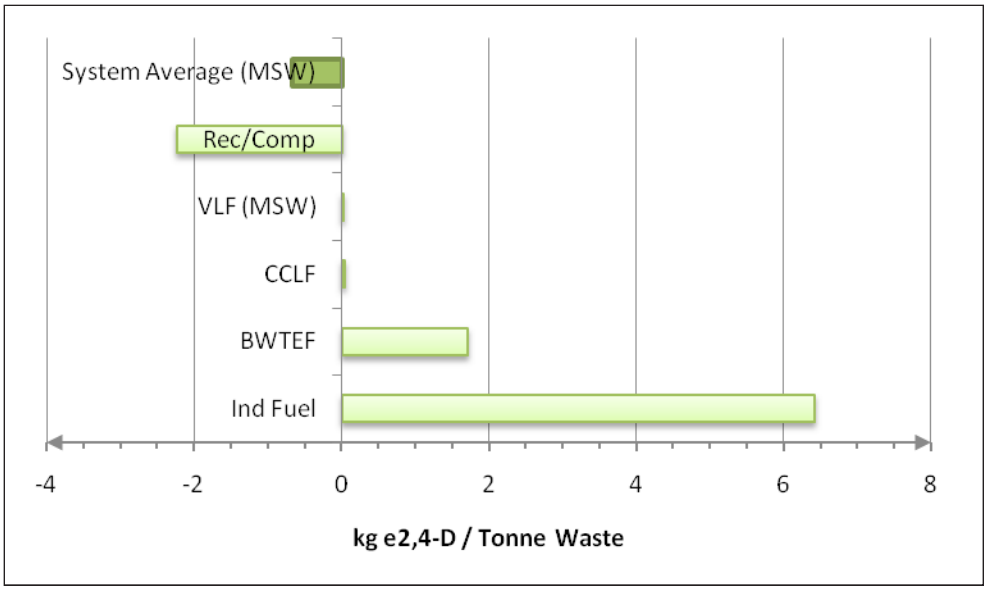
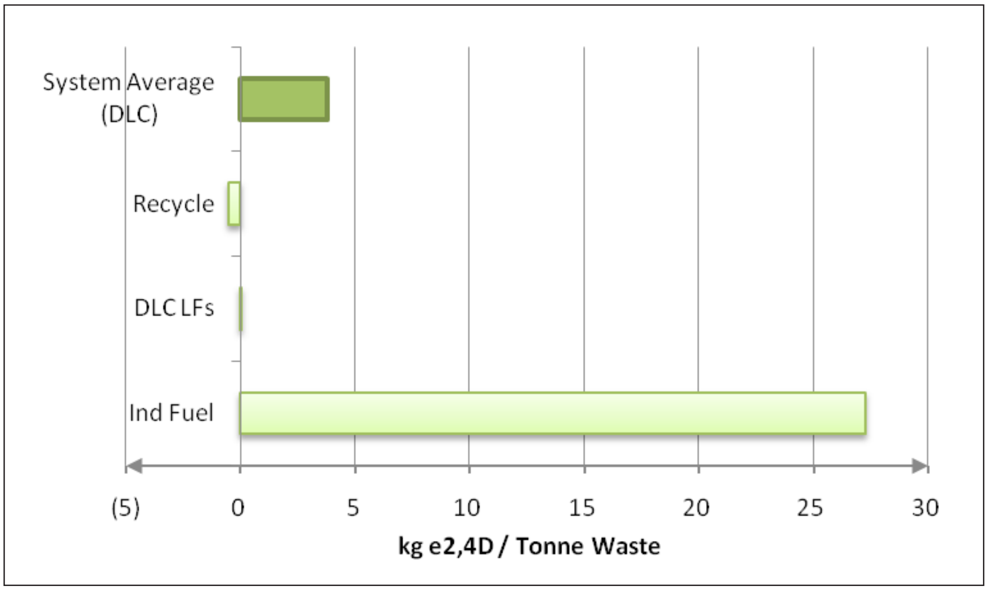


Figure 3.18 Ecosystem Toxicity Emissions per Tonne – DLC (2008)



Section 4: LCA RESULTS FOR ZERO WASTE SCENARIO

4.1 Introduction

This section presents LCA results for the Zero Waste scenario. The Zero Waste scenario assumes progressive waste diversion over the 20-year period, resulting in 83% diversion by 2029 and a 50% reduction in disposal from some 1.6 million tonnes in 2008 to 803,900 tonnes in 2029. The waste diversion and disposal assumptions used in this assessment are provided in **Tables 2.6** and **2.7**. Results are presented in terms of:

1. A comparison of waste management methods in terms of average emissions per tonne of waste in 2008 (53% diversion) and 2029 (83% diversion);
2. Total potential emissions and emissions savings from increases in recycling, composting and diversion of source separated wood waste, used lubricating oil and scrap tires to industrial fuel uses; and
3. Total potential emissions and emissions savings associated with waste disposal under the Zero Waste scenario, taking into consideration three disposal system sensitivity analyses for the 2029 scenario year.

4.2 Comparison of Average Emissions per Tonne

This section presents results in terms average emissions per tonne of waste (kg emissions/tonne waste) reduced or produced by waste management options in the Zero Waste scenario. Emissions per tonne were calculated by dividing total emissions by total tonnes of waste estimated to flow to each option. The system configuration and modeling assumptions used to develop these estimates are discussed in Section 2 of this study, with details presented in Appendices A and B.

With respect to estimating per tonne emissions impacts of waste disposal methods under the Zero Waste scenario, as discussed in Section 2, it was assumed that the hypothetical future disposal system would consist of the set of MSW and DLC disposal facilities existing under the Base Case, with the same relative waste volume allocations as the Base Case. Some of the facilities in this model would be subject to certain kinds of known or planned upgrades that would improve environmental performance, as well as to changes in the mix of future fuel offsets. For example, the Burnaby WTE facility is scheduled to receive air emissions upgrades that will significantly reduce emissions of NOx, SO2 and HCL (see Appendix B for details).

The per tonne results provide the basis for comparing waste management options to each other in the Zero Waste scenario, and to the Base Case. The focus of the presentation in this section is on the comparison of results between 2008 (53% diversion) and 2029 (83% diversion), the horizon year for the Zero Waste scenario. **Table 4.1** presents a summary of the results.

Table 4.1 Potential Emissions Per Tonne – MSW & DLC (2008 & 2029)

Management Method[1]	Climate Change (kg eC02/tonne)	Human Health (kg eToluene/ tonne)	Ecosystem Toxicity (kg e2,4-D/tonne)
2008 (53% diversion)			
Recycling/ Composting	(1,152)	(591)	(2)
Industrial Fuel	(1,420)	843	26
Vancouver MSW LF	(270)	110	<0.5
Cache Creek MSW LF	(153)	6	<0.5
DLC LFs	(226)	2	<0.5
Burnaby MSW WTEF	244	103	2
2029 (83% diversion)			
Recycling/ Composting	(1,228)	(677)	(1)
Industrial Fuel	(1,115)	1,018	26
Vancouver MSW LF	(258)	(2)	>(0.5)
Cache Creek MSW LF	(320)	(7)	>(0.5)
DLC LFs	(240)	2	<0.5
Burnaby MSW WTEF	425	104	1

(1) Management Method Average = Total emissions divided by total waste disposed or recycled by waste management method.

Figure 4.1 Greenhouse Gas Emissions per Tonne – MSW & DLC (2008 & 2029)

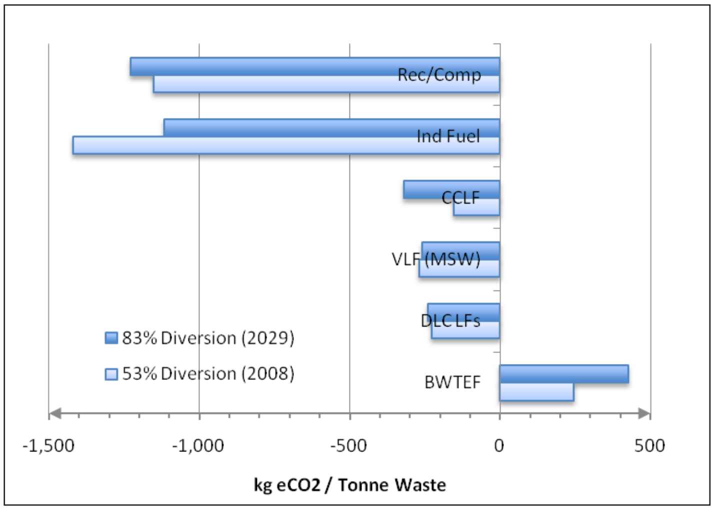
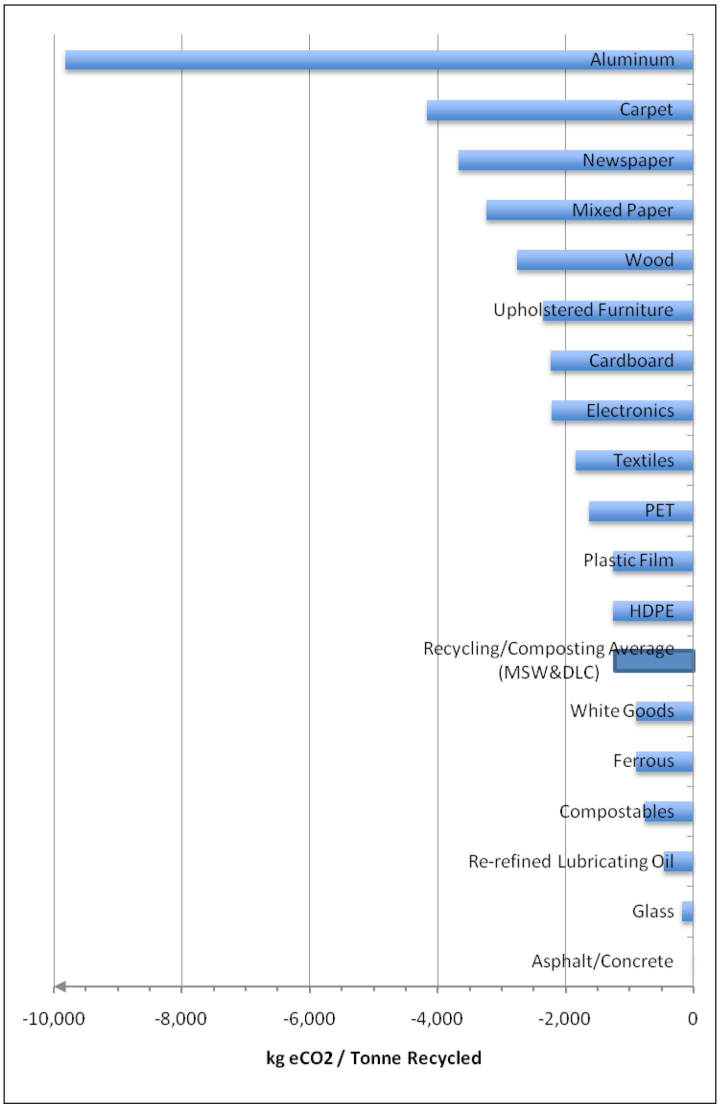


Figure 4.2 Greenhouse Gas Emissions per Tonne – Select Recyclables (2029)



4.2.1 Climate Change

Figure 4.1 presents the differences between the Base Case and Zero Waste scenario (2029) in GHG emissions per tonne of waste for each waste management option. The following sections discuss significant findings.

Recycling/Composting

On a per tonne basis, GHG emissions reductions for recycling and composting improved by 7%, from 1,152 kg eCO2 saved per tonne of waste recycled in 2008 to 1,228 kg eCO2/tonne waste in 2029. This improvement is caused by an increase in recycling rates for specific materials such as plastics, newspapers and cardboard, whose diversion provides relatively large climate change benefits. As well, it was assumed that new products and materials would be recycled through EPR programs, such as carpet, textiles and upholstered furniture. An overview of the GHG emissions savings associated with recycling selected types of discards in 2029 is presented in **Table 4.2** and **Figure 4.2.**

Table 4.2 Greenhouse Gas Emissions – Select Recyclables (2029)

Product / Material	kg eC02 / Tonne Recycled or Composted
Aluminum	(9,827)
Carpet	(4,164)
Newspaper	(3,666)
Mixed Paper	(3,236)
Wood	(2,753)
Upholstered Furniture	(2,345)
Cardboard	(2,236)
Electronics	(2,220)
Textiles	(1,837)
PET	(1,638)
Plastic Film	(1,258)
HDPE	(1,258)
Recycling/Composting Average (MSW & DLC)	**(1,228)**
Ferrous	(900)
White Goods	(900)
Compostables	(757)
Re-refined Lubricating Oil	(463)
Glass	(181)
Asphalt/Concrete	(14)

Industrial Fuels

On a per tonne basis, GHG emissions reductions from wastes used as fuel in industrial boilers are 21% lower in 2029 than in than in 2008, changing from 1,420 kg eCO2 per tonne saved in 2008 to 1,115 kg eCO2 saved per tonne in 2029. This change is in part based on the assumption that, as a result of private sector initiatives, along with the BC carbon tax, less coal and more natural gas will be consumed for industrial power. Natural gas has lower carbon intensity than coal. As the ratio of natural gas to coal increases, substituting wood, lubricating oil or rubber for industrial fuels will offset fewer fossil-based GHGs.

Disposal

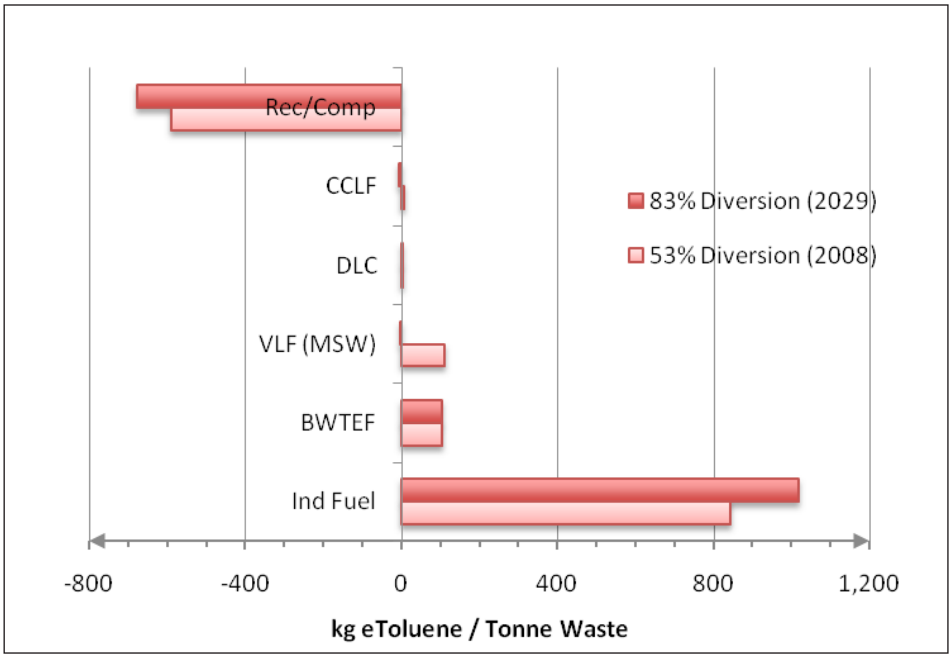
The results show per tonne emissions at the Cache Creek landfill changing 109%, from 153 kg eCO2 saved per tonne in 2008 to 320 kg eCO2 saved per tonne in 2029. This improvement is the result of the anticipated installation at Cache Creek of a facility to convert captured methane to liquid natural gas (LNG). The LNG will be used to replace petroleum diesel in the truck tractors that haul MSW from transfer stations in the Vancouver region to Cache Creek and then backhaul wood chips.

For the Vancouver landfill, GHG emissions savings decreased from 270 kg eCO2 saved per tonne in 2008 to 258 kg eCO2 saved per tonne in 2029. With respect to the Burnaby WTE facility, the results show emissions increasing 74%, from 244 kg eCO2 per tonne in 2008 to 425 kg eCO2 per tonne in 2029. The major reason for the decline in GHG savings at the Vancouver landfill and the increase in GHG emissions at the Burnaby WTE facility was the modeling assumption that in 2008 through 2014, natural gas is the offset fuel for power generation. It was assumed that for the 2019, 2024 and 2029 scenario years, the offset would be a renewable fuel, i.e., a fuel with zero greenhouse gas emissions.[36] Therefore, these facilities are not credited a reduction in eCO2 emissions for energy they generate from waste in 2019, 2024 and 2029.

4.2.3 Human Health

Figure 4.3 presents the differences between the Base Case and Zero Waste scenario (2029) in Human Health emissions per tonne of waste for each waste management option. The following sections discuss significant findings.

Figure 4.3 Human Health Emissions per Tonne – MSW & DLC (2008 & 2029)



Recycling/Composting

On a per tonne basis, Human Health emissions reductions for recycling and composting improved by 15%, from 591 kg eToluene saved per tonne of waste recycled in 2008 to 677 kg eToluene per tonne waste in 2029. This improvement is caused by an increase in recycling rates for specific materials such as plastics, newspapers and cardboard whose diversion provides relatively high Human Health benefits. As well, new types of products and materials have been added to the mix for recycling and EPR, such as carpet, textiles and upholstered furniture, which also have high Human Health benefits. An overview of the emissions savings associated with recycling selected types of discards in 2029 is presented in **Table 4.3** and **Figure 4.4.**

Industrial Fuels

Human Health emissions associated with diverting wood, rubber and lubricating oil to industrial fuel applications were found to increase 21%, from 843 kg eToluene in 2008 to 1,018 kg eToluene per tonne in 2029 (**Figure 4.3**). This change is in part due to the modeling assumption that relatively increasing proportions of natural gas and lower proportions of coal will be used as industrial fuels in the future. As a result, the Human Health benefits of substituting wood, rubber and lubricating oil fuels for these industrial fuels will be reduced because combustion of natural gas has lower Human Health emissions than combustion of coal.

Figure 4.4 Human Health Emissions per Tonne – Select Recyclables (2029)

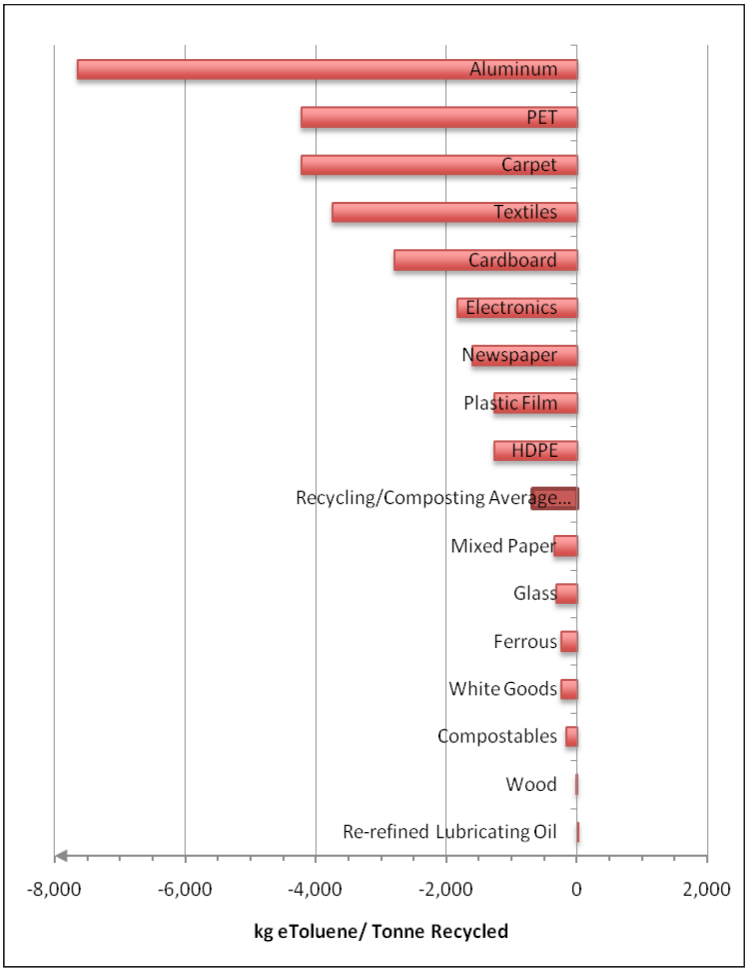


Table 4.3 Human Health Emissions – Select Recyclables (2029)

Product / Material	kg eToluene / Tonne Recycled or Composted
Aluminum	(7,646)
PET	(4,212)
Carpet	(4,212)
Textiles	(3,742)
Cardboard	(2,802)
Electronics	(1,830)
Newspaper	(1,598)
HDPE	(1,262)
Plastic Film	(1,262)
Recycling/Composting Average (MSW & DLC)	**(677)**
Mixed Paper	(341)
Glass	(316)
White Goods	(239)
Ferrous	(239)
Compostables	(165)
Wood	(8)
Re-refined Lubricating Oil	10

Disposal

The results show per tonne emissions at the Vancouver landfill changing from 110 kg eToluene produced per tonne of waste in 2008 to 2 kg eToluene saved per tonne of waste in 2029. This improvement is attributable to the assumption that by 2029 the existing internal combustion engine technology used for landfill gas combustion would be replaced with a cleaner burning microturbine technology. Adoption of microturbine technology would, in particular, improve performance in terms of the emission of particulates and particulate precursors associated with internal combustion engine technology.

The results show per tonne emissions at the Cache Creek landfill changing from 6 kg eToluene produced per tonne in 2008 to 7 kg eToluene saved per tonne in 2029. This improvement is the result of the anticipated installation at Cache Creek of a facility to convert captured methane to liquid natural gas (LNG).

