The analysis of the potential of material and energy recovery of municipal waste in Canada

Fowler, Patrick

U N I V E R S I T Y   O F   Z A G R E B

FACULTY OF MECHANICAL ENGINEERING
AND NAVAL ARCHITECTURE

International Master of Science Programme: Sustainable Energy Engineering

THE ANALYSIS OF THE POTENTIAL OF MATERIAL AND ENERGY RECOVERY OF MUNICIPAL WASTE IN CANADA

MASTER THESIS

PATRICK FOWLER

ZAGREB – 2011

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Supervisor:
Prof. dr. sc. SLAVEN DOBROVIĆ

Candidate:
PATRICK FOWLER

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Prof. dr. sc. SLAVEN DOBROVIĆ
Doc. dr. sc. IGOR SUTLOVIĆ

Institution at which work is filled: UNIVERSITY OF ZAGREB, FMENA

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Sustainable Energy Engineering

Zagreb, June 29th, 2010

MASTER THESIS PROPOSAL

Candidate: **Patrick Fowler, dipl. ing.**

Title: **The analysis of the potential of material and energy recovery of municipal waste in Canada**

Thesis Contents:

This thesis will investigate overall potential of material and energy recovery of municipal waste in Canada. The analysis of the potential will include all material and energy flows, but also the emissions of pollutants to the environment as a direct or indirect result of particular treatment of municipal waste.

The introductory part of the thesis will give an explanation of basic terms and definition of the concept of sustainable integrated waste management. Special emphasis will be given to the hierarchy of waste treatment practices in the context of sustainability of particular treatment.

Based on review of recent reports, the thesis will present Canada's current situation in waste management sector, including the comparison with some other countries and the rest of the world. Following chapter will give an overview and description of all major waste treatment practices which will be analysed further on regarding its environmental influence. Special attention of this analysis will be given to the greenhouse gasses emissions related to particular treatment.

The analysis of the potential of material and energy recycling of municipal solid waste in Canada will be done according to the chosen methodology and based on several development scenarios of waste management system. Scenarios differ regarding the quantity of waste being diverted to material or energy recycling. Besides two extremes with maximum diversion towards material and energy recycling, several other scenarios with different shares of treatment practices will be also analysed.

The analysis of each scenarios will include an assessment of material and energy flows and resulting emissions of pollutants with a special emphasis on the greenhouse gases. In the discussion of the results, each scenario has to be evaluated regarding the preservation of natural resources. Based on the comprehensive discussion, conclusion remarks will be given in a way that could help policy makers to create more sustainable surroundings in the waste management sector, especially in the Canada.

Thesis proposed:
Thesis submitted:

Supervisor:	Chairman of Committee for postgraduate studies:	Project Director:
Doc. dr. sc. Slaven Dobrović	Prof. dr. sc. Tomislav Filetin	Prof. dr. sc. Tonko Ćurko

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PREFACE/PURPOSE

This purpose of this final paper is to complete the requirements for the international Master of Science program with specialization in Sustainable Energy Engineering from FSB, University of Zagreb, Croatia.

The aim of this final paper is to demonstrate that the candidate can deal with a particular topic using technical knowledge and professional methods, and consequently prove he or she deserves the degree of MSc SEE.

In this case, the broad topic of *The Analysis of the Potential of Material and Energy Recovery of Municipal Waste in Canada* is suitable in the context of sustainable energy engineering and meets the requirements of the final paper. In addition the results of this paper are placed in the context of the Canadian environment for analysis since it is the author's home country.

Originally the focus of this paper was to explore waste-related products to energy (energy recycling) technologies and elaborate on the greenhouse gas effects of these. However, as is the case with most sustainability topics, a small portion could not be analysed without considering waste-related management as a whole. Therefore, the concepts and hierarchy of waste-related management are explored and a new sustainable hierarchy is developed to ensure waste-related products to energy can be attributed the proper importance relative to other strategies.

Finally, this paper draws conclusions from the three main chapters in order to propose improvements to Canadian waste-related policies. Consequently it hopes to sensitise Canadians to the issues and reduce the environmental impacts of this industry.

SAŽETAK (CROATIAN)

Gospodarenje otpadom složena je problematika koja se značajno razvila tijekom vremena. U suvremenom kontekstu, s okolišem u prvom planu, tradicionalne metode samostalno ne mogu zadovoljiti potrebe. Čak se i naša postojeća definicija i upotreba riječi otpad mora promijeniti. Održivo i integrirano gospodarenje otpadom (Sustainable and integrated waste-related management (SIWRM)) je holistički pristup tradicionalnom gospodarenju otpadom, s jasno definiranim načelima i naglaskom na prevenciju i redukciju.

Uloga otpadnih proizvoda prema energiji (waste-related products to energy (WRPtE)) u toj hijerarhiji održivog i integriranog gospodarenja otpadom je vrlo važna. Također poznate kao recikliranje energije, te tehnologije mogu proizvesti neke opipljive količine energije iz proizvoda koji se inače smatraju otpadom. Moderne tehnologije su projektirane da zadovolje najstrože ekološke standarde te se u većini slučajeva preferiraju kao alternativa samom odlaganju otpada.

Politika Kanade prema WRPtE i SIWRM je neusmjerena i nejasna. Pokrajine su prepuštene same određivati ciljeve, a regije bi trebale razvijati i provoditi svoje planove. Postoji pogodnost u strukturi koja dopušta da strategije budu specifične za regije, međutim utjecaj na okoliš tih aktivnosti mora biti postavljen na nacionalnoj razini, s politikom koja rukovodi regionalnim aktivnostima.

Emisije stakleničkih plinova su globalni problem i industrija povezana s otpadom je veliki neto proizvođač stakleničkih plinova. S pravilnim izborima napravljenim u kontekstu SIWRM-a, ta industrija zapravo može postati korisna. Svaka komponenta prisutna u našim otpadnim/obnovljivim proizvodima (W&RP) ima svoje karakteristike koje se, ako se ispravno iskorištavaju, mogu ponovno koristiti za druge namjene ili reciklirati za dobivanje novih proizvoda ili čak energije.

U Kanadi proizvodimo više otpadnih/obnovljivih proizvoda po stanovniku od većine razvijenih zemalja, dio njih odvajamo s odlagališta, i neke izvozimo u SAD. Industrija je neto proizvođač emisija stakleničkih plinova i trenutne politike promiču odlagališta naspram WRPtE postrojenja, s nejasnim nacionalnim ciljevima za smanjenje otpada, odvajanje ili pretvorbu.

Konačno, ovaj će rad pokazati usporedbu Kanade i drugih zemalja u ovom području, koji je njihov potencijal za odvajanje i emisije stakleničkih plinova za razne scenarije. Preporuke su načinjene kako bi pomogle Kanadi utvrditi ciljeve i razvojne programe u pogledu održive budućnosti.

ABSTRACT/SUMMARY (ENGLISH)

Waste-related management is a complex topic which has evolved significantly over time. In a modern context, with the environment at the forefront, traditional methods alone cannot satisfy the needs. Even our current definition and use of the word *waste* needs to change. Sustainable and integrated waste-related management (SIWRM) is a holistic approach to traditional *waste management*, with clearly defined principles and focus on prevention and reduction.

The role of waste-related products to energy (WRPtE) in this SIWRM hierarchy is very important. Also known as energy recycling, these technologies can produce some tangible quantities of energy from products otherwise considered *waste*. Modern technologies are designed to meet the most stringent environmental standards and in most cases are preferable to landfills as a disposal alternative.

Canada's policy towards WRPtE and SIWRM is unfocused and unclear. Provinces are left to set their own targets and the regions are supposed to develop and implement their own plans. There are benefits to a structure which allows strategies to be region specific however the environmental impact of this activity should be addressed at the national level, with policies to guide the regional activities.

Greenhouse gas (GHG) emissions are a global issue and the waste-related industry is a large net producer of GHGs. With proper choices made within a SIWRM context, this industry can actually become a sink rather than a source. Each component present in our waste & recoverable products (W&RP) has its own characteristics which, if managed correctly, can be re-used for other purposes or recycled to generate new products or even energy.

In Canada we generate more W&RP per capita than most developed nations, we divert a fraction of it from landfill, and we export some to the USA. The industry is a net producer of GHG emissions and current policies promote landfills over WRPtE facilities, with no clear national targets for waste reduction, diversion or conversion.

Ultimately, this paper will demonstrate how Canada compares to other countries in this field, what their potential for diversion is and the associated GHG emissions for various scenarios. Recommendations are made to help Canada establish targets and development programs towards a sustainable future.