With respect to the Burnaby WTE facility and DLC landfills, the results show negligible changes in per tonne Human Health emissions in 2029 compared to 2008.

4.2.4 Ecosystem Toxicity

Figure 4.5 presents the differences between the Base Case and Zero Waste scenario (2029) in Ecosystem Toxicity emissions per tonne of waste for each waste management option. The following sections discuss significant findings.

Recycling/Composting

The results for recycling and composting show that this approach continues to reduce Ecosystem Toxicity emissions on a per tonne basis under the Zero Waste scenario. There is a marginal difference in values between these two years (-1.53 in 2008 compared to -1.46 in 2029) that is considered to be within the range of uncertainty. **Table 4.4** and **Figure 4.6** shows per tonne emissions reductions for selected discards sent to recycling in 2029.

Table 4.4 Ecosystem Toxicity Emissions – Select Recyclables (2029)

Product / Material	kg e2,4-D / Tonne Recycled or Composted
Aluminum	(39.18)
Electronics	(6.35)
Cardboard	(3.65)
Newspaper	(3.45)
Compostables	(2.02)
Glass	(1.73)
Recycling/Composting Average (MSW & DLC)	**(1.46)**
Textiles	(1.45)
Asphalt/Concrete	(0.44)
PET	(0.35)
Carpet	(0.35)
Mixed Paper	(0.29)
Wood	(0.10)
HDPE	(0.08)
Plastic Film	(0.08)
Re-refined Lubricating Oil	4.50

Figure 4.5 Ecosystem Toxicity Emissions per Tonne – MSW & DLC (2008 & 2029)

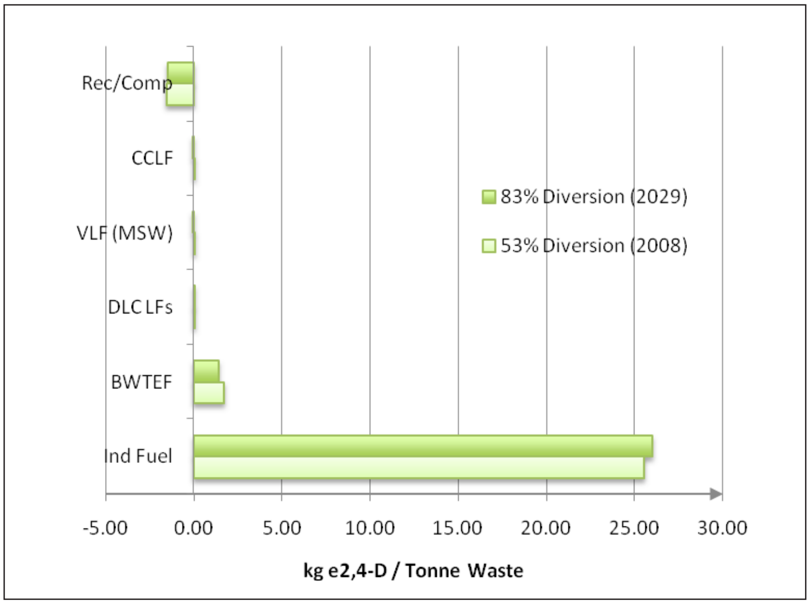


Figure 4.6 Ecosystem Toxicity Emissions per Tonne – Select Recyclables (2029)

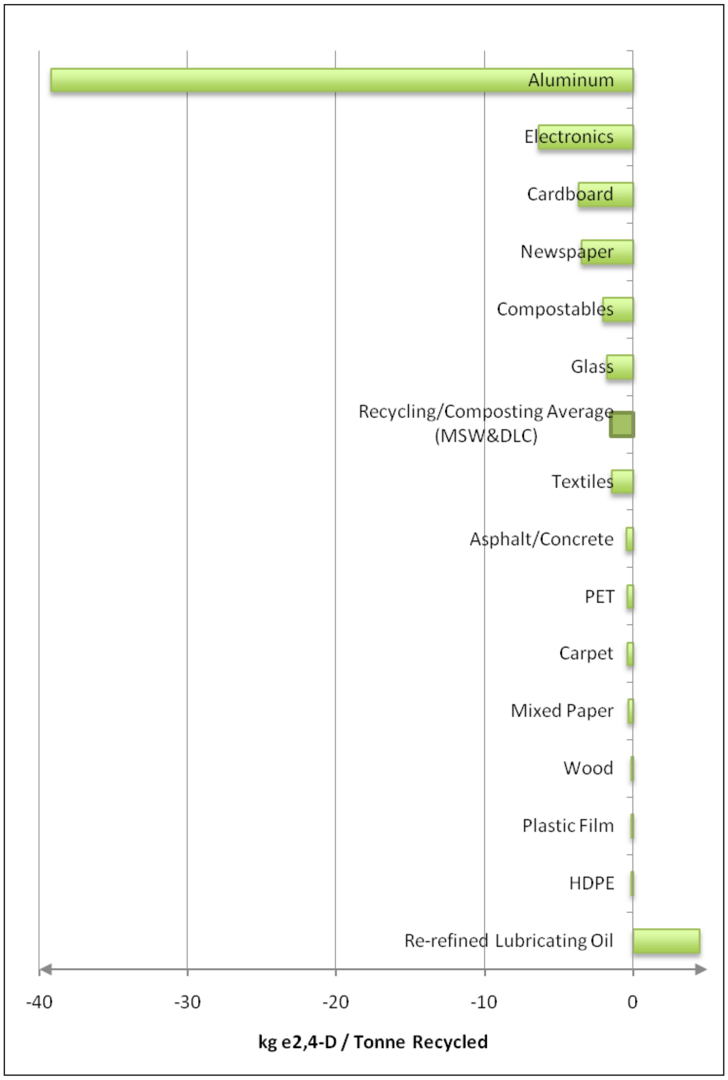


Table 4.5 Total Potential Emissions, Waste Diversion – MSW & DLC (2008 & 2029)

Management Method	Waste (tonnes)	Climate Change (tonnes eC02)	Human Health (tonnes eToluene)	Ecosystem Toxicity (tonnes e2,4-D)
2008 (53% diversion)				
Recycling/ Composting	1,634,200	(1,883,200)	(965,600)	(2,500)
Industrial Fuel	196,000	(278,300)	165,200	5,000
Net Diversion Total[(1)]	**1,830,200**	**(2,161,500)**	**(800,500)**	**2,500**
2029 (83% diversion)				
Recycling/ Composting	3,514,800	(4,315,300)	(2,379,400)	(5,100)
Industrial Fuel	353,500	(394,300)	359,900	9,200
Net Diversion Total[(1)]	**3,868,300**	**(4,709,600)**	**(2,019,500)**	**4,100**

(1) Net Diversion Total = Sum of total emissions by management method. Numbers may not add due to rounding.

Disposal

As shown in **Table 4.1**, the results indicate a minor improvement in Ecosystem Toxicity emissions at the Cache Creek landfill, with emissions changing from under 0.5 kg e2,4-D produced in 2008 to under 0.5 kg e2,4-D saved in 2029. This change is attributable to the anticipated installation of a facility to convert captured methane to liquid natural gas (LNG), as discussed in Section 4.2.1. The results also indicate a minor improvement in Ecosystem Toxicity emissions at the Burnaby WTE facility, from 2 kg e2,4-D in 2008 to 1 kg e2,4-D in 2029, attributable to the assumption that planned improvements in emissions controls at this facility would be implemented after 2014 (see **Appendix B**). Ecosystem Toxicity emissions improved at the Vancouver landfill, from under 0.5 kg e2.4-D produced in 2008 to under 0.5 kg e2,4-D saved in 2029 due to the adoption of microturbine technology for landfill gas utilization. The average emissions for the DLC landfills stayed constant at less than 0.5 kg e2,4-D per tonne.

4.3 Total Potential Emissions: Waste Diversion

Table 4.5 presents a summary of results (MSW and DLC combined) for total potential emissions from recycling, composting and industrial fuel uses for the years 2008 and 2029. **Appendix F** provides detailed results for the MSW and DLC systems for 2014, 2019, 2024 and 2029.

'Total potential emissions' refers to the total net tonnes saved or produced by these waste management options in a given year. For the purposes of this analysis, the given years are 2008 (the Base Case scenario) and 2029 (the horizon year of the Zero Waste scenario). When reviewing the total emissions results, it is important to bear in mind that the results are relative to the total tonnes of waste flowing to these waste management options in the given year, as shown in Column 2 of **Table 4.5.**

4.3.1 Climate Change

As waste diversion is increased from 53% to 83% under the Zero Waste scenario, total GHG emissions savings associated with these activities will more than double, from 2,161,500 tonnes eCO2 in 2008 to 4,709,600 tonnes in 2029.[37] As indicated below in **Figure 4.7**, recycling is projected to provide reductions of 3,769,500 tonnes of eCO2 by 2029 and composting 545,800 tonnes eCO2. As such, recycling and composting account for more than 90% of GHG reductions associated with waste diversion. The GHG reductions benefits associated with these activities are due to increased upstream GHG reductions. These upstream GHG reductions are caused by the energy and pollution savings when products are manufactured from recycled materials instead of virgin raw materials, and when compost is used in place of synthetic fertilizers. Sending increasing volumes of wood, lubricating oil and scrap tires to industrial fuel end uses is projected to result in a 40% increase in GHG emissions savings associated with these activities.

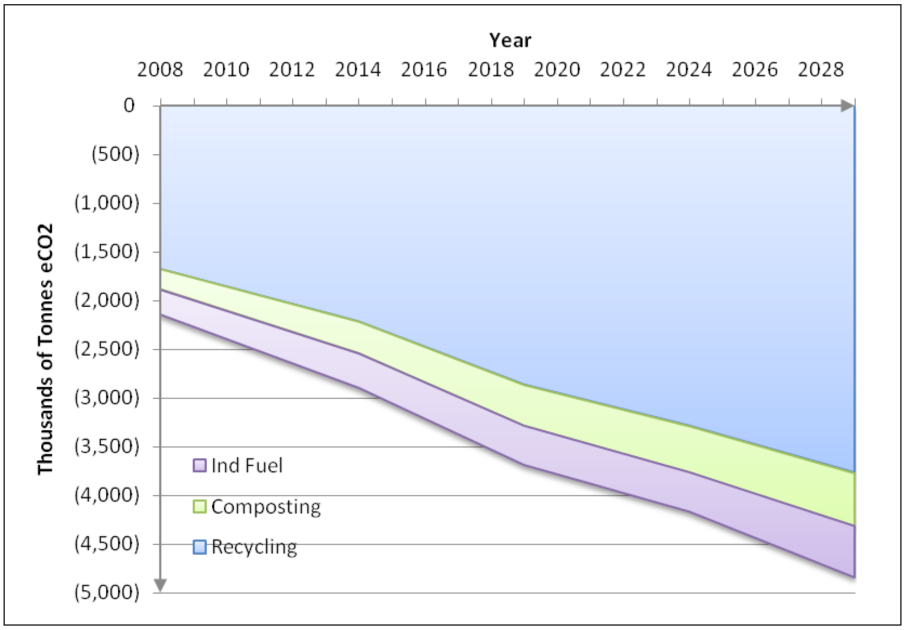
4.3.2 Human Health

Under the Zero Waste scenario, with waste diversion rising from 53% in 2008 to 83% in 2029, Human Health emissions savings associated with recycling and composting grow by 2.5 times, from 965,600 tonnes in 2008 to 2,379,400 tonnes in 2029. In comparison, increased diversion of wood, lubricating oil and scrap tires to industrial fuel uses will result in a 120% increase in total potential Human Health emissions, rising from 165,200 tonnes to 359,900 tonnes of eToluene. This increase is driven by the increased volume of waste diverted to industrial fuel, as well as by the assumption that the ratio of coal to natural gas as the fuel offset will change from 50/50 in 2008 to 25/75 in 2029.

4.3.3 Ecosystem Toxicity

The results of the LCA analysis show that recycling and composting account for emissions reductions of 5,100 tonnes of e2,4D in 2029, up from 2,500 tonnes reduced in 2008. In contrast, emissions from industrial fuel end uses were estimated to increase by 84%, rising from 5,000 tonnes in 2008 to 9,200 tonnes e2,4-D in 2029. This increase in total emissions is primarily driven by the 80% increase in the volume of wood, lubricating oil and scrap tires diverted to industrial fuel use in 2029 compared to 2008. It should also be noted that the analysis assumes current emission standards for boilers through to 2029. If emissions controls were to improve, the e-2,4D emissions from industrial fuel end uses would be reduced.

Figure 4.7 Net Greenhouse Gas Emissions from Waste Diversion (2008-2029)



4.4 Total Potential Emissions: Disposal System

Section 4.2 presented the environmental impacts of disposal system facilities on a per tonne basis, providing the basis for comparison of each waste management facility to other management options in that year and to the Base Case. Using the per tonne emissions estimates, this section of the study considers how the volume of waste received at particular disposal facilities may affect the total potential emissions released to the environment under the Zero Waste scenario. As the allocation of the volume of waste between disposal facilities is altered, the total emissions produced or saved may change, more or less, depending on the environmental performance of each facility on a per tonne basis.

To gain insight into this relationship, a set of three sensitivity analyses were run on the allocation of the volume of waste in the MSW disposal system at 2029 (83% diversion). Given that the future configuration of the MSW disposal system is unknown, and it was beyond the scope of this study to define the optimal system, any number of allocation options could be used for the analysis. For these three sensitivity analyses, it was assumed that 100% of residual MSW would be allocated to the Vancouver landfill, the Cache Creek landfill and the Burnaby WTE facility, respectively. These allocations did not take into consideration actual or planned facility capacities or financial costs; they were strictly intended to profile environmental impacts. No variation was assumed for the DLC system (i.e., same allocation as the 2008 Base Case). Table 4.6 presents a summary of the findings from the sensitivity analyses. Details are presented in Appendix F, Table 4.

Table 4.6 Disposal System Sensitivity Analyses (2029)

Management Method	Waste (tonnes)	Climate Change (tonnes eCO2)	Human Health (tonnes eToluene)	Ecosystem Toxicity (tonnes e2,4-D)
Sensitivity 1				
Vancouver MSW LF	545,200	(140,400)	(1,100)	>(50)
DLC LFs	258,600	(62,100)	600	<50
Net Disposal Total	**803,900**	**(202,500)**	**(500)**	**>(50)**
Sensitivity 2				
Cache Creek MSW LF	545,200	(174,500)	(3,900)	>(50)
DLC LFs	258,600	(62,100)	600	<50
Net Disposal Total	**803,900**	**(236,600)**	**(3,300)**	**>(50)**
Sensitivity 3				
Burnaby MSW WTEF	545,200	231,700	56,600	800
DLC LFs	258,600	(62,100)	600	<50
Net Disposal Total	**803,900**	**169,600**	**57,200**	**800**

(1) Net Diversion Total = Sum of total emissions by management method. Numbers may not add due to rounding.

4.4.1 Climate Change

The findings for the three sensitivity analyses show that to manage 545,200 tonnes of residual MSW in 2029, both the Vancouver and Cache Creek landfills would prevent the release of total potential GHG emissions, by 140,400 and 174,500 tonnes eCO2 respectively. The Burnaby WTE facility would produce total GHG emissions of approximately 231,700 tonnes eCO2 to manage the same amount of residual MSW.

4.4.2 Human Health

Both the Vancouver and Cache Creek landfills would prevent the release of total potential emissions harmful to Human Health, by 1,100 and 3,900 tonnes eToluene respectively. The Burnaby WTE facility would produce total potential Human Health emissions of approximately 56,600 tonnes eToluene to manage the same 545,200 tonnes of residual MSW.

4.4.3 Ecosystem Toxicity

Both the Vancouver and Cache Creek landfills would also prevent the release of total potential emissions harmful to ecosystems, by 20 and 40 tonnes e2,4-D respectively. The Burnaby WTE facility would produce total potential Ecosystem Toxicity emissions of approximately 780 tonnes e2,4-D to manage the same 545,200 tonnes of residual MSW.

Section 5 : CONCLUSION

5.1 Recycling & Composting

Overall, the findings of this study show that recycling and composting are far better approaches than waste disposal at mitigating the life cycle environmental impacts associated with products and materials in the waste stream. Recycling and composting are the only waste management options that were found to prevent detrimental impacts for all three environmental concerns: Climate Change, Human Health and Ecosystem Toxicity.

The potential benefits were found to be even greater in terms of recycling and composting MSW as compared to DLC waste. In fact, recycling and composting MSW reduces more Climate Change impacts, more Human Health impacts, and more Ecosystem Toxicity impacts per tonne of waste than any other management method.

It was also shown that the environmental benefits increase significantly with the increasing diversion of wastes to recycling and composting under the Zero Waste scenario. For example, under the Zero Waste scenario, by 2029:

- Total tonnes of climate changing greenhouse gas (GHG) emissions prevented from being released to the atmosphere annually would more than double.
- The total Human Health impact reductions associated with recycling and composting were estimated to be nearly 2 ½ times greater than those saved in 2008. These reductions would be more than enough to offset detrimental Human Health impacts produced by all other waste management methods.
- Recycling and composting resulted in twice as many Ecosystem Toxicity impact reductions compared to 2008.

Given the clear superiority of recycling and composting from an environmental perspective, strategic planning for the implementation of a zero waste objective should focus on developing recycling and composting-based programs and business opportunities. As the MSW system currently has a significantly lower waste diversion rate than does the DLC system, and it holds the potential for significantly greater environmental benefits on a per tonne basis, diverting products and materials in the MSW waste stream should be a priority.

The findings point to the need for a zero waste strategy that prioritizes the diversion of all organic waste to composting systems, maximizes the effectiveness of existing recycling programs and initiatives, and moves rapidly forward with the development of new diversion efforts such as Extended Producer Responsibility (EPR) initiatives.

5.2 Industrial Fuel Applications

The findings show that diverting source separated wastes (i.e., wood, used lubricating oil, scrap tires) to industrial fuel applications results in significant Climate Change (GHG) impact reductions while at the same time producing significant levels of Human Health and Ecosystem Toxicity impacts. These impacts are primarily attributable to the large volume of wood waste in the wastes diverted to industrial fuel end uses under the Base Case and Zero Waste scenarios. In contrast, the LCA study showed that sending wood to recycling (pulp or board manufacturing) reduces impacts in all three categories.

The initial conclusion to be drawn from these findings is that for wood waste, in terms of environmental protection, the priority should be given to finding reuse and recycling markets for these materials.

It is important to state that the findings regarding Human Health and Ecosystem Toxicity impacts of waste wood combustion in industrial boilers are subject to considerable uncertainty in the scientific community, particularly with respect to the US EPA emissions profiles for industrial boilers used in this study. The application of more stringent environmental controls, with improvements in the industrial boiler technologies, will positively alter the LCA results.

5.3 Disposal Options

The study findings show that disposal options (landfilling and waste-to-energy) are unfavourable compared to recycling where environmental impacts are concerned. These findings also show that disposing MSW in landfills is more favourable than waste-to-energy in all three environmental impact areas, particularly once organics are removed from the waste stream.

Given these findings, disposal options should be seen only as interim solutions necessary to bridge the gap between the present situation and a zero waste objective achieved within a 20 - 30 year time horizon. Under these conditions, disposal options should be assessed in terms of their flexibility and whether they will facilitate or hinder the achievement of the zero waste objective.

5.4 Limitations and Additional Research

This study focused specifically on the life cycle environmental impacts associated with the Base Case and Zero Waste scenarios defined within. It did not take into consideration financial, economic or social impacts associated with various waste management methods or strategies. As such, the findings and conclusions drawn from this research are limited to the environmental aspects of strategic planning.

Additional research and analysis is required to develop an integrated assessment of the financial, economic and social aspects of these scenarios. Among other things, such research should address the potential local economic benefits arising in the context of developing reuse, recycling, composting and EPR take-back programs under a zero waste strategy.

With respect to modeling the configuration of waste disposal facilities, this study modeled a Base Case consisting of the existing MSW and DLC waste disposal systems in Metro Vancouver, including the Vancouver and Cache Creek landfills, the Burnaby WTE facility, and DLC landfills in the region. In terms of modeling a future disposal system in the region under the Zero Waste scenario, it was beyond the scope of the study to identify an optimal or preferred system. Instead, for comparative purposes, the study estimated emissions of pollutants per tonne of waste disposed under the Zero Waste scenario using the same set of facilities and relative allocation of residual waste flows as currently exists.

The study also provided a set of MSW disposal system sensitivity analyses for the year 2029 at 83% diversion in order to gain insight into the total potential emissions from MSW disposal under three alternative waste flow allocations. Numerous alternative waste flow allocations for MSW disposal could be modeled. The options selected consisted of allocating 100% of MSW residuals to the Vancouver landfill, the Cache Creek landfill and the Burnaby WTE facility, respectively. These options were considered sufficient for the purpose of gaining insight into total potential emissions from MSW facilities in the absence of a regional plan for a future system.

With respect to the Climate Change related impacts of disposal options, the study took into consideration the issues of whether and how to account for greenhouse gas emissions from the biogenic fraction of the waste stream. In particular, in this study, landfills are given credit for storage of non- or slowly-degrading biogenic materials such as wood and paper. Sensitivity analyses on the global warming potential (GWP) of methane were also run to compare the effects of 25-year versus 100-year GWP assumptions on emissions estimates for waste management options. The findings for these analyses confirmed the overall conclusions of the report.

While this study modeled a wide range of potential pollutants, it did not model dioxin and furan emissions associated with the Burnaby WTE facility or other waste management facilities or programs. There were two reasons for this: (1) publicly available data on these emissions for the Burnaby WTE facility is unclear regarding speciation of dioxins and furans that may have been measured in emissions tests at the Burnaby WTE facility. Different dioxins and furans have widely different environmental impacts; (2) in some cases there is a lack of data on dioxin and furan emissions for other waste management methods or activities modeled in the study. Because dioxins/furans weigh heavily in the calculation of Human Health and Ecosystem Toxicity impacts, it was considered misleading to include dioxins and furans for only some and not all facilities and processes.

An additional limitation is that the characterization and extent of the environmental impacts of emissions associated with heavy metals such as lead, cadmium and mercury is a matter of debate in the scientific community, particularly with respect to the Human Health and Ecosystem Toxicity impacts. Accordingly, the estimated potential impacts of these pollutants associated with sending wood waste to industrial boilers, and residual MSW to the Burnaby WTE facility, are considered to be uncertain.

Section 6: REFERENCES

Bare, Jane C. (2002). *Developing a Consistent Decision-Making Framework by Using the U.S. EPA's TRACI*. U.S. Environmental Protection Agency, Cincinnati, OH.

Bare, Jane C., G.A. Norris, D.W. Pennington and T. McKone (2003). *TRACI:* "The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts," *Journal of Industrial Ecology*; 6(3-4): 49-78.

Barlaz, M., *et al* (2003a). "Comparing Recycling, Composting and Landfills," *BioCycle*; 44(9): 60-66.

Barlaz, M., *et al* (2003b). "Evaluating Environmental Impacts of Solid Waste Management Alternatives," *BioCycle*; 44(10): 52-56.

Beauchemin, P. and M. Tempier (2008). *Emissions from Wood-Fired Combustion Equipment*. Prepared by Envirochem Services Inc. Prepared for BC Ministry of Environment, Victoria, BC.

BC Stats (2008). *Regional Population Estimates and Projections*. Accessed at www.bcstats.gov.bc.ca/data/pop/pop/dynamic/PopulationStatistics/SelectRegionType.asp?category=Census

Best, Jordan (2008). *RCBC Background Paper: Examining the Waste-to-Energy Option.* Prepared for the Recycling Council of British Columbia, October 2008. Accessed at www.rcbc.bc.ca/files/u3/policypaper_101024_wteoption.pdf

Boughton, Bob. and A. Horvath (2004). "Environmental Assessment of Used Oil Management Methods," *Environmental Science & Technology*; 38(2): 363-368.

Brewers' Distributor Limited – British Columbia (2007). *BDL Annual Product Stewardship Report: March 31, 2007 to March 31, 2008*. Accessed at www.env.gov.bc.ca/epd/recycling/bev/reports/pdf/brewers_2007_08.pdf

Brewers' Distributor Limited – British Columbia (2008). *Auditor's Report: Prepared for Brewers' Distributor Ltd. – British Columbia*. Prepared by S.J. Yeung, Chartered Accountant, July 3, 2008. Accessed at www.env.gov.bc.ca/epd/recycling/bev/reports/pdf/brewers-audit_2007_08.pdf

British Columbia Climate Action Secretariat (2008). *Climate Action Plan*. Accessed at www.climateactionsecretariat.gov.bc.ca/cat/report.html

British Columbia Ministry of Energy, Mines & Petroleum (2007). *The BC Energy Plan: A Vision for Clean Energy Leadership*. Accessed at www.energyplan.gov.bc.ca/

British Columbia Ministry of Environment (2002). *British Columbia Industry Product Stewardship Business Plan 2002/2003 – 2004/2005*. Accessed at www.env.gov.bc.ca/epd/recycling/resources/reports/pdf/prodstew_plan.pdf

British Columbia Ministry of Environment, Office of the Deputy Minister (2007). *To: Industry Product Stewardship Stakeholders and Interested Parties Re: Recycling Regulation – Adding New Products. Reference # 93490.* Memorandum dated June 26, 2007. Accessed at www.env.gov.bc.ca/epd/recycling/resources/new_products/pdf/new_products.pdf

British Columbia Ministry of Environment (2007). *BC Lead-Acid Battery Collection Program: Provincial Program to Assist with the Collection, Transportation and Recycling of Scrap Lead-Acid Batteries – Program Summary.* Prepared for the Environmental Quality Branch, September 2007. Accessed at www.env.gov.bc.ca/epd/recycling/batt/pdf/battery-prog-sum-mar09.pdf

British Columbia Ministry of Environment (2008). *BC Expands List of Regulated Recyclable Products.* Media release dated April 24, 2008. Accessed at www.env.gov.bc.ca/epd/recycling/pdf/news_release_24apr08.pdf

British Columbia Queen's Printer (2008). "Recycling Regulation, B.C. Reg. 449/2004," *Environmental Management Act.* (Deposited October 7, 2004. Includes amendments up to B.C. Reg. 374/2008, December 9, 2008). Accessed at www.qp.gov.bc.ca/statreg/reg/E/EnvMgmt/449_2004.htm

British Columbia Used Oil Management Association (2007). *BCUOMA 2007 Annual Report*. Accessed at www.usedoilrecycling.com/resources/file/BC/BCUOMA_AR07.pdf

British Columbia Used Oil Management Association (2008). *BCUOMA Report to Director, Environmental Quality Branch [British Columbia Ministry of Environment]: Annual Report 2007 Calendar Year*. Prepared for BC Ministry of Environment, June 27, 2008. Accessed at www.usedoilrecycling.com/resources/file/BC/2007ReportToDirector.pdf

California Integrated Waste Management Board (2008). *Overall Framework for an Extended Producer Responsibility System in California*. Board Meeting, Agenda Item 12, Attachment 1 (Final), January 23, 2008. Accessed at www.ciwmb.ca.gov/EPR/Framework/Framework.pdf

California Product Stewardship Council, Northwest Product Stewardship Council, Vermont Product Stewardship Council and BC Product Stewardship Council (2008). *Joint Framework Principles for Product Stewardship Policy*. *May 2008*. Accessed at www.productpolicy.org/sites/default/files/JointFrameworkPrinciplesDec2008.pdf

Canadian Council of Ministers of the Environment (1998). *National Emission Guideline for Cement Kilns. Initiative N306. Prepared by the Multistakeholders Working Group and Steering Committee*. Winnipeg, MB.

Canadian Council of Ministers of the Environment (2009). *Discussion Document: Towards a Canada-Wide Action Plan for Extended Producer Responsibility – Draft for Consultation*. Prepared for CCME, February 2009. Accessed at www.ccme.ca/assets/pdf/epr_cap_consult_e.pdf

Cicas, G., H.S. Matthews, and C. Hendrickson (2006). *The 1997 Benchmark Version of the Economic Input-Output Life Cycle Assessment (EIO-LCA) Model*. Green Design Institute, Carnegie Mellon University, Pittsburgh, PA.

City of Hutchinson, MN (2008). “Composting” website. Accessed at www.ci.hutchinson.mn.us/composting.html

City of Ottawa, Ontario (2007). “City of Ottawa Take it Back!” website. Accessed at www.ottawa.ca/takeitback

City of Los Angeles (2008). *Guiding Principles for A 20-Year Zero Waste Plan*. Accessed at www.zerowaste.lacity.org/home/index.html

City of Vancouver (2009). Vancouver Landfill 2008 Annual Report. Transfer and Landfill Operations Branch. Accessed at http://vancouver.ca/engsvcs/solidwaste/landfill/report.htm

Constable Associates Consulting Inc. and T.Nyman (2004). *Georgia Basin/Puget Sound Industrial and Energy Sector Air Emissions Outlook*. Prepared for Environment Canada, Pacific and Yukon Division.

Coon, Scott (2009). Personal communication. Landfill Gas Management Specialist, R.W. Beck Inc. February 10, 2009.

Electronics Stewardship Association of BC (2007). *ESABC 2007 Annual Report*. Accessed at www.env.gov.bc.ca/epd/recycling/electronics/reports/pdf/ESABC-2007.pdf

Encorp Pacific (Canada) (2007). *Encorp Pacific (Canada) 2007 Annual Report*. Accessed at www.env.gov.bc.ca/epd/recycling/bev/reports/pdf/encorp_2007.pdf

Encorp Pacific (Canada) (2008). *Supplement to 2007 Annual Report: Schedule of Deposits Received and Refunds Paid for Year Ended December 31, 2007*. Prepared for BC Ministry of Environment, August 20, 2008. Accessed at www.env.gov.bc.ca/epd/recycling/bev/reports/pdf/encorp_returns-2007.pdf

Franklin Associates (1998). *Environmental and Economic Analysis of Glass Container Recycling from Portland’s Curbside Collection Program, Final Report*. Prepared for City of Portland, July 1998.

Gartner Lee Limited (2005). *Demolition, Landclearing and Construction Waste Composition Study*. Prepared for Greater Vancouver Regional District.

Gartner Pinfold Consulting (2008). *Economic Impacts of the BC Recycling Regulation*. Prepared for B.C. Ministry of Environment, Environmental Quality Branch, August 2008. Accessed at www.env.gov.bc.ca/epd/recycling/resources/reports/pdf/econ-impacts-recycle-reg.pdf

Greater Vancouver Regional District (2005). *GVRD Solid Waste Management 2004 Annual Report*. Accessed at www.metrovancouver.org

Greater Vancouver Regional District (2006). 2005 *Annual Report for the GVRD Waste-to-Energy Facility.* Accessed at www.metrovancouver.org

Greater Vancouver Regional District (2008). *Key Facts – Metro Vancouver Population Estimates 1996-2007*. Accessed at www.metrovancouver.org

Golder Associates Inc. (2009). Methane Collection and Oxidation Efficiency Assessment Cache Creek Landfill, BC. Prepared for Wastech Services Ltd., draft June 4, 2009.

Institute for Energy and Environmental Research (IFEU) (2005). *Ecological and Energetic Assessment of Rerefining Used Oils to Base Oils: Substitution of Primarily Produced Base Oils Including Semi-synthetic and Synthetic Compounds*. Prepared for GEIR (Groupement Européen de l'Industrie de la Régénération GEIR – the European re-refining industry association), February 2005. Heidelberg, Germany.

Intergovermental Panel on Climate Change (2007a). *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, New York.

Intergovernmental Panel on Climate Change (2007b). *Climate Change 2007: Mitigation*. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, New York.

King County, Washington (2008). "King County Take it Back Network" web site. Accessed at http://your.kingcounty.gov/solidwaste/takeitback/index.asp

King County, Pierce County, Snohomish County, and City of Tacoma, Washington (2008). "Take-It Back Network" website. Accessed at "www.takeitbacknetwork.org/

Lantz, Dan (2008). "Mixed results: Do the advantages of single-stream recycling hold up in a head-to-head comparison? An examination of several single-stream and dual-stream programs tell the tale," *Resource Recycling Magazine*. December 2008.

Lafarge Project Committee (1996). *Lafarge Canada Inc. Richmond Cement Plant Modernization Project*. Accessed at: http://a100.gov.bc.ca/appsdata/epic/documents/p27/1037147043921_9036ce24fbac4cf193849918a0c7f07d.pdf

Lawrence Berkeley National Laboratory (undated). *CalTOX model*. Description, references and downloadable manual and software available at: http://eetd.lbl.gov/IED/ERA/caltox/index.html

Lippiatt, Barbara C. (2007). *BEES 4.0 Building for Environmental and Economic Sustainability, Technical Manual and User Guide*. US Department of Commerce Technology Administration, National Institute of Standards and Technology, Publication NISTIR 7423, May 2007.

Marbek Resource Consultants and Enviros RIS (2002). *Assessing When to Implement Extended Producer Responsibility: Final Report*. Prepared for Environment Canada, January 2002. Accessed at www.env.gov.bc.ca/epd/recycling/resources/reports/pdf/marbek_reports/finalrpt_2002.pdf

Metro Vancouver (2008). *Strategy for Updating the Regional Solid Waste Management Plan: Discussion Document, revised March 2008*. Accessed at www.metrovancouver.org

Metro Vancouver Waste Management Committee (2008). *Zero Waste Challenge Implementation – Achieving the 70% Target, October 2008*. Accessed at www.metrovancouver.org

Michaels, M. and G. Hamblin (2008). "LFG Collection Efficiency: The Fine Tuning of Landfill Gas," *MSW Management*, March 2008.

Moore & Associates (2003). *Metro Solid Waste & Recycling, Impact of Mandatory Recycling Ordinances and Disposal Bans on Commercial Fiber Recycling: Final Report #030102, April 2003*. Prepared for Portland Metro.

Morawski, Clarissa. (2008a). "The New "Eco-Currency": New Model Monetizes Environmental Benefits And Reveals New Cost Savings In Waste Diversion," *Solid Waste & Recycling*, December/January 2008.

Morawski, Clarissa. (2008b). "Composting – Best Bang for MSW Management Buck," *Biocycle*; 49(10): 23-28.

Morris, Jeffrey. (1996). "Recycling Versus Incineration: An Energy Conservation Analysis," *Journal of Hazardous Materials;* 47: 277-293.

Morris, Jeffrey. (2005). "Comparative LCAs for Curbside Recycling Versus Either Landfilling or Incineration with Energy Recovery," *International Journal of Life Cycle Assessment*; 10(4): 273-284.

Morris, Jeffrey, H. S. Matthews, F. Ackerman, M. Morris and R. Hlavka (2007). *The Washington State Consumer Environmental Index (CEI) – A Summary of the Development of a Tool to Understand and Support Consumer Choices That Have Preferable Environmental Outcomes*. Prepared for the Washington State Department of Ecology, July 31, 2007.

Morris, Jeffrey, and J. Bagby (2008). "Measuring Environmental Value for Natural Lawn and Garden Care Practices," *International Journal of Life Cycle Assessment*; 13(3): 226-234.

Morris, Jeffrey (2008a). *Environmental Impacts for Clean Wood Waste Management Methods: Preliminary Results.* Prepared for Seattle Public Utilities, September 2008.

Morris, Jeffrey (2008b). *Environmental Impacts from Carpet Discards Management Methods: Preliminary Results*. Prepared for Seattle Public Utilities, October 2008.

Nenninger, Fred (2008). *Zero Waste Challenge Implementation – Achieving the 70% Target, September 29, 2008*. Memorandum prepared for Metro Vancouver Solid Waste Committee. Accessed at www.metrovancouver.org

Okereke, Victor O., Ph.D., P.E., BCEE (2007). Personal communication. Interim Managing Engineer, Engineering Services Section, Solid Waste Division, King County Department of Natural Resources and Parks.

Portland Metro. Metro *Portland 2006-2007 Solid Waste and Recycling Year in Review*. Accessed at www.oregonmetro.gov/files/planning/06-07_swr_annual_report_w.pdf

Portland Office of Sustainable Development (2002). *Beyond 60%: Program Strategies for Achieving the 2005 Solid Waste Recycling Goal.* March 2002. Accessed at www.portlandonline.com/shared/cfm/image.cfm?id=111088

Portland Office of Sustainable Development, City of Portland (2007). *Recycling Program Summary.* August 2007. Accessed at www.portlandonline.com/shared/cfm/image.cfm?id=174961

Portland Office of Sustainable Development (2008). *Portland Recycles! Plan, revised April 2008*. Accessed at www.portlandonline.com/shared/cfm/image.cfm?id=194082

Post-Consumer Pharmaceutical Management Association (2008). *Medications Return Program Pharmaceutical Annual Report: January 2007 to December 2007*. Prepared for BC Ministry of Environment, June 30, 2008. Accessed at www.medicationsreturn.ca/ar2007.pdf

Product Care Association (2008). *Product Care 2007 Annual Report for Paint Category, Solvent and Flammable Liquids Category, Pesticide Category, Gasoline Category: Reporting Period January 2007 to December 31, 2007.* Prepared for BC Ministry of Environment June 30, 2008. Accessed at www.medicationsreturn.ca/ar2007.pdf

Product Policy Institute (2009). *California, Oregon Introduce Legislation to Reform Waste Management – National Framework Policy Introduced in Canada*. Media release dated March 2, 2009. Accessed at www.productpolicy.org/sites/default/files/PPI-EPR-Framework-CA-OR-CAN-FINAL.pdf.

Regional District of Nanaimo (2008). "Regional District of Nanaimo Commercial Food Waste Diversion," web site. Accessed at www.rdn.bc.ca/cms.asp?wpID=1068

Research Triangle Institute (1999a). *A Decision Support Tool for Assessing the Cost and Environmental Performance of Integrated Municipal Solid Waste Management Strategies: Users Manual, Draft EPA/xxx-R-99-xxx.*

Research Triangle Institute (1999b). *Application of Life-Cycle Management to Evaluate Integrated Municipal Solid Waste Management Strategies, Draft EPA/xxx-R-99-xxx.*

R. W. Beck, (2004a). *City of Roseville, Recycling Pilot Program Summary, Ramsey County, Minnesota.* Prepared for Ramsey County Department of Health, December 2005.

R. W. Beck (2004b). *Anaerobic Digestion Feasibility Study, Final Report*. Prepared for Bluestem Solid Waste Agency and Iowa Department of Natural Resources, April 2004.

R. W. Beck (2007). *Comparative Evaluation of Waste Export and Conversion Technologies Disposal Options -- Internal Draft*. Prepared for King County Department of Natural Resources and Parks Solid Waste Division, May 2007.

Seattle Public Utilities (2004). *On the Path to Sustainability: 2004 Plan Amendment, December 2004*. Accessed at www.seattle.gov

Seattle Public Utilities (2007). *Seattle Solid Waste, Recycling, Waste Reduction, and Facilities Opportunities, Volumes I & II, April 2007*. Accessed at www.seattle.gov

Seattle Public Utilities (2008a). *Apartment Recycling Report June 2008, September 2008*. Accessed at www.seattle.gov/util/stellent/groups/public/@spu/@usm/documents/webcontent/spu01_003757.pdf

Seattle Public Utilities (2008b). *City of Seattle Recycling Rate 2007 Update, July 2008*. Accessed at www.seattle.gov

Seattle Public Utilities (2008c). *Residential Organics Report June 2008, September 2008*. Accessed at www.seattle.gov

The Sheltair Group (2008). *Environmental Life Cycle Assessment of Solid Waste Management: Evaluation of Two Waste Disposal Scenarios for the Metro Vancouver Region, Final Report and Appendices*. Prepared for Regional Utility Planning Division, Policy and Planning Department, Metro Vancouver, February 11, 2008.

Skumatz Economic Research Associates, Inc., (2007). *North American Waste Management Systems Comparison Study: Outstanding Communities and Programs in North America and Beyond*. Prepared for Metro Vancouver, December 2007.

Snohomish County, WA (2009). "Snohomish County Public Works, Solid Waste Division, Take It Back Programs," web site. Accessed at http://www1.co.snohomish.wa.us/Departments/Public_Works/Divisions/SolidWaste/TakeItBack/

St. Paul Public Schools (2000). *Ramsey/Washington County Resource Recovery Project, Governor Awards Application, 2000*.

Technology Resource Inc. (2005) *Solid Waste Composition Study*. Prepared for Greater Vancouver Regional District.

Technology Resource Inc. (2008). *Solid Waste Composition Study*. Prepared for Metro Vancouver (Greater Vancouver Sewerage and Drainage District).

Tire Stewardship BC (2007). *Tire Stewardship BC Annual Report 2007*. Accessed at www.env.gov.bc.ca/epd/recycling/tires/reports/pdf/TSBC-2007.pdf

US EPA, North Carolina State University, and Research Triangle Institute (2003). *Municipal Solid Waste Life-Cycle Database for the Decision Support Tool on Municipal Solid Waste Management*. Research Triangle Park, NC.

US EPA (2006). *Solid Waste Management and Greenhouse Gases – A Life-Cycle Assessment of Emissions and Sinks, 3rd edition*. Environmental Protection Agency, Washington, D.C.

US EPA Technology Transfer Network Clean Air Technology Centre (2008). *LandGEM (Landfill Gas Emissions Model version 3.02)*. Accessed at www.epa.gov/ttn/catc/dir1/landgem-v302.xls

US EPA (2008). *WAste Reduction Model (WARM), updated August 2008*. Accessed at www.epa.gov/climatechange/wycd/waste/calculators/Warm_home.html

Wihersaari, Margareta (2005a). *Aspects On Bioenergy As A Technical Measure To Reduce Energy Related Greenhouse Gas Emissions*. Academic dissertation for the Ph.D. in Technology, Helsinki University of Technology.

Wihersaari, Margareta (2005b). "Evaluation of Greenhouse Gas Emissions Risks From Storage of Wood Residue," *Biomass and Energy*; 28 (5): 444-453.

ENDNOTES

1 The GVRD Solid Waste Management 2004 Annual Report presents estimates of the quantities of materials recycled, by sector and material type, as well as the quantities of waste disposed.

2 See www.env.gov.bc.ca/epd/recycling.

3 Gartner Lee Limited (2005), Technology Resource Inc. (2005), Technology Resource Inc. (2008)

4 The BC Stats projected growth rate for the region was 1.9% in 2008. See BC Stats (2008) and Metro Vancouver (2008).

5 See BC Stats (2008). Because the model used per capita waste generation rates based on 2006 waste generation estimates, it does not take into account the decline in waste generation associated with the current economic downturn. Therefore, the waste generation assumptions used in this study may be viewed as "worst case."

6 E.g., Metro Vancouver Waste Management Committee (2008).

7 See British Columbia Ministry of Environment, Environmental Quality Branch (2007).

8 See Canadian Council of Ministers of the Environment (2009).

9 The use phase of the product life cycle is not considered in this study. The use phase is typically ignored when the purpose of the LCA is to compare environmental impacts for different waste management options. This is because pollutant emissions from using a product are the same whether the product is manufactured from 100% virgin raw materials, 100% recycled materials, or a mix of recycled and virgin materials. Thus, in comparing recycling versus disposal, the difference in environmental impacts is not changed by including use phase emissions from recycled-content products and virgin-content products when calculating the total emissions for recycling and disposal.