KEY WORDS (ENGLISH/CROATIAN)

English	Croatian
Sustainable and Integrated Waste-Related Management	Održivo i integrirano gospodarenje otpadom
Material Recycling	Recikliranje materije
Energy Recycling	Recikliranje energije
Greenhouse Gasses Emissions	Emisije stakleničkih plinova
Waste Management	Gospodarenje otpadom
Waste Related Policy	Politika upravljanja otpadom

LIST OF SYMBOLS & ABBREVIATIONS

AB	Alberta
AD	Anaerobic Digestion
As	Arsenic
BC	British Columbia
BCE	Before the Common Era
BFB	Bubbling Fluidized Bed
C	Carbon
C&D	Construction & Demolition
CA/CAN	Canada
CCME	Canadian Council of Ministers of the Environment
Cd	Cadmium
CE	Common Era
CEE	Central & Eastern Europe
CEPA	Canadian Environmental Protection Act
CFB	Circulating Fluidized Bed
CH_4	Methane
CHP	Combined Heat and Power
Cl	Chlorine
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_{2eq}	Carbon Dioxide Equivalent
Cr	Chromium
Cu	Copper
DDOC	Dissimilated DOC
DOC	Degradable Organic Carbon
EC	Environment Canada
EfW	Energy from Waste
EPR	Extended Producer Responsibility
EU	European Union
F	Fluorine
FB	Fluidized bed
Fe	Iron
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GWP	Global Warming Potential
H	Hydrogen
H2O	Water
H2S	Hydrogen Sulphide
HC	Hydrocarbon
HCl	Hydrogen Chloride
HCN	Hydrogen Cyanide
HDPE	High Density Polyethylene
HF	Hydrogen fluoride
Hg	Mercury

HHV	Higher Heating Value
IC&I	Industrial, Commercial and Institutional
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IWM	Integrated Waste Management
IWMC	Island Waste Management Corporation
K	Potassium
Kt	Kilo ton
LCA	Life Cycle Analysis
LFG	Landfill Gas
LHV	Lower Heating Value
MB	Manitoba
MC	Moisture Content
MRMR	Municipal Refuse Management Regulations
Mt	Mega ton
MW&RP	Municipal Waste & Recoverable Products
N	Nitrogen
NB	New Brunswick
NH_3	Hydrogen Nitride (Ammonia)
NIMBY	Not In My Back Yard
NL	Newfoundland
NO_x	Nitrogen Oxides
NS	Nova Scotia
NWT	Northwest Territories
O	Oxygen
OECD	Organisation for Economic Co-operation and Development
ON	Ontario
P	Phosphorous
Pb	Lead
PEI	Prince Edward Island
PET	Polyethylene Terephthalate
PM	Particulate Matter
ppm	Parts per million
QC	Quebec
RCV	Refuse Collection Vehicle
RDF	Refuse Derived Fuel
RTS	Refuse Transfer Station
S	Sulphur
SIWRM	Sustainable & Integrated Waste-Related Management
SK	Saskatchewan
SO_2	Sulphur Dioxide
TC	Total Carbon
TEQ	Toxicity Equivalent
UK	United Kingdom
UN	United Nations
UNDP	United Nations Development Programme

UNEP	United Nations Environmental Programme
US EPA	United States Environmental Protection Agency
VOC	Volatile Organic Compound
W&RP	Waste & Recoverable Products
WDO	Waste Diversion Ontario
WEEE	Waste Electrical and Electronic Equipment
WRM	Waste-Related Management
WRP	Waste-Related Products
WRPtE	Waste-Related Products to Energy
Zn	Zinc

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CHAPTER 1: INTRODUCTION

1.1 Introduction

As economic activity increases globally, the amenities that westerners have become used to are being desired by developing countries, and rightfully so. The so called “flattening of the earth” has allowed for more people around the globe to contribute and profit in the fast changing global economy. The inevitable consequence is that environmental changes are occurring at an alarming rate. Resources are being depleted, the ice caps are melting, seas are rising, and finely balanced ecosystems are suffering devastating and perhaps irreversible damage. Mother Earth is under siege. All indications point to a continuation of this destructive trend.

The waste we produce is only a portion of the problem, but it’s a critical indicator of both our current lifestyle and our detachment from the environment around us.

Consider the history of man and the evolution of *waste management* [1]. In the beginning, most waste was organic; hunting and food remains and fecal matter, which had an insignificant effect on human health and the environment. Nomadic tribes living off the land would simply relocate when the waste became too excessive. When man began living in caves, wastes would be piled up at the entrances. The inhabitants could move when and if it became a problem. Around 9000 BCE, humans started abandoning their nomadic ways for a more sedentary lifestyle. The change from hunters to farmers and craftsmen increased the amount of waste generated. The stationary lifestyle also required that waste be transported away from the habitations. Rules and best practices had started to emerge and hence *waste management* was born.

As early as 9000 BCE, waste was being taken away from the settlements in an effort to keep insects, bacteria and animals away from the people. The Minoans (3000 – 1000 BCE) would put their waste in a pit and periodically cover it with dirt, which may in fact be the first landfills. Even the Bible has instructions on how to manage human waste (Deuteronomy 23:12-13). Up to this point, wastes were the responsibility of the homeowner. Various laws would only force inhabitants to dispose of their refuse outside of city boundaries. It was the Romans however, in 14 CE, who were the first to commission a common workforce for waste collection.