10 The model is reviewed in Morawski (2008a and 2008b).

11 WARM is available at www.epa.gov/climatechange/wycd/waste/calculators/Warm_home.html.

12 See Research Triangle Institute (1999a and 1999b) and EPA *et al* (2003). Both the DST and the database are available through Research Triangle Institute.

13 Available at www.eiolca.net.

14 Available at www.bfrl.nist.gov/oae/software/bees/model.html.

15 Information about TRACI is available at www.epa.gov/nrmrl/std/sab/traci/ . Also see Bare (2002) and Bare *et al* (2003).

16 The CEI model is detailed in Morris *et al* (2007).

17 Available in Morris (2008a) and Morris (2008b).

18 Available in Franklin (1998).

19 Available in the Beck (2004) and Beck (2007) reports.

20 Dioxin/furan emissions were not included in the calculations of environmental impacts for the Burnaby WTE facility or for other waste management options. There were two reasons for this: (1) while Sheltair (2008) provides data, it is not clear from the report which particular dioxin or furan is being used to aggregate the numerous species of dioxins and furans that may have been measured in the emissions tests at Burnaby WTE facility. Different dioxins and furans have widely different environmental impacts; (2) in some cases there is a lack of data on dioxin/furan emissions for other waste management methods modeled in the study. Because dioxins/furans weigh heavily in the calculation of human health and ecosystem environmental impacts, it would be misleading to include dioxins/furans for only some and not all facilities and processes.

21 LandGEM is available at www.epa.gov/ttncatc1/products.html.

22 See Morris *et al* (2007).

23 Bare (2002) and Bare *et al* (2003).

24 See a description of the CalTOX model, references, and downloadable manual and software at http://eetd.lbl.gov/IED/ERA/caltox/index.html.

25 See Intergovernmental Panel on Climate Change (2007a), Table 2.14.

26 In other studies the aggregation is sometimes in terms of carbon equivalents rather than carbon dioxide equivalents. One can readily convert one aggregation quantity to the other by means of the equation $CO2 = (44/12)*C$, based on the atomic weight of oxygen (O) = 16 and carbon (C) = 12.

27 See Bare *et al* (2003) and Lippiatt (2007) for a detailed description and discussion of these environmental impact categories.

28 See Morris and Bagby (2008) for a discussion on how these cost estimates were derived

29 Used oil accounted for 6.5% of total industrial fuels and rubber accounted for 1.5% of total industrial fuels. Paint and flammable liquids were included in the used oil estimates and modeling assumptions due to lack of relevant product profiles and emissions data. It was estimated that paint and flammable liquids accounted for less than 5% of HHW used as industrial fuel in EPR programs.

30 City of Vancouver (2009); Golder Associates Ltd. (2009)

31 Accurately accounting for the climate change impacts of disposal facilities requires that carbon storage is either counted as an offset to GHG emissions for landfills, or counted as a GHG emission for WTE facilities. In this study, it is counted as an offset to landfill GHG emissions.

32 See **Appendix D** for a discussion regarding the lack of methanogenesis in submerged landfills.

33 It should be noted that Sheltair (2008) used the average rate of GHG emissions per kilowatt hour of electricity consumed in BC as the GHG offset for energy generated by MSW disposal facilities. Due to the high proportion of BC electricity that is provided by hydropower, the GHG offset in Sheltair (2008) is approximately 10 times lower than the GHG offset from electricity generated by natural gas fuel used in the LCA for this report.

34 US EPA AP-42

35 It should be noted that newer technologies (such as micro turbines for generating electricity from landfill gases, and particulate and acid gas emissions controls on internal combustion engines) may substantially reduce these negative human health impacts. This technological factor is taken into consideration for the Vancouver Landfill under the Zero Waste scenario. It was assumed that microturbine technology will be employed for landfill gas utilization at VLF in 2029.

36 The BC Energy Plan sets a goal of zero net GHG emissions from existing thermal power plants by 2016 and all new electricity generation projects will have zero net GHG emissions. BC Ministry of Energy, Mines & Petroleum (2007). The BC Energy Plan: A Vision for Clean Energy Leadership.

37 It should be noted that not all of the increase in GHG reductions is attributable to increases in the percentage of waste diverted. Rather some of it is due to increased waste generation, which increases the overall tonnage of recyclables available for diversion independent of the waste diversion rate.

APPENDICES

Appendix A

DATA SOURCES & ASSUMPTIONS – DIVERSION

Appendix B

DATA SOURCES & ASSUMPTIONS – DISPOSAL

Appendix C

ZERO WASTE STRATEGIES RESEARCH

Appendix D

SAMPLE METHODOLOGY – CLEAN WOOD WASTE MANAGEMENT

Appendix E

SENSITIVITY ANALYSIS – GLOBAL WARMING POTENTIAL OF METHANE

Appendix F

SUMMARY OF LCA RESULTS

Appendix A:
DATA SOURCES & ASSUMPTIONS – DIVERSION

Table A.1 Data Sources and Assumptions - Diversion Methods

Material / Product	Assumptions
Paper & Paperboard	
Newspaper	**Recycling** Air and water emissions for 100% virgin versus 100% recycled-content newsprint manufacturing based on US EPA WARM (for GHGs) and US EPA DST (for non-GHGs) models. Air and water emissions caused by curbside collection, processing and hauling to end-use markets also based on US EPA WARM and DST models, except that the average hauling distance from recyclables processing plant to end-use manufacturers increased to 800 km by truck. (Or the distance by rail car or ship that a tonne of material can be transported using the same amount of fuel required for shipping 800 km by truck. This distance by rail is over 3,000 km and even farther by ship.) One tonne of 100% recycled-content newsprint estimated to require 1.1 tonnes of recycled newspapers.
Corrugated Cardboard	**Recycling** Emission estimate sources same as for newspaper. One tonne of 100% recycled-content corrugated cardboard estimated to require 1.1 tonnes of recycled cardboard.
Mixed Paper	**Recycling** Emission estimate sources same as for newspaper. Mixed paper estimated to be 67% boxboard, magazines, newspaper and phone books, and 33% office paper and book paper. Production of 100% recycled-content paper and paperboard products from mixed paper estimated to require 1.4 tonnes per tonne of product.
Aseptic Beverage Containers	**Recycling** Emission estimate sources same as for newspaper. Aseptic beverage containers modeled as 95% chemical pulp paper (similar to cardboard box linerboard, except bleached) and 5% film plastic.
Other Paper	**Composting** Air and water emissions estimates for compostables based on US EPA DST model and Morris and Bagby (2008).
Plastics	
Film Plastic	**Recycling** Emission estimate sources same as for newspaper. Modeled as low density polyethylene (LDPE). Production of one tonne of 100% recycled-content film plastic estimated to require 1.2 tonnes of recycled film.
Plastic Beverage Containers	**Recycling** Emission estimate sources same as for newspaper. Modeled as polyethylene terephthalate (PET). Production of one tonne of 100% recycled-content PET plastic estimated to require 1.2 tonnes of recycled plastic beverage containers.
Rigid Plastic Containers	**Recycling** Emission estimate sources same as for newspaper. Modeled as high density polyethylene (HDPE). Production of one tonne of 100% recycled-content HDPE estimated to require 1.2 tonnes of recycled HDPE containers for food and other products.
Textiles	**Recycling** Emissions from recycling plastic-polymer textiles modeled as same as for recycling PET.
Other Plastics	**N/A**

Continued

Table A.1 (Cont'd) Data Sources and Assumptions - Diversion Methods

Material / Product	Assumptions
Organics (Compostable)	
Yard Trimmings	**Composting** Air and water emissions estimates for compostables based on US EPA DST model and Morris and Bagby (2008).
Food Scraps	**Composting** Air and water emissions estimates for compostables based on US EPA DST model and Morris and Bagby (2008).
Wood (Unpainted/untreated pallets, wood furniture, lumber)	**Recycling** See **Appendix D** for emissions estimate sources for recycling wood into papermaking pulp. **Industrial Fuel** 50% substitutes for coal and 50% for natural gas in industrial boilers in 2008. As coal use ramps down (due to BC carbon tax and other factors) the amount of wood wastes being used in place of coal falls and the amount used in place of natural gas rises until by 2029, 25% substitutes for coal and 75% substitutes for natural gas. Other assumptions and estimates for the life cycle of wood waste used as industrial fuel are detailed in **Appendix D.** Air emissions from wood combustion in industrial boilers based on US EPA AP42 emissions profiles for clean wood waste, supplemented by regionally specific information on industrial boiler types and APC controls in Beauchemin, P. and M. Tampier (2008). *Emissions from Wood-Fired Combustion Equipment*. Prepared for BC Ministry of Environment. Air emissions from the combustion of coal and natural gas that are offset by wood waste combustion are also based on US EPA AP42 emissions profiles for industrial boilers, supplemented by information on boiler types and APC (air pollution control) devices used in local and Canadian cement kilns (Lafarge (1996), Constable Associates (2004), CCME (1998)). Air emissions from production and distribution of coal and natural gas that are offset by wood waste combustion are based on the Carnegie Mellon EIOLCA model. Water emissions from production and distribution of coal and natural gas that are offset by wood waste combustion are based on the Carnegie Mellon EIOLCA model.

Continued

Table A.1 (Cont'd) Data Sources and Assumptions - Diversion Methods

Material / Product	Assumptions
Organics (Non-compostable)	
Wood (Treated wood; Finished wood such as plywood and OSB; Finished wood furniture, non-composite)	**Industrial Fuel** It was assumed that a portion of "Non-compostable" wood as defined in the Metro Vancouver waste composition study, such as plywood, was clean wood for the purposes of industrial fuel combustion.
Textiles	**Recycling** Emissions estimate sources from recycling non-compostable textiles modeled as same as for recycling cardboard.
Leather	N/A
Rubber	**Recycling** GHGs and particulates emissions reductions estimates from recycling rubber, mainly tires, into crumb rubber substitute for virgin rubber based on Pieter van Beukering et al, *Waste Management and Recycling of Tyres in Europe,* prepared for the Ministry of Environment of the Czech Republic, prepared by the Institute for Environmental Studies, Amsterdam, The Netherlands, report number R98/13, December 1998. Estimates for toxics and carcinogenic emissions impacts from recycling rubber into crumb rubber were not available. **Industrial Fuel** 50% substitutes for coal and 50% for natural gas in industrial boilers in 2008. It was assumed that as coal use ramps down (due to BC carbon tax and other factors) the amount of rubber waste being used in place of coal falls and the amount used in place of natural gas rises until by 2029 25% substitutes for coal and 75% substitutes for natural gas. Heating value for tire derived fuel is 36.1 MJ per kilogram. 0.9MJ per kilogram energy used for used tire shredding and wire removal with 75% recovery of weight of scrap tire for fuel use. Air emissions from used rubber combustion in industrial boilers based on Pieter van Beukering *et al, Waste Management and Recycling of Tyres in Europe,* prepared for the Ministry of Environment of the Czech Republic, prepared by the Institute for Environmental Studies, Amsterdam, The Netherlands, report number R98/13, December 1998. No emissions data available for toxics and carcinogens from combusting used rubber in industrial boilers. Air emissions from the combustion of coal and natural gas that are offset by used rubber combustion are based on US EPA AP42 emissions profiles for industrial boilers. Air emissions from production and distribution of coal and natural gas that are offset by used rubber combustion are based on the Carnegie Mellon EIOLCA model. Water emissions from production and distribution of coal and natural gas that are offset by used rubber combustion are based on the Carnegie Mellon EIOLCA model.
Multiple/Composite Materials	N/A
Metals	
Ferrous	**Recycling** Emission estimate sources same as for newspaper. One tonne of 100% recycled-content steel estimated to require 1.2 tonnes of recycled ferrous metals.
Aluminum/ Other Non-Ferrous	**Recycling** Emission estimate sources same as for newspaper. One tonne of 100% recycled-content aluminum estimated to require 1.1 tonnes of recycled aluminum.
Other Metal	N/A

Continued

Table A.1 (Cont'd) Data Sources and Assumptions - Diversion Methods

Material / Product	Assumptions
Glass	
Glass Beverage Containers	**Reuse** Refillables estimated to make 15 round trips between consumers and beverage producers. Fourteen of those trips offset production of new containers and bottle is recycled after 15th use (Source: Brewers Distributors Limited Annual Product Stewardship Report, March 31, 2007 to March 31, 2008). Air and water emissions for new container production (virgin or recycled content) from US EPA DST. Air emissions from natural gas used to generate electricity for washing bottles 14 times based on US EPA AP42. Air and water emissions from production and distribution of natural gas based on Carnegie Mellon EIOLCA model. Energy use for bottle washing based on estimate that washing 1 bottle requires 0.95MJ. Industry standard beer bottle weighs 265 grams. **Recycling** Emission estimate sources same as for newspaper for recycling glass into new glass containers. One tonne of 100% recycled-content glass containers estimated to require just a little over one tonne of recycled glass. For the recycling of glass into fiberglass insulation, air and water emissions are based on Franklin Associates, *Environmental and Economic Analysis of Glass Container Recycling from Portland's Curbside Collection Program*, prepared for the City of Portland by Franklin Associates, Prairie Village, KS, July 1998. For recycling of glass into construction aggregate, air and water emissions are based on US EPA, *Background Document for Life-Cycle Greenhouse Gas Emissions Factors for Clay Brick Reuse and Concrete Recycling*, EPA530-R-03-017, Washington, DC, November 2003. This document provides energy source and use estimates for virgin versus recycled aggregate production.
Glass Food Containers	**Recycling** Emission estimate sources same as for glass beverage containers.
Other Glass	N/A
Inorganic Building Materials	
Gypsum	**Recycling** Gypsum board material content estimated at 6% paperboard and 94% gypsum. Air and water emissions estimates for recycling gypsum board are based on US Dept of Commerce National Institute for Standards and Technology's BEES life cycle assessment model for building materials.
Masonry and Concrete	**Recycling** Air and water emissions sources for recycling masonry and concrete into construction aggregate same as for recycling glass into construction aggregate.
Rock/Dirt/Ceramic/Soil/ Rubble	**Recycling** Recycling of rock, dirt, ceramic, soil and rubble assumed to result in no change to air and water emissions.
Rigid Asphalt Products	**Recycling** Recycling of rigid asphalt products assumed to result in no change to air and water emissions.
Carpet	**Recycling** Air and water emissions estimates from carpet recycling based on Morris, J., *Environmental Impacts from Carpet Discards Management Methods: Preliminary Results*, prepared for Seattle Public Utilities, by Sound Resource Management Group, Seattle, WA, October 2008.
Other (Asphalt, etc.)	**Recycling** Air and water emissions from recycling asphalt into construction aggregate are same as for recycling masonry and concrete into construction aggregate.
Electronic Waste	
Electronics & Small Appliances	**Recycling** Electronic products recycled by dismantling or shredding them into plastics (45%) with same recycling impacts as HDPE, glass (15%), ferrous (15%) and aluminum (15%). Sources for air and water emissions estimates for recycling each of these four materials are given above in this table.
Household Hazardous	

Continued

Table A.1 (Cont'd) Data Sources and Assumptions - Diversion Methods

Material / Product	Assumptions
Household Hazardous (general)	Assumed that 49% of HHW is combusted as industrial fuel (modeled as used lubricating oil), 47% is re-refined used lubricating oil, and 4% is paint reuse.
Lubricating Oil	**Recycling (Re-refined Used Lubricating Oil)** Air and water emissions from re-refining used lubricating oil from Boughton and Horvath (2004). **Industrial Fuel (Used Lubricating Oil)** Because most of the HHW that is combusted is used oil, the environmental impacts for combusting HHW in industrial boilers are estimated based on used oil combustion. Fifty percent of the used oil substitutes coal, and 50% substitutes natural gas in industrial boilers in 2008. It was assumed that as coal use ramps down (due to BC carbon tax and other factors) the amount of used lubricating oil being used in place of coal falls and the amount used in place of natural gas rises. By 2029, 25% of the oil substitutes for coal and 75% substitutes for natural gas. Air emissions from used oil combustion in industrial boilers based on US EPA AP42 emissions profiles for fuel oil and waste oil. Air emissions from the combustion of coal and natural gas that are offset by used oil combustion are also based on US EPA AP42 emissions profiles for industrial boilers. Air emissions from production and distribution of coal and natural gas that are offset by used oil combustion are based on the Carnegie Mellon EIOLCA model. Water emissions from production and distribution of coal and natural gas that are offset by used oil combustion are based on the Carnegie Mellon EIOLCA model.
Paint	**Reuse** Air and water emissions for new paint manufacturing from Carnegie Mellon EIOLCA model; handling and transportation for used paint assumed to have emissions equivalent to handling and transportation for new paint.
Household Hygiene	
Household Hygiene	N/A
Bulky Objects	
White Goods (Large Appliances)	**Recycling** Recycling white goods estimated to have same impacts as recycling ferrous scrap metals.
Upholstered	**Recycling** Upholstered bulky objects recycled by dismantling them into wood (50%), organic textiles (25%) and plastic textiles (25%). Sources for air and water emissions estimates for recycling each of these three materials are given above in this table.
Other Bulky Objects	**Recycling** Recycling of other bulky objects assumed to result in no change to air and water emissions.
Fines/Miscellaneous	
Fines/Miscellaneous	**Recycling** Recycling of fines and miscellaneous assumed to result in no change to air and water emissions.

Appendix B:
DATA SOURCES AND ASSUMPTIONS– DISPOSAL

B.1 Introduction

This appendix presents data sources and assumptions regarding:

1. Disposal Facilities. Where possible, site-specific information was incorporated into MEBCalc for the following facilities:
   - Vancouver Landfill (MSW landfill)
   - Cache Creek Landfill (MSW landfill)
   - Demolition, landclearing and construction (DLC) landfills
   - Burnaby Waste-to-Energy Facility (MSW incinerator)
   - Data sources and key assumptions for each facility are listed in **Table B.1**.

2. Natural Gas Offsets. **Table B.2** lists emissions data sources and fuel substitution estimates for the natural gas and diesel fuel offsets from production of energy from wastes.

3. Comparison with assumptions in Sheltair (2008): *Environmental Life Cycle Assessment of Solid Waste Management: Evaluation of Two Waste Disposal Scenarios for the Metro Vancouver Region*.

B.2 Disposal Facility Data Sources and Assumptions

Table B.1 Data Sources and Operational Assumptions – Disposal Facilities

Facility	Sources for Air Emissions	Sources for Water Emissions	Existing and Proposed Operational Characteristics
Vancouver MSW Landfill	(1) US EPA LandGEM Version 3.02 (k = .35 based on average precipitation in Vancouver; MSW Lo = 130 in 2008 trending down to 86 by 2029 for the zero waste scenario) for non-methane emissions from the landfill. (2) US EPA WARM calculator for waste material specific methane emissions from the landfill. (3) US EPA DST (Research Triangle Institute 1999a) for emissions from landfill flare, from internal combustion engines used to generate electricity from collected landfill gas, and from landfill operations.	US EPA DST (Research Triangle Institute 1999a) for emissions to water from landfill.	(1) Landfill gas collection efficiency = 75%. (2) 125 kilowatts net electricity to grid and 559 MJ hot water to greenhouses per tonne MSW landfilled. (3) Energy offsets based on natural gas through 2014 and renewables after 2014. (4) Landfill carbon storage based on US EPA WARM calculator. (5) LandGEM gas generation calculations for 140 years following MSW landfilling. (6) Microturbines replace current engines (ICE) in 2029. Turbine emissions modeled on LFG flare emissions.
Cache Creek MSW Landfill	(1) US EPA LandGEM Version 3.02 (k = .025 based on average precipitation in Cache Creek area; MSW Lo = 130 in 2008 trending down to 86 by 2029 for the zero waste scenario) for non-methane emissions from the landfill. (2) US EPA WARM calculator for waste material specific emissions from the landfill. (3) US EPA DST (Research Triangle Institute 1999a) for emissions from landfill flare and from landfill operations. (4) Dr. John Barclay, Prometheus Energy, for emissions from conversion processes for liquid natural gas from landfill gas.	US EPA DST (Research Triangle Institute 1999a) for emissions to water from landfill.	(1) Landfill gas collection efficiency = 75%. (2) 114 liters LNG per tonne MSW landfilled is processed using 110 kilowatt hours of electricity beginning 2014. (3) Substitution of 1.7 liters LNG per liter diesel fuel in long-haul trucks. (4) LNG in truck compression engines has 45% less NOx, 30% less CO, same particulates, no fossil CO2 vs. diesel. (5) Landfill carbon storage based on US EPA WARM calculator. (6) LandGEM gas generation calculations for 140 years following MSW landfilling.
DLC Landfills	(1) Landfill emissions based on 10% of arid area landfill gas generation due to below water table conditions at DLC landfills and lack of methanogenesis under water. (2) US EPA DST for emissions from landfill operations.	US EPA DST (Research Triangle Institute 1999a) for emissions to water from landfill.	No landfill gas collection.
Burnaby MSW WTE Facility	(1) Emissions from MSW combustion based on Sheltair (2008), Table 4.1. (2) US EPA DST for emissions from WTE facility operations.	US EPA DST (Research Triangle Institute 1999a) for emissions to water from WTE operations.	(1) Net electricity generation 527 kWh per tonne MSW. (2) Marketable steam generation 1,183 MJ per tonne MSW. (3) Beginning 2014 NOx/SO2/HCL emissions decreased 81%/61%/80%, respectively, versus 2008, per Sheltair (2008), Table 4.1.

Table B.2 Data Sources - Production and Combustion of Natural Gas and Diesel

Offset Fuels	Sources for Air Emissions	Sources for Water Emissions	Operational Characteristics
Natural Gas *- Production*	Carnegie Mellon EIOLCA model	Carnegie Mellon EIOLCA model	
Natural Gas *- Combustion*	US EPA AP-42 emissions data for combustion in industrial boilers		(1) 1 kilowatt hour of electricity generated from MSW offsets 0.2 cubic meters natural gas used to generate electricity in a combined cycle natural gas fired turbine. (2) one GJ of steam or hot water heat energy offsets 25 cubic meters of natural gas fired in an industrial boiler.
Diesel Fuel *- Production*	Carnegie Mellon EIOLCA model	Carnegie Mellon EIOLCA model	
Diesel Fuel *- Combustion*	US EPA DST emissions for long-haul trucking.	US EPA DST emissions for long-haul trucking.	1.7 liters of LNG from landfill gas offset 1 liter of diesel.

B.1 Comparison with Assumptions in Sheltair (2008)

In 2008, Metro Vancouver commissioned The Sheltair Group to compare the life cycle impacts of landfilling and waste-to-energy. The assumed operational characteristics for MSW landfills in this study (detailed in **Table B.1**) differ in several important respects from the assumptions in Sheltair (2008). These differences and the rationales for them include:

B.1.1 Biogenic Carbon

Assumption: Sheltair (2008) excluded carbon storage in the study's "Base Case" analysis but presented a sensitivity analysis that showed there would be a significant difference in the findings of the study if carbon storage was included. In this study, MSW landfills get credit for storing carbon in products manufactured from forestry resources and other cellulosic wastes such as yard debris.

Rationale: When trees are harvested to manufacture paper and paperboard, dimensional lumber, engineered wood, and other wood products, these products provide ongoing storage for a significant portion of the carbon that was sequestered during growth of the harvested trees. The Intergovernmental Panel on Climate Change (IPCC) includes landfill carbon storage as a carbon sink:

> "Because landfills function as relatively inefficient anaerobic digesters, significant long-term carbon storage occurs in landfills, which is addressed in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories."[i]

The IPCC goes on to say,

> "Since lignin is recalcitrant and cellulosic fractions decompose slowly, a minimum of 50% of the organic carbon landfilled is not typically converted to biogas carbon but remains in the landfill... Carbon storage makes landfilling a more competitive alternative from a climate change perspective, especially where landfill gas recovery is combined with energy use."[ii]

As such, in an LCA comparing MSW landfills and WTE facilities, it is necessary to account for the release or continued storage of this previously stored carbon. In this study, this accounting is as follows:

- Landfill methane accounts for the portion of this stored carbon that is released in MSW and DLC landfills.

- The continued storage of the remaining previously stored carbon in landfills accounts for the overall climate change impacts of landfills as compared with WTE facilities.
- Ignoring carbon storage would bias the life cycle analysis by ignoring the substantial biogenic carbon that is released to the atmosphere when wood products and other cellulosic discards are incinerated versus being stored in a landfill.

B.1.2 Landfill Gas Capture Rate

Assumption: Sheltair 2008 assumed a landfill gas capture rate of 65%. In this study, MSW landfills are assumed to capture at least 75% of the landfill gases generated over the 140 years following disposal of MSW in a landfill with a landfill gas collection system.

Rationale: The rationale for this assumption is based on the following information:

The default landfill gas capture efficiency in US EPA's WARM software, and the report supporting it (EPA 2006) is 75%. The default capture efficiency in US EPA's DST model is 88% (EPA 2003, Research Triangle Institute 1999a). Michels and Hamblin (2008) report that statewide landfill gas collection efficiency for 24 Wisconsin landfills improved continuously from 77% in 2000 to 85% in 2004. Engineers responsible for the King County (WA) Cedar Hills landfill report that their measurements of methane escaping from the landfill face compared with methane captured in their landfill gas collection system indicates a capture versus fugitive gas rate of over 90%.[iii] "Intensive field studies of the CH4 mass balance at cells with a variety of design and management practices have shown that >90% recovery can be achieved at cells with final cover and an efficient gas extraction system."[iv]

Given this evidence, 75% capture efficiency is likely a low estimate for lifetime landfill gas capture at a well-managed modern landfill facility. However, if either the Vancouver landfill or the Cache Creek landfill are shown not to be capturing this level of gas, it is recommended that gas collection systems be improved and expanded to achieve this 75% minimum landfill gas capture efficiency. This is relatively low cost and given the body of work indicating that 75% is very achievable it should be required for landfills receiving Vancouver region MSW for disposal.

B.1.3 Fuel Offsets

Assumption: Sheltair (2008) used the average rate of GHG emissions per kilowatt hour of electricity consumed in BC as the GHG offset for energy generated by MSW disposal facilities. Due to the high proportion of BC electricity that is provided by hydropower, the GHG offset in Sheltair (2008) is approximately 10 times lower than the GHG offset from electricity generated by natural gas fuel. In this study, natural gas is the fuel used to calculate offsets for energy generated from MSW in 2008.

Rationale: Natural gas fired generating facilities currently are used as the marginal or peaking power source for electricity on the US Western Systems Coordinating Council grid[v], and BC imports some of its power from that grid. Furthermore, the use of natural gas for calculating power offsets is conservative with respect to the estimated margin by which recycling and composting are preferable to disposal in terms of climate change impacts. It was assumed that for the 2019, 2024 and 2029 Zero Waste scenario years, a renewable energy source would be the offset power generation fuel. This is based on The BC Energy Plan goals of achieving zero net GHG emissions from existing thermal power plants by 2016 and having all new electricity generation projects producing zero net GHG emissions.[vi]

---

[i] Intergovernmental Panel on Climate Change (2007b), page 589. See Box 10.1 on pages 591-592 for estimates of landfill carbon storage in the various regions of the world.

[ii] Ibid, page 601.

[iii] Okereke, Victor O. (2007).

[iv] Intergovernmental Panel on Climate Change (2007b), page 600.

[v] R. W. Beck (2007).

[vi] BC Ministry of Energy, Mines & Petroleum (2007).

Appendix C:
ZERO WASTE STRATEGIES RESEARCH

C.1 Introduction

Research on waste diversion strategies in various jurisdictions was conducted to assist in the development of diversion assumptions and projections for the Zero Waste scenario. Particular emphasis was placed on programs and plans in Seattle and Portland. These cities share similarities with Vancouver in terms of their populations, climate, commitment to waste diversion, and their position as the major employment and population centers in their respective geographic regions. Appendix C presents a summary of this research.

C.2 Extended Producer Responsibility (EPR)

"The Organization for Economic Co-operation and Development (OECD) defines EPR as an environmental policy approach in which a producer's responsibility, physical and/or financial, for a product is extended to the post-consumer stage of a product's life cycle. There are two key features of EPR policy: (1) the shifting of responsibility (physically and/or economically, fully or partially) upstream to the producer and away from municipalities, and (2) to provide incentives to producers to take environmental considerations into the design of the product."[1] As a policy approach, EPR has arisen in the context of municipal and senior government efforts to address environmental and operation challenges posed by the increasing volume and toxicity of products and materials in solid waste streams. EPR is intended to provide the basis for achieving waste prevention through product redesign and reductions in consumption, and development of effective reuse, recycling and hazardous waste management programs tailored to specific products.

British Columbia

In British Columbia, the EPR policy framework is based on a full-producer responsibility model. Producers are responsible for the life cycle management of their products, including the costs of post-consumer collection and management of products regulated under the *BC Recycling Regulation*.

BC has already implemented a significant number of EPR programs. These include programs for beverage containers; used lubricating oil, filters, and empty oil containers; paint; flammable liquids; pesticides; medications; computers, computer peripherals, desktop printers, fax machines and TVs; and tires. The Province has made a commitment to add two new products to the *BC Recycling Regulation* every three years. In 2008, the Province announced the expansion of the electronics program to include a wide range of electrical and electronic products. A new program for mercury containing light bulbs and thermostats was also announced. A range of other products has been identified on a published list for potential future EPR programs, including high volume and bulky products such as packaging, construction and demolition materials, furniture and textiles.[2]

The *BC Recycling Regulation* is a flexible piece of legislation that was designed to make the uptake of new EPR programs as efficient as possible. Overarching principles and requirements for all EPR programs are established in the body of the regulation, providing a framework for addressing the diversity of products in the waste stream. Schedules are appended to the body of the regulation for different product categories. This structure gives the provincial government the capacity to create new EPR programs by adding new schedules to the regulation, as opposed to creating new regulations for each new EPR program.

Other Jurisdictions

The concept of EPR, especially the full producer responsibility approach, is gaining momentum in other jurisdictions:

- Washington State, in 2006, adopted legislation requiring an EPR program for computers and televisions. The program, E-cycle Washington, was launched in January 2009. Government officials acknowledge that the program is largely modeled after BC's electronics stewardship program.
- The state of California is considering the California Product Stewardship Act, a bill based on framework EPR policy adopted by the California Integrated Waste Management Board in January 2008.
- Oregon is considering a product stewardship framework bill that names mercury-containing lights and rechargeable batteries as initial product areas.
- The Canadian Council of Ministers of the Environment, in February 2009, published a proposed action plan to introduce harmonized EPR programs across the country.[3] The plan seeks to implement EPR programs for the following products within six years after the plan is adopted:
  - Packaging
  - Printed materials
  - Compact fluorescents and other lamps containing mercury
  - Electronics and electrical products
  - Household hazardous and special wastes
  - Automotive products

  The plan also proposes the following new EPR programs within eight years of the plan being adopted:
  - Construction and Demolition materials
  - Furniture
  - Textiles and carpet
  - Appliances, including ozone-depleting substances (ODS)

Local Government Role

Local governments can play a central role in the implementation of EPR. In British Columbia, some elements of their involvement include: continuing to advocate for provincial action on new programs; implementing disposal bans, recycling requirements and related financial incentives/disincentives on products covered by EPR programs; facilitating land use planning; building and business permitting requirements to support the development of EPR businesses; and integrating EPR as a central component of public communications on waste management. Local governments can also commission studies to provide feedback on existing programs, prioritize new ones, and prepare business cases to help them advocate for new programs.

Local Product Stewardship Councils

Local governments have led the push for provincial and state framework EPR legislation by forming a collective voice through product stewardship councils. The Northwest Product Stewardship Council (representing local governments in Washington and Oregon), the California Product Stewardship Council, and the Vermont Product Stewardship Council have endorsed framework principles for EPR based on BC's full producer responsibility model.

Local EPR Networks

Table C.1 lists products collected by local (voluntary) EPR networks that are facilitated by Snohomish County, WA[4], King County, WA,[5] and the City of Ottawa.[6] Ottawa's Take it Back! Program has grown from three automotive products taken back by 16 automotive retailers in 1997, to more than 97 different products taken back by over 500 retailers, charitable organizations and depots in 2005.

Ottawa's Take-it Back network is actually a hybrid EPR/recycling network. Many network participants appear to be recyclers who are not directly or even indirectly connected to the producers themselves. Still, according to the city's website, the network is intended to encourage local businesses to "take back" many of the household materials that they sell, and to ensure they are reused, recycled or disposed of properly. The website notes as a success that the Take-It-Back network has become an alternative to the residential recycling boxes and Household Hazardous Waste depots for some materials.

Ottawa has attempted to quantify the amount of material diverted through the Take-It-Back program. In 2002, Ottawa audited 14 different products taken back by participating retailers. It was determined that participating retailers diverted a minimum of 402 tonnes per year from the landfill or City run hazardous waste depots. Examples of the quantities of material diverted are:

- 14,000 tires
- 56,000 litres of used motor oil
- 5,400 litres of antifreeze
- 25,000 pairs of eyeglasses taken back for donation to developing countries
- 7,600 printers

Table C.1 Local EPR Networks – Products Collected

Products Collected	Ottawa, ON	Snohomish County, WA	King County, WA
Automotive			
Antifreeze		●	
Automobiles	●		
Car Parts	●		
Lead-acid Batteries	●	●	
Mercury Switches		●	
Radiators	●		
Tires	●	●	
Transmission Filters & Oil	●		
Electronic & Electrical Equipment			
Appliances (Small & Large)	●		
Audio/Visual Equipment	●		
Batteries (Non-Rechargeable & Rechargeable)	●	●	
Breakers/Switches/Wiring	●		
CDs, DVDs, Floppy Disks & Cases	●		
Cell Phones		●	
Computers & Peripherals	●	●	●
Electric Motors	●		
Electronic Gaming Equipment	●		
Fluorescent Tubes/CFLs	●	●	●

Continued

Table C.1 (Cont'd) Local EPR Networks – Products Collected

Products Collected	Ottawa, ON	Snohomish County, WA	King County, WA
Lamps	●		
Laser Cartridges	●		
Lawn Mowers, Snowblowers	●		
Light Fixtures	●		
Pagers & Personal Digital Assistants	●		
Power Tools	●		
Telephones & Telecommunications	●		
TVs	●		
Garden Supplies			
Flower Pots	●		
Plastic Flats	●		
Styrofoam Flats	●		
Hazardous			
Gasoline	●		
Kerosene	●		
Lubricating Oil & Filters	●	●	
Paint		●	
Pharmaceuticals	●	●	
Propane Tanks	●	●	
Sharps	●	●	
Thermostats (Mercury Switches)		●	
Health			
Canes	●		
Electric Hospital Beds	●		
Electric Lift Systems	●		
Eyeglasses	●		
Livestock Medication	●		
Mobility Aids	●		
Walkers, Wheelchairs & Parts	●		
Household Products			
Barbecues	●		

Continued

Table C.1 (Cont'd) Local EPR Networks – Products Collected

Products Collected	Ottawa, ON	Snohomish County, WA	King County, WA
Bicycles & Parts	●		
Books	●		
Bubble Wrap	●		
Burlap Coffee & Rice Bags	●		
Camping Gas Cartridges	●		
Clothes Hangers	●		
Dry Cleaning Bags	●		
Plastic Grocery Bags	●		
Scrap Metal	●		
Styrofoam Chips	●		

In Washington state, Snohomish County, King County, Pierce County and the City of Tacoma partnered to form a local Take-It-Back network for electronics.[7] The network is a group of retailers, repair shops, non-profit organizations, waste haulers and recyclers. County officials started the network to provide consumers with convenient recycling opportunities, and, equally important, to encourage the state to adopt a statewide electronics EPR program. (The regulation was adopted in 2006, and the new program, E-Cycle Washington, was launched in January 2009.) Many of the Take it Back Network members participate in E-Cycle Washington and accept computers, monitors, laptops and TVs for free. They also accept additional e-waste for a fee, including printers, mice, keyboards, fax machines, scanners, batteries, etc.

Private Sector Role

Voluntary Take-Back Programs
Private companies are promoting EPR by establishing voluntary take-back programs. Examples include the Rechargeable Battery Recycling Corporation, Tim Horton's packaging recycling program, and London Drugs' take-back program for packaging and e-waste.

Local Processing Capacity
Both the government of British Columbia and the CCME consider local processing capacity and recycling markets to be key criteria when they prioritize new EPR programs.

C.3 Food Waste Programs

Several communities in North America (e.g. Hutchinson, Minnesota) are beginning to collect residential food waste in the same container as curbside yard waste. This is possible in places where processing facilities receiving the materials are permitted to accept both food and yard waste. In addition, a few pilot programs have been implemented around the U.S. collecting residential food waste separately from yard waste. The cost effectiveness of such an approach is still being evaluated.

In Seattle, post-consumer commercial food, such as cafeteria waste contaminated with takeout containers, paper plates, cups, etc. is diverted and processed by co-composting it with yard waste. A key to success with post-consumer food waste is that the containers and cutlery must be compostable. Many products advertise that they are “biodegradable”, although whether or not a material that claims to be biodegradable can *actually* be composted is dependent on the receiving facility and the process. Therefore a material testing and approval program, such as the one managed by Cedar Grove Composting, the private company that processes Seattle’s post-consumer cafeteria waste, is one way to address biodegradable items that are accepted in the food waste container).

The St. Paul Minnesota Public Schools recently implemented a large-scale post-consumer food waste composting program. This school district has more than 42,000 students and 80 different schools. In the 2007/08 school year, 52 schools within the district implemented a food-for-livestock program. Each of these sites has trained its students and staff to source-separate their food waste in their respective cafeterias. The food waste is then cooked per Minnesota Animal Health Standards and fed to pigs. The program received a Governor’s Award and is estimated to reduce the volume of commercial waste needing to be disposed by nearly 30%. This has resulted in savings to the district because of reduced MSW collection costs realized through a resource management program.

Pre-consumer commercial food waste, such as trimmings produced by restaurants and grocery stores, is compatible with a source-separated collection and processing program because it tends to be produced in higher volumes and is not contaminated with packaging. Pre-consumer commercial food waste is therefore well suited to energy and nutrient recovery in processes such as anaerobic digestion and conventional aerobic composting in enclosed systems.

Large-scale food waste diversion, whether collected with yard waste or as a separate commodity, is relatively new in North America. As such, compost facilities are becoming better at managing the material, and energy recovery technologies such as anaerobic digestion, are becoming more financially and operationally viable. As collection and processing capacity develops over time, it is expected that communities will begin to consider mandatory diversion and /or disposal bans for food waste. In this regard, the Regional District of Nanaimo’s commercial food waste ban, implemented in 2005, provides a local example of a community moving ahead with policy tools to support the development of private sector food waste diversion. Implementation of the ban followed regional licensing of the International Composting Corporation in-vessel facility in Nanaimo, BC.[8]

C.4 Curbside Collection Methods and Rate Structures

Enhancements to curbside recycling and refuse collection programs can be used to optimize diversion and manage costs. Variables that can be modified include degree of material separation (source separated, dual stream, single stream), rate structures, collection frequencies, container sizes, and items collected. For example, studies have shown that providing residents with larger collection containers has a direct correlation with increased diversion rates.[9] Use of automated or semi-automated collection systems allows consideration of alternate containers (i.e. matching sets of wheeled toters instead of various combinations of bags and bins).

Degree of Material Separation

Seattle and Portland have implemented single stream recycling programs (i.e. fully co-mingled) with wheeled carts. Single stream recycling is a growing trend that refers to a system in which all paper fibres and containers are mixed together in a collection truck, instead of being sorted into separate commodities (newspaper, cardboard, plastic, glass, etc.) or groups (i.e. fiber and containers) by the resident and handled separately throughout the collection process. In single stream collection, the collection and processing system must be compatible to handle the fully co-mingled mixture of recyclables. Single-stream allows for more efficient fleet utilization and route optimization by reducing the need for specialized recycling collection vehicles and allowing greater volumes of material to be carried on a collection vehicle. Over time, this reduces the energy required during the collection of the material through improved payloads and routing.

On the other hand, there are a number of drawbacks associated with single stream recycling. Notably, single stream recycling typically results in higher processing costs, greater energy consumption, and higher residue rates than dual stream or source separated. With respect to marketing recyclables, program operators may be exposed to greater market risks, a significant concern during market downturns, due to contamination issues and lower quality outputs. For a recent discussion of these issues in a Canadian context, see Lantz 2008.

Pay-As-You Throw

In Seattle, garbage fees are mandatory (i.e. “mandatory pay”). However, residents may choose their own subscription levels for different container sizes (45-litre, 75-litre, 120-litre, 240-litre, 360-litre). Many cities offer a “mini-can” subscription level, with a 70-litre container. Seattle has gone further by offering a 45-litre “micro-can” The micro-can costs $11.05 a month compared to a 96-gallon toter for $52.95. This represents a significant financial incentive to encourage diversion and waste prevention.

One measure of Seattle’s success using a variable can rate to prevent waste is that 62 percent of the City’s residents are one-can customers, 25 percent are mini-can customers, and five percent subscribe to the micro-can service. Only eight percent subscribe to two or more cans of service. These percentages contrast with the situation prior to the introduction of variable rates, when 60 percent of single-family customers subscribed to one can and 39% subscribed to two or more cans.

Austin, Texas represents a mature variable rate, or “Pay-As-You-Throw”, program in North America. The program is designed as an economic incentive to increase diversion. Billing occurs monthly and residents have the choice of three cart sizes. The 2008 base rate of $8.75 per month includes unlimited curbside recycling and yard debris collection. Cart sizes and prices are $4.75 for 30-gallons, $10.00 for 60-gallons, and $16.50 for 90-gallons, and the cart exchange fee is waived for customers seeking smaller cart sizes.

The City of Minneapolis offers a unique program to attempt to reward those who recycle. Residents are billed a flat monthly fee of $23 for solid waste services that includes collection of refuse, recyclable materials, yard waste, and bulky materials. If the resident participates in the recycling program once a month, then they receive a $7 per month credit on their bill. In other words, the resident receives a recycling rebate.

C.5 Multi-Family Residential Programs

Most communities find the implementation of effective multi-family programs to be a challenge. Multi-family recycling and refuse collection tend to be regulated like the commercial sector, but the waste generated is more like the residential sector.

Part of the challenge in the multi-family sector is that there is little direct link between recycling goals or requirements and the behavior of individual tenants. Tenants have little to no control over the location, capacity or convenience of the recycling system at their residence. Property managers and owners have limited influence over the actual recycling and disposal behavior of the tenants. A two-pronged approach including tenant education and oversight of property managers/owners is necessary to overcome these barriers.

Portland, Oregon implemented a strong multi-family recycling program. A City ordinance was passed in 2005 requiring standardized recycling systems at every multifamily property. Glass is collected in one container and all other recyclables (paper, metal, plastic) are commingled in a second container. A consistent and predictable collection system at the multifamily properties makes recycling education for tenants more effective. While all properties must be in compliance, City staff has assisted about one half of the complexes in converting to this standard. All properties are expected to be in compliance by 2010.

Other requirements for multifamily properties include:

- Multifamily property owners are required to provide a recycling system for tenant use at each property.
- The collection system for recyclables must be as convenient as that provided for garbage.
- Property managers are required to provide tenants with recycling education materials within 30 days of move-in, and on an annual basis.

The City of St. Paul, Minnesota has similar standardized collection requirements for multi-family residences, accompanied by mandatory recycling requirements. These have been very effective at enhancing program participation for its multi-family recycling program.

C.6 Commercial Sector Programs

Both Seattle and Portland offer commercial recycling and collection models based on a public sector service delivery model, rather than a fully privatized model. Both cities offer a widely used program whereby businesses that generate low volumes of waste (i.e. < 90 gallons per week) are eligible to contract for less expensive residential type collection, including recycling service.

Both cities provide for commercial collection of recyclables through franchise or contract agreements with private contractors. In Portland, the City has adopted a goal of diverting 75% of the commercial waste stream. A key to this program is that waste haulers providing service within the City are required to collect 14 specifically listed recyclables, report collection volumes to the City, and pay a tip fee surcharge for disposal (no fee is imposed on recyclables). In addition several haulers offer a recycling-only service. Portland is also proposing mandatory business recycling requirements for food, containers, and construction waste. Additional information about mandatory recycling programs is discussed below under Bans and Recycling Requirements.

C.7 Preventing and Diverting DLC waste

There are two primary methods of improving DLC diversion. The first is facility-based, and involves improving customer access to drop-off facilities and support for the development of mixed DLC recycling facilities in the region. This could also involve take-back programs for used building materials at hardware and carpet stores, and/or encouraging the development of salvage and re-use stores.

Common recyclable DLC wastes include lumber, drywall, metals, masonry (brick, concrete, etc.), carpet, plastic, pipe, rocks, dirt, paper, cardboard, and green waste related to land development. DLC recycling facilities typically focus recycling efforts on clean wood, metals, concrete, asphalt, plastic and cardboard. In British Columbia, gypsum drywall is also targeted due the presence of a mature market and the disposal ban.

One example of a "state-of-the-art" DLC facility is Recovery 1, a privately-owned company in Tacoma, Washington. From 1993–2006, Recovery 1 claims an overall recycling rate of 98%. This high rate of diversion is achieved by careful exclusion of asbestos, mercury, and other unacceptable wastes, and by separating materials into over 15 commodities suitable for market. High-achieving facilities such as Recovery 1 are not yet common in the DLC recycling industry, although given the proper set of market conditions and/ or contractual obligations, it may be possible to achieve similar recycling rates.

The second primary method for enhancing DLC diversion is based on directing generator behavior, which can be done with the use of rate incentives, building permit requirements, and market development. This could include such methods as:

- Adopting rate incentives that make disposal of mixed DLC waste more expensive than recycling;
- Mandating submittal of a recycling plan for all building projects over a certain dollar value (as proposed in Seattle and Portland);
- Mandating that DLC waste be delivered only to a licensed recycler and/or demonstrating a certain diversion rate;
- Developing and promoting pilot projects that show the benefit of de-constructing and recycling as compared to demolition (Seattle); and/or
- Developing markets for building products made with recyclable materials.

C.8 Bans and Recycling Requirements

Mandatory recycling requirements and disposal bans have the potential to increase diversion at little cost to government. However, reliable management options must be available upon implementing such an approach.

Mandatory recycling requirements typically require generators to separate a defined list of materials for recycling, or to recycle a certain percentage or number of the materials they generate. Enforcement of mandatory recycling requirements is typically directed at the generator.

Disposal bans prohibit disposal of certain materials and /or limit solid waste loads to a maximum percentage of banned materials. Enforcement of disposal bans is usually directed at collectors, but can focus on generators and / or disposal facilities such as landfills and transfer stations.

Based upon experiences in other communities, it is observed that the most successful disposal bans have certain features in common. It is essential that reasonably available alternatives to disposal exist and are relatively convenient for the generator, the ban and alternatives be widely publicized, support is built among stakeholders such as haulers, businesses, and residents, and a phase-in or grace period is used to introduce the program before strict enforcement is implemented. In general, bans that are enacted without provision for enforcement, or with weak enforcement, are not effective.

In 2003, Portland Metro commissioned a study to determine the impact that mandatory recycling ordinances and disposal bans aimed at the commercial sector have on markets for recycled paper. The 2003 study investigated the impact of mandatory recycling and disposal bans on the quantity, quality, and price of recycled paper in five North American communities, including Greater Vancouver. The study found that these policies increase the amount of commercial fiber recovered, and that they have limited impact on fiber quality or price. Since most programs were adopted concurrently with other enhancements to recycling programs and measurement methodology, the study did not attempt to isolate any specific impact on diversion rates.

C.9 Diversion Programs in Seattle and Portland

In developing projections for the Zero Waste scenario, diversion strategies in use or planned for implementation over the next five years in Seattle and Portland were reviewed. Tables **C.2** through **C.7** list these strategies.

Table C.2 Wood Waste Strategies

Strategy #	Strategies
WOOD-1	Incentivize Development of Private Mixed DLC Debris Recycling Facility
WOOD-2	DLC Waste Pre-processing Requirement for Commingled Material
WOOD-3	DLC Disposal Ban
WOOD-4	Mandatory waste diversion plan for projects over a specified size or value
WOOD-5	Create a Larger Difference Between Disposal Tip Fee and Fee to Dump Source Separated DLC Waste
WOOD-6	Salvage and Reuse Swap Sites
WOOD-7	Market Development for DLC Materials
WOOD-8	Residential On-Demand Collection of DLC Waste
WOOD-9	Building & Demolition Permit DLC Reuse and Recycling Fee Deposit
WOOD-10	Take-Back Program for Used Building Materials at Home Product Centers
WOOD-11	Pre-approved Certification of DLC Recycling Compliant Facilities
WOOD-12	Eco Parks for Resource Sharing and Material Market Development
WOOD-13	Demonstration deconstruction and salvage projects
WOOD-14	Mandatory DLC recycling of 75 percent recycling with improve notification, education and verification of compliance
WOOD-15	Mandatory recycling rate (i.e. 75%) at projects with a permit value over $50,000

Table C.3 Yard Waste Strategies

Strategy #	Strategies
YW-1	Commercial Food and / or Yard Waste Disposal Ban
YW-2	Residential Yard Waste Disposal Ban
YW-3	Expand residential yard waste collection frequency to weekly, year-round in urban areas
YW-4	Set minimum standards for yard waste collection in rural areas
YW-5	Multifamily Food and Yard Waste Collection
YW-6	Commercial Weight-Based Garbage Rates (incorporates disincentive to dispose organics)
YW-7	Volume-Based Rate Structures for Residential Garbage, Organics, and Recyclables Collection
YW-8	Pet Waste Composting
YW-9	Explore options for animal waste. Manage the significant amount of animal waste in community parks.

Table C.4 Food Waste Strategies

Strategy #	Strategies
FOOD-1	Commercial Food and / or Yard Waste Disposal Ban
FOOD-2	Residential Food Waste Disposal Ban
FOOD-3	Commercial Weight-Based Garbage Rates (incorporates disincentive to dispose organics)
FOOD-4	Multifamily Food and Yard Waste Collection
FOOD-5	Residential Curbside Organics Collection to Include All-Food Waste
FOOD-6	Permit Requirement that Restaurants Must Have Food Waste Collection Space and Material Handling Facilities
FOOD-7	Anaerobic Digestion Reactor for Organics Processing and Biofuels Production
FOOD-8	Technical assistance to commercial kitchens
FOOD-9	Commercial food waste collection and composting available
FOOD-10	Establish new mandatory food scrap diversion in commercial waste
FOOD-11	Commercial food scrap collection with subsidized tip fee ($7.50/ton)

Table C.5 Fibre Strategies

Strategy #	Strategies
FIBRE-1	Mandatory Commercial Recycling Container
FIBRE-2	Take-Back Program for Product Packaging by Retail Sellers
FIBRE-3	Establish a new mandatory paper and containers recycling requirement for commercial waste.
FIBRE-4	Commercial haulers required to offer traditional recycling service.
FIBRE-5	Expand Inspection & Enforcement Program, Commercial/Institutional Waste Audits
FIBRE-6	Rate Structure Review for Recyclables Collection
FIBRE-7	Establish the 75 percent commercial recycling requirement as a long-term goal for multifamily
FIBRE-8	Performance-Based Contracting for Solid Waste Service Contracts (Resource Management)
FIBRE-9	Enhanced Waste Screening at Transfer Stations for Exclusion of Banned Recyclables
FIBRE-10	Commercial Weight-Based Garbage Rates (incorporates disincentive to dispose organics)
FIBRE-11	Reusable Transport Packaging
FIBRE-12	Packaging Tax
FIBRE-13	Ban recyclables in residential garbage
FIBRE-14	Single stream residential recycling collection

Table C.6 Plastic Strategies

Strategy #	Strategies
PL-1	Ban PVC Plastic Packaging
PL-2	Take-Back Program for Product Packaging by Retail Sellers
PL-3	Disposal Ban for Recyclables in Commercial Waste
PL-4	Compostable Plastic Bags
PL-5	Subsidize Reusable Diaper Services from Fee on Disposable Diaper Purchases
PL-6	Disposal Ban for Used Oil Bottles
PL-7	Product Ban for Polystyrene To-Go Containers and Single-Serve Foodservice
PL-8	Take-Back Program for Foam Packaging – Negotiate with the Association of Foam Packaging Recyclers
PL-9	Pesticide Container Recycling Program
PL-10	Packaging Tax
PL-11	Add additional plastics to residential recycling program
PL-12	Advance disposal fee on disposable shopping bags
PL-13	Phased ban on plastics in food takeout containers and utensils / shift to compostable disposables
PL-14	Ban recyclables in residential garbage
PL-15	Establish a new mandatory paper and containers recycling requirement for commercial waste.

Table C.7 E-Waste and Appliance Strategies

Strategy #	Strategies
EA-1	Implement expanded EPR
EA-2	Salvage and Reuse Swap Sites
EA-3	List Repair and Recycling Opportunities
EA-4	On-Demand Annual or Biannual Bulky Item Recycling Collection
EA-5	Expand neighborhood recycling events
EA-6	Free toxics "roundup" events throughout the region, including E-waste.

---

[1] Environment Canada. 2007. Extended Producer Responsibility. Accessed at www.ec.gc.ca/epr/default.asp?lang=En&n=EEBCC813-1

[2] British Columbia Ministry of Environment, Office of the Deputy Minister (2007).

[3] Canadian Council of Ministers of the Environment (2009).

[4] Snohomish County, Washington (2009).

[5] King County, Washington (2008).

[6] City of Ottawa, Ontario (2007).

[7] King County, WA; Pierce County, WA; Snohomish County, WA and City of Tacoma (2008).

[8] Regional District of Nanaimo (2008).

[9] R.W. Beck (2004a).

Appendix D:
LCA EXAMPLE – CLEAN WOOD WASTE MANAGEMENT

D.1 Introduction

One of the key material discards in Vancouver region wastes is untreated and unpainted wood ("clean" wood wastes). **Table D.1** provides results for the life cycle climate change impacts analysis of methods for managing clean wood discards in MSW and DLC waste. This appendix provides a discussion of the calculations that yielded the estimates shown in the table as such discussion may illuminate many of the life cycle emissions inventory data sources and the typical LCA methodology used to produce the LCA results in Section 3 of this report. Much of the discussion in this appendix is from Morris (2008a).

The life cycle analysis for wood waste management indicates that there are environmental impacts much beyond the boundaries of the processing or disposal facilities where wood wastes are managed. To fully account for these impacts one needs to examine the entire life cycle of wood products from tree growth through manufacturing of wood products and on to wood products becoming wastes generated from construction and demolition activities or from end-of-life product discards.

Table D.1 GHG Emissions and Emission Offsets – Metro Vancouver Wood Waste

	Recycle To Paper Pulp	Use as Fuel to Replace Nat. Gas	Use as Fuel to Replace Coal	Dispose at BWTEF	Dispose at Vancouver LF (Energy from LFG)	Dispose at Cache Creek LF (Flare LFG)	Dispose at DLC LF (Vent LFG)
	(kilograms eC02 per tonne wood waste)						
Emissions							
Processing & Chipping	70	70	70				
Chip Storage	10	10	10				
Hauling	3	5	5	3	1	14	1
Combustion		34	34	34			
Biodegradation					324	324	134
Energy Generation Equipment				0	0		
Landfill Gas (LFG) Flare						0	
Landfill/WTE Operations				22	33	33	33
Offsets							
Carbon Storage	-1,439				-1,253	-1,253	-626
Tree Harvest	-1,350						
Pulping Wood Production	-46						
Natural Gas Production & Combustion		-1,033		-364	-91		
Coal Production & Combustion			-2,150				
NET EMISSIONS…	**-2,753**	**-914**	**-2,031**	**-327**	**-986**	**-882**	**-453**

This life cycle begins with sequestration of carbon and other substances in trees as they grow. After harvest, the tree wood becomes a feedstock for sawmills to make dimensional lumber and for manufacturers to produce engineered products such as plywood and oriented strand board (OSB). These wood products are used in construction activities where a minor portion becomes scrap as a result of wood being shaped for incorporation in structures. After a time, the remaining major portion also becomes scrap when structures are dismantled during demolition activities.

Table D.1 shows the stages in the wood product life cycle where emissions occur as a result of the management method used for wood waste. All the management options shown in **Table D.1** entail destruction of the scrap wood product so that it can no longer be used for its original purpose. These options involve grinding the wood waste into chips for pulp and paper or for combustion in industrial boilers, burying the waste wood in one of the Vancouver region's landfills where it undergoes biodegradation, or burning the waste wood in the Burnaby WTE facility. As a result new wood products need to be manufactured to take the place of the destroyed products.

Normally, the emissions generated from manufacturing new wood products would need to be included in the life cycle assessment. However, in the case where one is comparing wood waste management options that do not include reuse, these emissions can be disregarded. If reuse of dimensional lumber or engineered wood products were to be analyzed as an option for management of construction and demolition wood wastes, then the emissions from lumber and wood products manufacturing that are avoided through reuse would need to be taken into account.

What cannot be ignored are the other emissions reductions that occur outside the waste management system as a result of choosing one or another of the management options shown in the column headings for **Table D.1**. These emissions reductions are listed in the rows under the Offsets heading in the table.

The first line item in the Offsets is carbon storage. Recycling scrap wood into pulp for papermaking preserves carbon sequestered from the atmosphere during tree growth and stored in wood products. This carbon storage is transferred from wood products into the paper or paperboard products that are manufactured from the pulp produced from chipped wood waste.

Recycling scrap wood into papermaking pulp also preserves an additional amount of sequestered carbon through the avoidance of tree harvesting that would otherwise occur to provide the wood chip inputs for pulp mills. There is an approximate 2 to 1 ratio between the total carbon content taken down in tree harvests and the amount of carbon that remains in manufactured wood products. The estimated GHG emissions savings due to avoided tree harvest is shown as the second offset in **Table D.1**. This amount represents the difference between total carbon in harvested trees and the amount stored in the wood products that continues to be stored when wood product wastes are recycled into pulp for manufacturing of paper and paperboard.

The three landfilling management options also all involve preservation of some of the carbon stored in manufactured wood products. The very slow degradation of wood in a landfill results in carbon remaining stored in the buried wood waste. Thus, these options also get an offset for continued carbon storage. However, landfilling does not avoid additional tree harvests and so does not get the tree harvest offset that recycling does.

In the case of the WTE and industrial fuel combustion options, most of the carbon stored in the wood product waste is liberated as CO2 during the combustion process. However, these CO2 emissions do not count as GHG releases as long as the forests that produce the trees used to manufacture lumber and engineered wood products are sustainably managed. That is, enough trees are growing over a fairly long time frame (100 years is often the reference time period) such that the carbon sequestered by tree uptake as forests grow is at least equal to the carbon released by the harvesting of trees and the ultimate release of carbon from forestry products such as paper and furniture when they reach the end of their useful life and are discarded and burned.[1] In LCA practice the typical assumption is that forests are being sustainably managed so that combustion of forestry products at the end of their useful life is assumed to be climate neutral, i.e., to cause no GHG releases.

The industrial fuel combustion options also get an offset as a result of substituting clean wood chips as a fuel for natural gas or coal. The WTE option gets an offset for avoided use of natural gas in the production of electricity. These offsets include:

- Avoided GHG emissions that would otherwise be generated during fuel resource extraction (mining or drilling), refining and distribution; and
- Avoided GHG emissions that would otherwise be generated during natural gas or coal combustion.

The other offset in **Table D.1** is the avoidance of GHG emissions from energy sources used for tree harvesting operations and preparation of wood pulp for manufacture into papermaking pulp. This avoidance is made possible when wood wastes are processed and chipped for input to pulp mills.

The details on the actual GHG emissions and offsets for each management method shown in **Table D.1** are provided below.

D.2 Discussion of GHG Emissions and Offsets Calculations

D.2.1 Processing and Chipping Wood Waste

The estimate that processing and chipping one tonne of wood waste causes emissions of 70 kilograms (kg) of eCO2 is based on an EPA/NCSU/RTI (2003) estimate of 94 kg GHG emissions for processing recyclables and an estimate by Wihersaari (2005a) that more than 20 kg eCO2 is emitted from the energy used to grind one tonne of naturally dried forestry residues into fuel chips.

The assumption is that the material moving equipment and conveyor systems for processing recyclables and processing wood waste require similar amounts of power. Further, the magnets used for separating commingled recyclables may be equivalent in per ton energy intensity to the magnets used to separate nail fragments from wood chips after grinding wood waste.

However, the two systems differ in that the building for processing recyclables likely is more energy intensive than the building for processing wood waste, because wood sorting operations are often in covered but not enclosed structures. There also are paper and cardboard baling systems, plastic sorting systems and glass sorting systems for recycling. At the same time, there are power requirements for grinding wood, with the attendant eCO2 emissions indicated in Wihersaari's study. Given these pluses and minuses we assumed that processing and chipping wood waste emits 75% of the eCO2 emissions from processing recyclables.

D.2.2 Methane Emissions from Wood Chip Storage Piles

Wihersaari (2005b) reported that methane and nitrous oxide emissions from chip storage piles yielded 150kg eCO2 emissions per tonne of chips from naturally dried forest residues, when the chips were stored in piles for 6 months. This result for forest residues cannot be directly used to estimate GHG releases from storage of chipped DLC wood wastes. However, Wihersaari's research suggests that the potential for GHG releases from finely chipped DLC wood wastes should not be entirely discounted. Even assuming a relatively short storage period, less moisture in DLC wood waste, and lower biodegradation rates for DLC wood compared with forest residues, it still seems prudent to include a nominal amount such as 10kg eCO2 per tonne as an estimate for GHG releases due to methane and nitrous oxide production under anaerobic conditions in DLC wood waste piles. This nominal estimate is a placeholder until actual measurements of GHG emissions from DLC wood waste piles become available.

D.2.3 GHG Emissions from Hauling

The life cycle analysis estimates that GHG emissions for long distance truck hauling amount to under 0.04 kg eCO2 per tonne kilometer (km). One-way mileage for Vancouver region wood waste management methods is assumed to average 50 km for combustion in industrial boilers, 10 km for recycling into papermaking pulp, 15 km for the Burnaby WTE facility plus 27 km for transport of bottom ash to the Vancouver landfill and 350 km for transport of fly ash to Cache Creek landfill (bottom ash weight amounts to 17.3% and fly ash 3.6% of weight of combusted wood[2]), 10 km for Vancouver or Ecowaste landfills, and 350 km for Cache Creek landfill.[3]

In addition, wood wastes recycled for papermaking pulp travel 125 km by barge, as do 20% of wood chips used as industrial fuels. Estimated GHG emission for barge transport is 0.01 per tonne kilometer based on barge transport being four times more fuel efficient than long distance truck transport.

D.2.4 GHG Emissions from Wood Combustion in Industrial Boilers

According to US EPA AP-42 emissions estimates there are a number of GHGs that are released when wood is combusted in industrial boilers. These include, 1,1,1-trichlooethane, carbon tetrachloride, CFC-11, chloroform, methylene chloride, methane, methyl bromide, methyl chloride, and nitrous oxide. In total these releases amount to 34 kg eCO2 per tonne of wood chips.

D.2.5 Carbon Storage and Methane Emissions from Wood in Landfills

According to EPA (2006) 1,253 kg of eCO2 remains stored and does not biodegrade in a tonne of wood landfilled in a well-managed dry-tomb MSW landfill. That same source estimates that a dry tomb MSW landfill that captures 75% of LFGs has fugitive emissions of methane that total 324 kg eCO2 per tonne of wood landfilled.

The DLC landfills used for wood waste disposal in the Vancouver region often bury wood waste below the water table. A recent analysis of this practice by a landill gas management specialist with the consulting firm R. W. Beck, Inc. (Seattle, WA) concluded the following:

> "There is very little supporting documentation regarding methanogenesis of submerged highly cellulosic materials in landfills. While there are construction and demolition landfills containing woody and plant materials that do produce methane, analytical knowledge of the generation potential and rate are for the most part unknown. We know it is small when compared to MSW in a modern sanitary landfill.
>
> "Based on twenty five years of landfill engineering and landfill gas management we also know that the bacterial methanogens are not active or present when moisture conditions are near or at submergence. Numerous landfills having experienced submerged conditions exhibit significantly reduced methane generation. Others that have been excavated below the submergence line show reduced biological degradation, particularly within the woody and highly cellulosic materials. Alternative degradation vehicles may be present (hydrolysis, fungi, acidity) but they do not present methane in significant concentrations.
>
> "Based on these observations, we may conservatively estimate the methane generation for woody and plant materials at between 5 and 10% of that for MSW. Moreover, if these materials are submerged, the rate of methanogenesis may be further reduced."[4]

In addition, some of the wood waste sent to DLC landfills is used for landfill site sculpting or otherwise managed non-anaerobically so that little methane is generated. Based on these practices the Vancouver region DLC landfills are assumed to generate lifetime methane totaling only 10% of the lifetime amounts that an MSW landfill does. On this basis the DLC landfill vents 134 kg eCO2 to the atmosphere for each tonne of landfilled wood waste.

Furthermore, because wood wastes buried in these DLC landfills will be subject to the types of decomposition that occur underwater from the actions of hydrolysis, fungi, and acidity, or will be subject to aerobic decomposition, it is assumed that carbon storage in the DLC landfill will be only half the magnitude of carbon storage in anaerobic conditions in an MSW landfill. This is a conservative estimate because, for example, wood wastes buried in submerged conditions are often found intact when landfills are excavated.

D.2.6 GHG Emissions from Energy Generation Equipment and from LFG Flaring

Because the internal combustion engines (ICE) typically used to generate electricity from landfill gas run on the methane generated by the biodegradation of wood, the conventional approach is to categorize CO2 emissions from ICE exhaust as biogenic as long as the forests used to produce dimensional lumber and engineered wood products are sustainably harvested. On this basis, there are no anthropogenic carbon emissions from the ICEs powered by LFGs.

Similarly, the CO2 emissions from combusting wood in a WTE facility are classified as biogenic, as are the CO2 emissions from flaring captured LFGs.

D.2.7 GHG Emissions from Disposal Facility Operations

EPA's WARM model includes 44 kg eCO2 for collecting, hauling and managing a tonne of garbage at a landfill, and 33kg for the same processes for a WTE facility. Because wood waste hauling emissions are accounted for separately, it is estimated that 33 and 22 kg eCO2 per tonne account for GHG emissions from landfill facility and WTE facility operations, respectively.

D.2.8 GHG Offsets for Carbon Storage

Carbon storage when wood waste is landfilled was covered above. Based on the EPA AP-42 estimate of 0.084 kilograms of biogenic carbon dioxide releases per megajoule (MJ) from wood combustion, and the estimate of 17.16 MJ per kilogram of wood, a tonne of wood waste contains 1,440 kg eCO2. This CO2 continues to be stored in the paper or paperboard that is manufactured from pulp produced from recycled wood waste.

D.2.9 GHG Offsets for Avoided Tree Harvest

According to EPA (2006) recycling one tonne of wood products avoids emissions of 2,790 kg of eCO2 due to reduced harvesting of trees. Wood waste contains 1,440 kg eCO2 per tonne. Thus, recycling wood waste avoids release of an additional 1,350 kg of eCO2 related to carbon that is removed from forests during tree harvest but that is not incorporated into dimensional lumber or engineered wood products.

D.2.10 GHG Offsets for Avoided Production of Forestry Wood for Pulping

According to the EIO-LCA 1997 benchmark model, a million US dollars of purchases from the pulp mill industry (EIOLCA sector 322110) results in generation of 2,094 tonnes eCO2. At an estimated wholesale price for papermaking pulp in 1997 of US$535 per tonne, this amounts to eCO2 releases of 1,120 kg per tonne of virgin pulp.

To estimate the reduction in GHGs when pulp is manufactured from recycled wood chips rather than newly harvested trees, the EIO-LCA model was used to compute the value of logging and lumber industry inputs to the pulping industry per million US dollars of pulp purchases. Inputs from these two industries amounted to, respectively, 9.2% and 4.5% of pulp industry purchases. The EIO-LCA model was next used to calculate eCO2 releases from US$92,000 in purchases from the logging industry and US$45,000 in purchases from lumber manufacturing. This determined that 4.1% of the pulp industry's GHG emissions were embodied in purchases of forestry and lumber making residues. On this basis using recycled wood chips to produce papermaking pulp saves 46 kg eCO2 per tonne of wood chips.

D.2.11 GHG Offsets for Avoided Production and Combustion of Natural Gas

Carnegie Mellon University (CMU) Green Design Institute's EIO-LCA model was also used to estimate GHG releases from production and distribution of natural gas. Emissions from purchases of natural gas from the natural gas distribution industry (EIOLCA sector 221200) amount to 0.35 kg eCO2 per cubic meter of gas, based on a 1997 wholesale price of US$0.16 for a cubic meter.

Chips from wood waste have an average heating value of 17.2 MJ per kilogram, or 17,160 MJ per tonne. Natural Gas has a heating value of 38.4 MJ per cubic meter. Thus, one tonne of wood chips supplant 449 cubic meters of natural gas.

EPA's AP-42 reports CO2 emissions per cubic meter of natural gas combustion at 1.95 kg. Combining production and combustion emissions for natural gas, one tonne of wood chips used as a fuel substitute for natural gas, thus, saves 1,033 kg eCO2.

To estimate the GHG offset for electricity production from landfill gas produced when wood waste is landfilled, US EPA's WARM model was used, with the following adjustment. WARM provides an estimate of the fossil fuel emissions offset from producing electricity with collected landfill gas. That offset is based on the mix of coal, natural gas and petroleum used for electricity generation in the US. However, for the life cycle analysis for Vancouver region waste management methods it is assumed that natural gas is the offset in 2008 and renewables are the offsets in future years.

On that basis the GHG emissions from avoided natural gas combustion amount to 77 kg eCO2. Adding in avoided GHG emissions from natural gas production and distribution, production of electricity via an internal combustion engine powered by landfill gas from wood waste disposed at the Vancouver landfill avoids 91 kg eCO2 that would otherwise be released in 2008 as a result of producing electricity using natural gas as fuel.

Based on WTE being approximately four times as efficient as a landfill at converting a tonne of wood waste disposal into electricity, it is estimated that a tonne of wood waste processed in the Burnaby WTE avoids 364 kg eCO2 that would otherwise be released in 2008 as a result of using natural gas for electricity generation.

WTE avoidance of natural gas is much lower than the avoided natural gas from direct combustion of wood chips in an industrial boiler. This is because a WTE facility is much less efficient at converting a material's heating value to electricity than is the combined cycle natural gas fired turbine used to generate electricity. The heating value of wood is also degraded as a result of wood waste being mixed with other MSW materials that are delivered to the Burnaby WTE facility.

D.2.12 GHG Offsets for Avoided Production and Combustion of Coal

The CMU EIO-LCA model was used to estimate GHG releases from production and distribution of coal. Emissions caused by purchases from the coal mining industry (EIOLCA sector 2i2100) amount to 82 kg eCO2 per tonne, based on a 1997 wholesale price of US$20.00 per tonne.

Chips from wood waste have an average heating value of 17.2 MJ per kilogram, or 17,160 MJ per tonne. Coal's heating value on average is 24.1 MJ per kilogram. Thus, one tonne of wood chips can substitute for 0.71 tonnes of coal.

EPA's AP-42 reports CO2 emissions per tonne of coal at 2,925 kilograms. GHG emissions from coal combustion amount to 2,932 kg eCO2 per tonne, including emissions of other GHGs such as methane, chloroform and nitrous oxide that are released when coal is burned. Combining production and combustion emissions, substituting one tonne of wood chips saves 2,150 kg eCO2 caused by coal combustion.

---

1 In the case of trees killed by pine beetles sustainable harvesting practices may be quite different than in a forest that is not infested with pine beetles.

2 See The Sheltair Group (2008), page 15 and Table 4-1 page 28.

3 Transport trucks delivering waste to Cache Creek backhaul wood chips. Thus, GHG emissions on the backhaul are not a burden for the hauling of wood waste to Cache Creek.

4 Coon, Scott (2009). Personal Communication. R.W. Beck Inc. Seattle, WA

Appendix E: SENSITIVITY ANALYSIS FOR GLOBAL WARMING POTENTIAL OF METHANE

E.1 Introduction

To evaluate the impacts from greenhouse gas (GHG) emissions to the atmosphere, as well as to better communicate the analysis of those impacts to policy makers and the public, life cycle practioneers use global warming potential (GWP) multipliers. GWP multipliers calculate climate change potentials for different pollutants in terms of their climate forcing strength relative to carbon dioxide. For example, according to the latest assessment report from the Intergovernmental Panel on Climate Change (IPCC)[1], methane and nitrous oxide emissions are 25 and 298 times stronger, respectively, than carbon dioxide in terms of their potential impact on the climate in the 100 years following their release to the atmosphere.

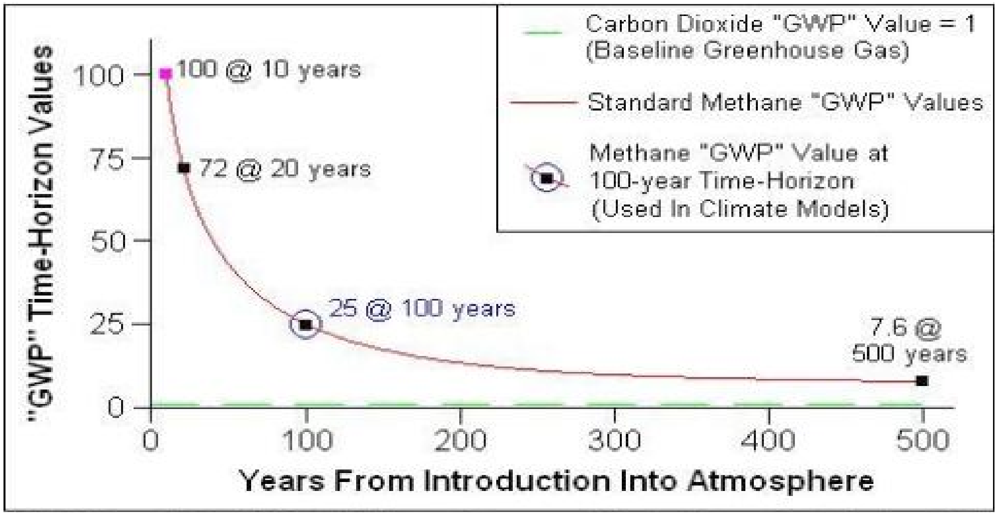
One hundred years is the typical impacts time horizon used in life cycle analysis to evaluate the potential climate change effects from current releases of greenhouse gases to the atmosphere. This is also the time horizon used in the analysis presented in the main body of this report.

However, the 100-year time horizon is not the only time frame possible for examining potential climate change impacts. The same reference table in the IPCC's latest assessment report – the fourth assessment report (AR4) – also lists GWPs for a 20-year time horizon. GWP multipliers for this shorter time horizon for methane and nitrous oxide are 72 and 289, respectively.

These two examples indicate that different GHG pollutants have climate change impacts and corresponding GWPs that can differ substantially depending on how long the effects of current releases are followed. This is due to the differing properties and atmospheric persistence of the various GHGs. Methane is less persistent and, hence, the GWP from current methane emissions is lower the longer the time horizon for evaluating the impacts of current methane releases. **Figure E.1** shows how the impact of current methane emissions relative to current carbon dioxide emissions declines as time passes.

Other GHGs besides nitrous oxide have GWP multipliers relative to carbon dioxide that, unlike methane, are higher for longer time periods. For example, the GWP for sulfur hexafluoride is 16,300 over 20 years, but 22,800 for the 100-year time horizon.

Figure E.1 Global Warming Potential for Methane Over Time



Source: IPCC AR4 Data, IPCC (2007).

To determine whether the conclusions of the life cycle analysis in this study change in any important ways if the time horizon is substantially shorter than 100 years, we calculated life cycle results for GHG releases in 2014 using a 25-year time horizon for the analysis of the impacts of those releases during the year 2014. The 25-year horizon seems appropriate because that period is substantially shorter than the conventional 100-year horizon. In addition, projections by different climate models tend to be in substantial agreement for the next 20 to 30 years. After that, however, models produce more divergent projections for global mean temperature change and resultant negative impacts on the planet such as occurrences of heat waves and precipitation intensity.[2] This suggests that 25 years may be the time limit on human efforts to reduce GHG emissions and prevent climate change catastrophe. Thus, it is important to know whether the life cycle analysis for 25 years produces different results than the analysis using the conventional 100-year time horizon.

E.2 Results of 25-Year Time Horizon for 2014

This section briefly reviews results of the life cycle analysis for 2014 using 25-year time horizon GWPs for greenhouse gas emissions from managing wastes generated in the Vancouver region. The differences in the life cycle calculations between this analysis and the calculations reported in the main body of this report are:

- the use of 25- instead of 100-year time horizon GWPs to compute carbon dioxide equivalents for the GHG emissions from management methods used for wastes generated in 2014, and
- the calculation of total methane emissions over the 25 years following waste disposal instead of over the entire period during which waste disposal today causes future methane releases.

Table 3.1 and **Figure E.2** shows how the 25-year GWP convention affects the average per tonne GHG emissions in 2014, compared to the 100-year GWP convention. Using 100-year GWPs, the two MSW landfills – Vancouver and Cache Creek – reduce GHG emissions by 271 and 267 kg per tonne landfilled, respectively. However, when the climate impacts of methane are considered over a 25-year time period, the Cache Creek landfill reduces GHG emissions by 134 kg, half the 100-year time horizon reduction. The Vancouver landfill actually increases GHG emissions by 200 kg eCO2/tonne under the 25-year scenario.

The Burnaby WTE facility continues to have greater climate change impacts under the 25-year time horizon. MSW combustion increases GHG releases due to emissions of fossil CO2 when plastic and rubber materials in MSW are burned. Climate-changing emissions caused by MSW combustion remain higher than the GHG releases caused by MSW landfilling at the Vancouver landfill, exceeding Vancouver landfill GHG releases by 9%.

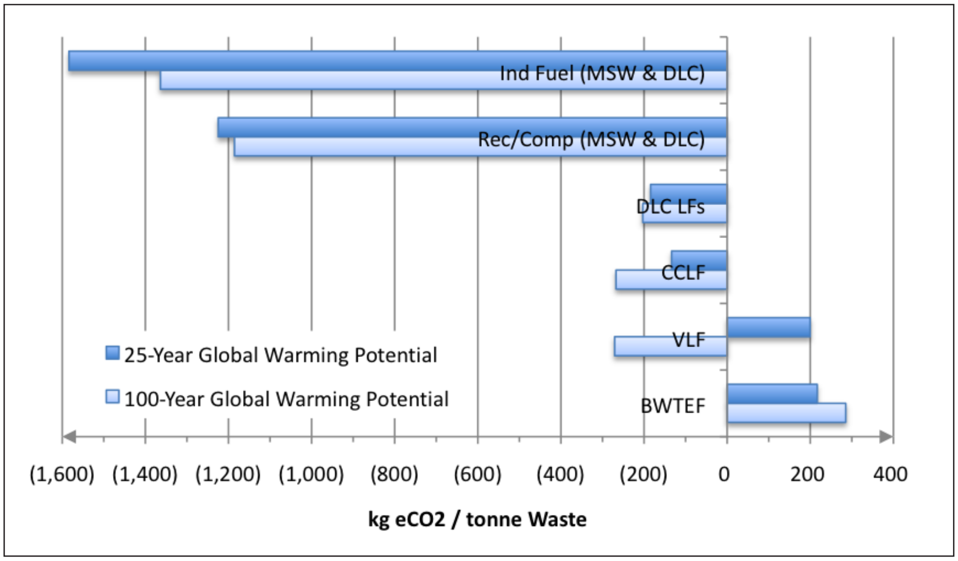
The change in GWP time horizon does not alter the conclusion shown in **Tables 3.1** and **3.2** (in Section 3) that combustion of MSW in the Burnaby WTE facility has greater human health and ecosystem toxicity impacts than burying MSW at the Vancouver or Cache Creek landfills.

Table E.1 Effect of Global Warming Potentials on GHG Estimates (2014)

Management Method	25-Year GWP (kg eCO2 / tonne Waste)		100-Year GWP (kg eCO2 / tonne Waste)	
	MSW	DLC	MSW	DLC
Recycle/Compost	(1,765)	(312)	(1,742)	(252)
Industrial Fuel	(1,122)	(1,613)	(965)	(1,417)
Vancouver MSW LF	200		(271)	—
Cache Creek MSW LF	(134)	—	(267)	—
DLC Landfills	—	(184)	—	(203)
Burnaby WTE Facility	217	—	285	—
System Average	(937)	(503)	(1,029)	(440)

(1) System Average is determined by dividing the Net System Total Potential Emissions by tonnes of waste. The average potential emissions for different waste management methods cannot be added.

Figure E.2 Effect of Global Warming Potentials on GHG Estimates (2014)



E.3 Results of 25-Year Time Horizon Combined with 90% LFG Capture Efficiency

Modern landfills with well-engineered landfill gas (LFG) capture systems achieve higher than 75% LFG capture rates, as discussed in Appendix B. This section reports the climate change impacts of landfilling for a 25-year time horizon with 90% LFG capture rates at the Cache Creek and Vancouver landfills.

Table E.2 provides the results of this combined GHG sensitivity analysis for a 25-year time horizon and 90% landfill gas capture efficiencies compared with the 100-year time horizon and 75% gas capture efficiencies used in the main body of this report. Under the 25-year time horizon and 90% gas capture scenario, both MSW landfills decrease GHG releases more than they do under the 100-year and 75% scenario discussed in the main report. This is because increasing a landfill's lifetime gas capture rate from 75% to 90% reduces fugitive methane emissions by 60% (from 25% of generated LFG down to 10%), resulting in a large drop in damage to the climate from fugitive landfill methane. In the case of the Vancouver landfill, the 60% decrease in fugitive emissions, combined with the additional captured methane available for generating electricity and heat, more than compensate for the higher global warming potential of methane over the 25-year time horizon.

Table E.2 Effect of Global Warming Potentials and Gas Capture Rate on GHG Estimates (2014)

Management Method	25-Year GWP & 90% Gas Capture (kg eCO2 / tonne Waste)		100-Year GWP & 75% Gas Capture (kg eCO2 / tonne Waste)	
	MSW	DLC	MSW	DLC
Recycle/Compost	(1,765)	(312)	(1,742)	(252)
Industrial Fuel	(1,122)	(1,613)	(965)	(1,417)
Vancouver MSW LF	(288)	—	(271)	—
Cache Creek MSW LF	(361)	—	(267)	—
DLC Landfills	—	(184)	—	(203)
Burnaby WTE Facility	217	—	285	—
System Average (1)	(1,066)	(503)	(1,029)	(440)

(1) System Average is determined by dividing the Net System Total Potential Emissions by tonnes of waste. The average potential emissions for different waste management methods cannot be added.

E.4 An Important Note on LCA Methodology for Landfills

One should note that these sensitivity analyses apply to methane releases in 2014 from MSW landfilled in 2014. Because MSW in a landfill decomposes slowly the actual generation of methane from MSW landfilled in 2014 will happen over a subsequent period of years. The length of that period is dependent on the rate of decomposition in the particular landfill. This rate in turn depends on, among other factors, the amount of moisture available for methanogenesis in the landfill.

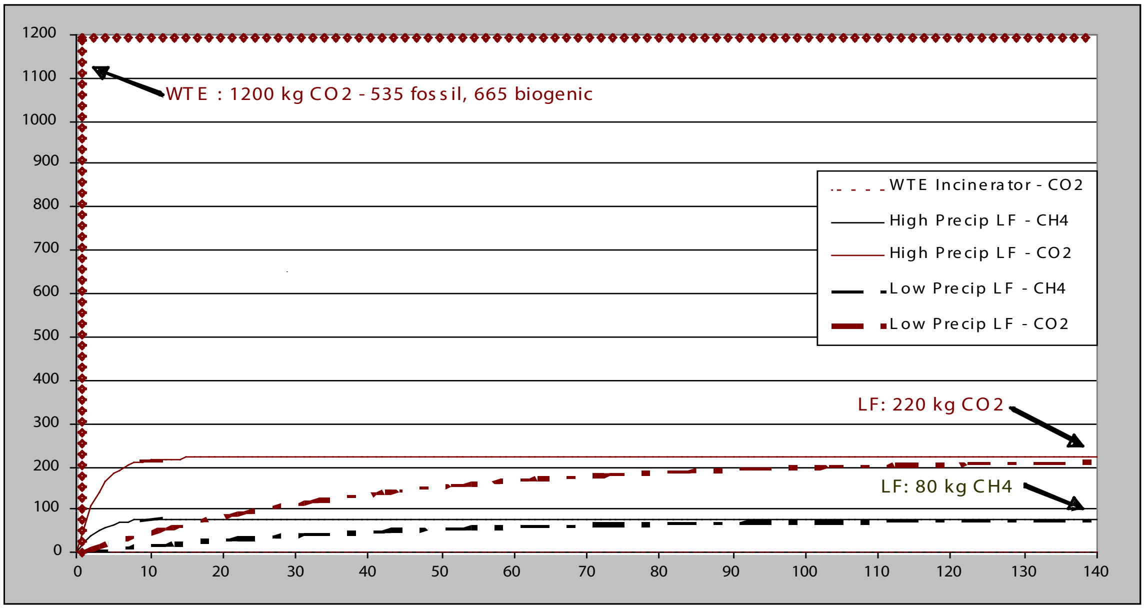
For example, the Vancouver landfill is in an area with much higher annual precipitation than the Cache Creek landfill. This results in the Vancouver landfill generating landfill gases, including methane, at a faster rate than Cache Creek.

In order to calculate the environmental impacts caused by emissions of landfill gases, it is customary in preparing a life cycle analysis to sum the lifetime generation of gases over time from material landfilled at a single point in time. The lifetime emissions sums are then used to characterize the methane generation profile of the landfill for material landfilled at a single point in time.[3]

Using this methodological custom as we have in the main body of this report, it does not matter whether material is landfilled at Cache Creek or Vancouver landfill. The total lifetime generation of landfill gas will be the same in either case. However, in terms of actual methane emissions in the 25 years following the landfilling of MSW it does matter. MSW landfilled at Cache Creek will generate lower amounts of landfill gas over the subsequent 25 years than MSW buried at Vancouver landfill. In fact, generation of landfill gases in general, and methane in particular, at the Vancouver landfill is essentially the same over both the 25- and 100-year time periods due to the high precipitation levels in the Vancouver area. However, methane generation at Cache Creek over the 25-year period is just 48% of lifetime methane generation.

Figure E.3 illustrates this difference by showing the methane (CH4) and CO2 generated over the 140 years following disposal of one tonne of MSW in a landfill in an area with high precipitation levels like Vancouver compared to an area of low precipitation like Cache Creek.[4] The figure indicates that methane generation over 25 years in the dry area landfill amounts to just 48% of the 80 kg of methane generation over a lifetime of 140 years as estimated by LandGEM. Similarly, during the 25 years following disposal of one tonne of MSW the dry area landfill generates just 48% of its lifetime emissions of 220 kg of CO2.

Figure E.3 CO2 and CH4 Generation from MSW Disposal Facilities



In contrast to the two landfills, **Figure E.3** also illustrates the instantaneous generation and release of the much higher 1,200 kg of CO2 when one tonne of MSW is combusted at the Burnaby WTE facility. Based on Metro Vancouver's 2007 waste composition study, one tonne of MSW results in 535 kg of fossil CO2 from combusting fossil-fuel bound materials such as plastics and rubber. The remaining 665 kg of CO2 is biogenic because it comes from combusting non-fossil fuel materials such as wood, paper, yard debris and food scraps. The difference between the two landfills and the WTE incinerator in total generation of carbon emissions is caused by the storage of biogenic carbon in the landfills. Landfill carbon storage is discussed in more detail in Appendix B.

Table E.3 highlights the impact of different LFG capture rates on GHG emissions from landfills, as well as total CO2 emissions over the conventional 100-Year time frame. As indicated in the table, GHG emissions decline substantially as the LFG capture rate increases. The table also shows the result that both GHG and total CO2 equivalent emissions are lower than WTE for landfills in either high or low precipitation areas. The reader should note that the table reflects GHG and CO2 emissions without taking into account GHG offsets from energy generated from WTE combustion of wastes or landfill combustion of captured methane. The table also does not reflect any credit for landfill storage of biogenic carbon that is released when wastes are combusted at a WTE facility.

Table E.3 Effect of LFG Capture Rate on Emissions of GHG CO2 Equivalents and Total CO2 Equivalents Over 100-Year Horizon

	GHGs & Biogenic CO2 Generated (kg eCO2 / tonne Waste)				GHGs & Biogenic CO2 Released to Atmosphere for WTE & High or Low Recipitation Area Landfill (kg eCO2 / tonne Waste)			
	WTE	**High Precipitation Landfill**	**Low Precipitation Landfill**		**WTE**	**75% Landfill Gas Capture**	**90% Landfill Gas Capture**	**100% Landfill Gas Capture**
Fossil CO2	535	—	—		535	—	—	—
Biogenic CO2 (1)	665	220	220		665	395	430	453
Methane (CH4) (2)	—	80	80		—	17	7	0
GHG eCO2 (3)	535	2,000	2,000		535	425	170	0
Total eCO2 (4)	1,200	2,220	2,220		1,200	820	600	453

(1) Includes CO2 from combusting methane in captured landfill gas.
(2) Releases exclude 15% of fugitive methane that is oxidized before reaching the landfill surface.
(3) Reflects carbon dioxide equivalents for climate changing GHGs; thus the figures include fossil CO2 and the CO2 equivalent of methane but exclude biogenic CO2 emissions.
(4) Reflects total carbon dioxide equivalent emissions, including biogenic CO2 as well as GHGs.

Table E.4 provides some additional perspective on the differences between WTE and low-precipitation-area landfills over the 25-year time horizon. In **Table E.4** releases for the low-precipitation-area landfill reflect 25-years of landfill CO2 and methane generation, and the higher GHG multiplier for the 25-year time horizon. The table indicates that the low-precipitation-area landfill has lower GHG and total CO2 equivalent releases than does WTE, even though the calculations for the landfill do not reflect the storage of biogenic carbon that is released when the WTE combusts materials such as wood, paper, and yard debris. The significance of this storage of biogenic carbon in landfills is shown in **Tables E.3** and **E.4** by total eCO2 emissions for the hypothetical landfill that captures and combusts 100% of generated methane versus the total WTE eCO2 emissions of 1,200 kilograms per tonne of MSW burned.

Table E.4 Effect of LFG Capture Rate on Emissions of GHG CO2 equivalents and Total CO2 Equivalents Over 25-Year Horizon

	GHGs & Biogenic CO2 Generated (kg eCO2 / tonne Waste)				GHGs & Biogenic CO2 Released to Atmosphere for WTE & Low Precipitation Area Landfill (kg eCO2 / tonne Waste)			
	WTE	High Precipitation Landfill	Low Precipitation Landfill		WTE	75% Landfill Gas Capture	90% Landfill Gas Capture	100% Landfill Gas Capture
Fossil CO2	535	—	—		535	—	—	—
Biogenic CO2 (1)	665	220	106		665	190	206	217
Methane (CH4) (2)	—	80	38		—	8	3	0
GHG eCO2 (3)	535	5,120	2,458		535	522	209	0
Total eCO2 (4)	1,200	5,340	2,563		1,200	712	415	217

(1) Includes CO2 from combusting methane in captured landfill gas.
(2) Releases exclude 15% of fugitive methane that is oxidized before reaching the landfill surface.
(3) Reflects carbon dioxide equivalents for climate-changing GHGs; thus the figures include fossil CO2 and the CO2 equivalent of methane but exclude biogenic CO2 emissions.
(4) Reflects total carbon dioxide equivalent emissions, including biogenic CO2 as well as GHGs.

---

1 IPCC (2007a), Table 2.14.

2 For global mean temperature projections divergence see SCS (2008), Figure 10. For precipitation intensity and occurrences of heat waves projections divergence see IPCC (2007A), Figures 10.18 and 10.19.

3 This methodological custom could also be thought of as portraying the steady state level of gas generation for a landfill that receives the same amount of waste every year and has been operating long enough that gas generated this year from decomposition of MSW disposed in this year is exactly offset by the decrease in total gas generation this year from MSW landfilled in all previous years.

4 The CH4 and CO2 generation estimates are based on US EPA's LandGEM (Landfill Gas Emissions Model) using the parameter Lo = 130 for potential methane generation capacity due to waste composition for MSW disposal at both landfills, and the methane generation rate parameter k = .35 and .025, respectively, for the high and low precipitation area landfills. These rates of decomposition estimates are based on annual precipitation of 1200 millimeters in the high precipitation area and 270 millimeters in the low precipitation area.

Appendix F: SUMMARY OF LCA RESULTS

In this appendix, **Tables F.1, F.2 and F.3** present the LCA results for the Base Case scenario (2008) and Zero Waste scenario in 2014, 2019, 2024 and 2029. In these tables, the disposal system for the Zero Waste scenario was modeled using the set of MSW and DLC disposal facilities existing under the Base Case, with the same relative waste volume allocations as the Base Case (notably, Vancouver landfill – 41% of MSW; Cache Creek landfill – 38% of MSW; Burnaby WTE facility – 21% of MSW). This hypothetical model was used to calculate environmental emissions of

Table F.1 Base Case and Zero Waste Scenarios - Potential Greenhouse Gas Emissions

	Total Potential Emissions (tonnes eCO2)					Average Potential Emissions Per Tonne(1) (kg eCO2 / tonne waste)				
	2008	**2014**	**2019**	**2024**	**2029**	**2008**	**2014**	**2019**	**2024**	**2029**
MSW System										
Diversion Rate	43%	55%	68%	75%	82%	43%	55%	68%	75%	82%
Recycling/ Composting	(1,758,200)	(2,338,000)	(3,009,100)	(3,453,200)	(3,958,400)	(1,837)	(1,742)	(1,687)	(1,651)	(1,618)
Industrial Fuel	(13,300)	(29,100)	(49,500)	(48,500)	(45,800)	(828)	(965)	(928)	(835)	(745)
Vancouver MSW LF	(143,600)	(126,200)	(77,800)	(66,800)	(57,800)	(270)	(271)	(219)	(221)	(258)
Cache Creek MSW LF	(73,900)	(113,200)	(91,500)	(78,200)	(65,200)	(153)	(267)	(284)	(284)	(320)
Burnaby MSW WTEF	67,600	69,200	97,900	82,900	49,600	244	285	530	526	425
Net System(2)	**(1,921,500)**	**(2,537,300)**	**(3,130,000)**	**(3,563,900)**	**(4,077,600)**	**(848)**	**(1,013)**	**(1,159)**	**(1,235)**	**(1,336)**
DLC System										
Diversion Rate	71%	77%	81%	81%	81%	71%	77%	81%	81%	81%
Recycling/ Composting	(125,000)	(201,800)	(274,000)	(319,600)	(356,900)	(185)	(252)	(304)	(324)	(334)
Industrial Fuel	(264,900)	(321,900)	(321,600)	(344,900)	(348,600)	(1,473)	(1,417)	(1,305)	(1,249)	(1,193)
DLC LFs	(78,200)	(61,200)	(60,000)	(57,800)	(62,100)	(226)	(203)	(211)	(217)	(240)
Net System(2)	**(468,200)**	**(585,000)**	**(655,600)**	**(722,300)**	**(767,600)**	**(389)**	**(440)**	**(458)**	**(472)**	**(474)**
Combined MSW and DLC System										
Diversion Rate	53%	63%	72%	77%	83%	53%	63%	72%	77%	83%
Recycling/ Composting	(1,883,200)	(2,539,800)	(3,283,000)	(3,772,900)	(4,315,300)	(1,152)	(1,186)	(1,223)	(1,225)	(1,228)
Industrial Fuel	(278,300)	(351,000)	(371,100)	(393,400)	(394,300)	(1,420)	(1,364)	(1,238)	(1,177)	(1,115)
Vancouver MSW LF	(143,600)	(126,200)	(77,800)	(66,800)	(57,800)	(270)	(271)	(219)	(221)	(258)
Cache Creek MSW LF	(73,900)	(113,200)	(91,500)	(78,200)	(65,200)	(153)	(267)	(284)	(284)	(320)
DLC LFs	(78,200)	(61,200)	(60,000)	(57,800)	(62,100)	(226)	(203)	(211)	(217)	(240)
Burnaby MSW WTEF	67,600	69,200	97,900	82,900	49,600	244	285	530	526	425
Net System(2)	**(2,389,600)**	**(3,122,300)**	**(3,785,600)**	**(4,286,200)**	**(4,845,200)**	**(689)**	**(815)**	**(916)**	**(971)**	**(1,037)**

(1) Average Potential Emissions per Tonne = Total Potential Emissions / Tonnes of Waste.

(2) Net System: For Total Potential Emissions columns, Net System equals the sum of total emissions by waste management method. (Numbers may not add due to rounding.) For Average Potential Emissions per Tonne columns, Net System equals the Net System Total Potential Emissions divided by tonnes of waste. (Average Potential Emissions for different waste management methods cannot be added.)

facilities on a per tonne basis, which in turn provided the basis for comparison of each waste management facility to other options in that year of the Zero Waste scenario and to the Base Case. See Section 2 (sections 2.2.2 and 2.2.3) for further discussion of disposal system configuration assumptions for the Base Case and Zero Waste scenarios.

Table F.4 shows the results of the Zero Waste scenario for 2029, with volume-based sensitivity analyses for the MSW disposal system. Disposal Sensitivities 1, 2 and 3 show the effects of disposing 100% of residual MSW to the Vancouver landfill, Cache Creek landfill and Burnaby WTE facility, respectively.

Table F.2 Base Case and Zero Waste Scenarios – Potential Human Health Emissions

	Total Potential Emissions (tonnes eToluene)					Average Potential Emissions Per Tonne (kg eToluene / tonne waste)				
	2008	**2014**	**2019**	**2024**	**2029**	**2008**	**2014**	**2019**	**2024**	**2029**
MSW System										
Diversion Rate	43%	55%	68%	75%	82%	43%	55%	68%	75%	82%
Recycling/Composting	(904,400)	(1,245,200)	(1,612,400)	(1,900,300)	(2,192,600)	(945)	(928)	(904)	(908)	(896)
Industrial Fuel	(4,500)	7,100	29,900	34,600	39,500	(276)	235	561	595	643
Vancouver MSW LF	58,700	50,200	40,200	34,700	(500)	110	108	113	114	(2)
Cache Creek MSW LF	2,800	(3,000)	(2,300)	(2,000)	(1,500)	6	(7)	(7)	(7)	(7)
Burnaby MSW WTEF	28,400	23,600	18,300	16,100	12,100	103	97	99	102	104
Net System(2)	**(819,000)**	**(1,167,400)**	**(1,526,300)**	**(1,816,900)**	**(2,142,900)**	**(361)**	**(466)**	**(565)**	**(630)**	**(702)**
DLC System										
Diversion Rate	71%	77%	81%	81%	81%	71%	77%	81%	81%	81%
Recycling/Composting	(61,200)	(104,800)	(131,200)	(158,700)	(186,800)	(90)	(131)	(146)	(161)	(175)
Industrial Fuel	169,600	221,300	255,100	294,300	320,300	943	974	1,035	1,066	1,097
DLC LFs	900	700	700	700	600	2	2	2	2	2
Net System(2)	**109,300**	**117,200**	**124,700**	**136,300**	**134,200**	**91**	**88**	**87**	**89**	**83**
Combined MSW and DLC System										
Diversion Rate	53%	63%	72%	77%	83%	53%	63%	72%	77%	83%
Recycling/Composting	(965,600)	(1,350,100)	(1,743,600)	(2,058,900)	(2,379,400)	(591)	(630)	(649)	(669)	(677)
Industrial Fuel	165,200	228,400	285,100	328,900	359,900	843	887	951	984	1,018
Vancouver MSW LF	58,700	50,200	40,200	34,700	(500)	110	108	113	114	(2)
Cache Creek MSW LF	2,800	(3,000)	(2,300)	(2,000)	(1,500)	6	(7)	(7)	(7)	(7)
DLC LFs	900	700	700	700	600	2	2	2	2	2
Burnaby MSW WTEF	28,400	23,600	18,300	16,100	12,100	103	97	99	102	104
Net System(2)	**(709,700)**	**(1,050,200)**	**(1,401,600)**	**(1,680,600)**	**(2,008,700)**	**(205)**	**(274)**	**(339)**	**(381)**	**(430)**

(1) Average Potential Emissions per Tonne = Total Potential Emissions / Tonnes of Waste.

(2) Net System: For Total Potential Emissions columns, Net System equals the sum of total emissions by waste management method. (Numbers may not add due to rounding.) For Average Potential Emissions columns, Net System equals the Net System Total Potential Emissions divided by tonnes of waste. (Average Potential Emissions for different waste management methods cannot be added.)

Table F.3 Base Case and Zero Waste Scenarios - Potential Ecosystem Toxicity Emissions

	Total Emissions (tonnes e2,4-D)					Average Potential Emissions Per Tonne (kg e2,4-D / tonne waste)				
	2008	**2014**	**2019**	**2024**	**2029**	**2008**	**2014**	**2019**	**2024**	**2029**
MSW System										
Diversion Rate	43%	55%	68%	75%	82%	43%	55%	68%	75%	82%
Recycling/ Composting	(2,100)	(2,900)	(3,500)	(4,000)	(4,500)	(2)	(2)	(2)	(2)	(2)
Industrial Fuel	100	400	1,000	1,100	1,100	6	14	19	19	19
Vancouver MSW LF	<50	<50	<50	<50	>(50)	<0.5	<0.5	<0.5	<0.5	>(0.5)
Cache Creek MSW LF	<50	>(50)	>(50)	>(50)	>(50)	<0.5	>(0.5)	>(0.5)	>(0.5)	>(0.5)
Burnaby MSW WTEF	500	300	300	200	200	2	1	1	1	1
Net System(2)	**(1,500)**	**(2,200)**	**(2,300)**	**(2,700)**	**(3,200)**	**(1)**	**(1)**	**(1)**	**(1)**	**(1)**
DLC System										
Diversion Rate	71%	77%	81%	81%	81%	71%	77%	81%	81%	81%
Recycling/ Composting	(400)	(500)	(500)	(600)	(600)	(1)	(1)	(1)	(1)	(1)
Industrial Fuel	4,900	6,200	6,800	7,600	8,100	27	27	27	28	28
DLC LFs	<50	<50	<50	<50	<50	<0.5	<0.5	<0.5	<0.5	<0.5
Net System(2)	**4,600**	**5,800**	**6,200**	**7,000**	**7,400**	**4**	**4**	**4**	**5**	**5**
Combined MSW and DLC System										
Diversion Rate	53%	63%	72%	77%	83%	53%	63%	72%	77%	83%
Recycling/ Composting	(2,500)	(3,400)	(4,000)	(4,600)	(5,100)	(2)	(2)	(2)	(1)	(1)
Industrial Fuel	5,000	6,600	7,800	8,700	9,200	26	26	26	26	26
Vancouver MSW LF	<50	<50	<50	<50	>(50)	<0.5	<0.5	<0.5	<0.5	>(0.5)
Cache Creek MSW LF	<50	>(50)	>(50)	>(50)	>(50)	<0.5	>(0.5)	>(0.5)	>(0.5)	>(0.5)
DLC LFs	<50	<50	<50	<50	<50	<0.5	<0.5	<0.5	<0.5	<0.5
Burnaby MSW WTEF	500	300	300	200	200	2	1	1	1	1
Net System(2)	**3,000**	**3,600**	**4,000**	**4,300**	**4,200**	**1**	**1**	**1**	**1**	**1**

(1) Average Potential Emissions per Tonne = Total Potential Emissions / Tonnes of Waste.

(2) Net System: For Total Potential Emissions columns, Net System equals the sum of total emissions by waste management method. (Numbers may not add due to rounding.) For Average Potential Emissions per Tonne columns, Net System equals the Net System Total Potential Emissions divided by tonnes of waste. (Average Potential Emissions for different waste management methods cannot be added.)

Table F.4 LCA Results for Zero Waste Scenario at 83% Diversion (2029) with Three Disposal Sensitivity Analyses

Waste Management Method	Waste (tonnes)	Total Potential Emissions (Tonnes)			Average Potential Emissions per Tonne(1) (Kilograms per tonne)		
		Climate Change (eCO2)	Human Health (eToluene)	Ecosystem Toxicity (e2,4-D)	Climate Change (eCO2)	Human Health (eToluene)	Ecosystem Toxicity (e2,4-D)
Disposal Sensitivity 1 – 100% Residual MSW to Vancouver Landfill							
Recycling/Composting	3,514,800	(4,315,300)	(2,379,400)	(5,100)	(1,228)	(677)	(1)
Industrial Fuel	353,500	(394,300)	359,900	9,200	(1,115)	1,018	26
Vancouver MSW LF (100% MSW)	545,200	(140,400)	(1,100)	>(50)	(258)	(2)	>(0.5)
DLC landfills	258,600	(62,100)	600	<50	(240)	2	<0.5
Net System(2)	**4,672,200**	**(4,912,200)**	**(2,020,000)**	**4,100**	**(1,051)**	**(432)**	**1**
Disposal Sensitivity 2 – 100% Residual MSW to Cache Creek Landfill							
Recycling/Composting	3,514,800	(4,315,300)	(2,379,400)	(5,100)	(1,228)	(677)	(1)
Industrial Fuel	353,500	(394,300)	359,900	9,200	(1,115)	1,018	26
Cache Creek MSW LF (100% MSW)	545,200	(174,500)	(3,900)	>(50)	(320)	(7)	>(0.5)
DLC landfills	258,600	(62,100)	600	<50	(240)	2	<0.5
Net System(2)	**4,672,200**	**(4,946,200)**	**(2,022,800)**	**4,000**	**(1,059)**	**(433)**	**1**
Disposal Sensitivity 3 – 100% Residual MSW to Burnaby WTE Facility							
Recycling/Composting	3,514,800	(4,315,300)	(2,379,400)	(5,100)	(1,228)	(677)	(1)
Industrial Fuel	353,500	(394,300)	359,900	9,200	(1,115)	1,018	26
Burnaby WTE (100% MSW)	545,200	231,700	56,600	800	425	104	1
DLC landfills	258,600	(62,100)	600	<50	(240)	2	<0.5
Net System(2)	**4,672,200**	**(4,540,000)**	**(1,962,300)**	**4,900**	**(972)**	**(420)**	**1**

(1) Average Potential Emissions per Tonne = Total Potential Emissions / Tonnes of Waste.

(2) Net System: For Total Potential Emissions columns, Net System equals the sum of total emissions by waste management method. (Numbers may not add due to rounding.) For Average Potential Emissions per Tonne columns, Net System equals the Net System Total Potential Emissions divided by tonnes of waste. (Average Potential Emissions for different waste management methods cannot be added.)