After the fall of the Roman Empire, Europe fell into a chaos. Knowledge and enforcement of *waste management* was lost. For generations Europeans returned to the old habits of dumping waste in the streets. During this time various laws had been made and revoked to help remediate the situation with little effect. By the 1800's London had a waste policy. Restrictions, laws and penalties were in place to prevent uncontrolled dumping. In 1875, the London Public Health Act mandated that refuse would be placed in bins in front of the homes and would be removed on scheduled days by the Sanitary Authority.

Cities around the world faced the same issues as they expanded, and most came to the same conclusions: Waste needed to be kept off the streets and away from residences. The concept of *waste management* was evolving, since collection, transportation and disposal was now required. This brings us to the system we now know today.

Of significance is the fact that the composition of waste has also evolved over time. Consider that before great civilizations were formed, most refuse was organic and would decay naturally. Non-biodegradable products such as tools, containers and jewellery were made to be durable and useful for a long time. Once industrialization began the activities of mining, quarrying, construction, demolition, agriculture and extraction, processing and combustion of fossil fuels produced some non degradable by-products. By the late 1800's the first commercial plastics were invented and we have not looked back since.

This is also the point in history where humans stopped throwing out only waste. When the extraction of resources surpassed our needs, we started discarding formerly reusable and recyclable products. From the industrial revolution on, humans have been increasingly disposing of Waste & Recoverable Products. We are no longer in an age of "waste" management as it has been historically known. Our traditional use of the word *waste* needs to be reviewed. The use of the word implies that a product is no longer useful, and *waste* is used to define everything, including recyclables and reusables. This will be reviewed later on in this chapter.

Currently, on a global scale, we generate approximately 1.55 billion tons of Municipal Waste & Recoverable Products (MW&RP) each year [2]. This figure includes, in general, only the Waste & Recoverable Products (W&RP) that enter the municipal streams (residential, institutional, commercial and light industry) and excludes those produced and managed otherwise (e.g. from large industry, mining, agriculture, energy production, some construction and demolition waste, etc.). Consequently, MW&RP accounts for only a small portion of the total W&RP generated in a country. Figures ranging from 5% to 26% have been observed [3], and these can be related to the Gross Domestic Product (GDP) of the country [4]. It is estimated that the world produces approximately 7.3 billion tons of W&RP annually. If the rest of the world was as wasteful as North Americans, it is estimated that we would produce 24.6 billion tons of W&RP per year.

Today, 49% of the world's population live in urban centres and the number is much higher in developed countries (75% to 85%) [5]. In addition, the number of megacities (more than 10,000,000 inhabitants) around the world is growing. In the 1950's New York was the only one, but in 1985 there were 9, in 2004 it was 19 and in 2005 up to 25. The trend is moving towards heavy urbanization (75% to 85% of the total population) living in cities. The next generation is known as hypercities (20 million or more). It is expected that by 2025 Asia alone will have 10 hypercities. These numbers are staggering.

As civilizations evolve, the standard of life and the population increases, so will the quantity of W&RP we generate. Moreover, as a rising number of people start living in dense urban centers the various W&RP management options will be limited. Today many parts of the developed world are struggling to gain a proper grasp of their W&RP management issues. Even in Canada, the existing infrastructures are stretched, landfills are becoming less popular, transportation is expensive and the impact on climate change is a growing concern.

"The need to develop sustainable *waste management* strategies and policies is being recognized on an increasing basis worldwide. For the first time, human activity is sufficiently great to have a real and recognizable impact on the global environment. Sustainable practices are becoming an actual requirement rather than simply a theoretical principle." [6].

So what are the appropriate sustainable waste-related management practices? What are Canada's policies regarding waste-related management? What are the environmental impacts of all this? This thesis will attempt to provide some answers.

The initial intent of this paper was to discuss waste-to-energy technologies. However, in the author's opinion waste and recoverable products to energy (WRPtE) are only one aspect of the *waste* issue and certainly not the only solution. Although integral to the concept of waste-related management, the importance of WRPtE technologies can only be understood in the context of the whole integrated system. This paper will discuss the concepts of waste-related management in detail and describe where WRPtE fits within it, before elaborating on this topic.

This paper is divided into five chapters;

Chapter 1: Introduction

Explains the genesis of waste-related management, proposes a new approach to the definition of the word *waste* and explains the methodology used in this paper.

Chapter 2: Waste-Related Management & Energy Recycling

Starting with the historical and traditional approach to waste-related management, the concepts of sustainable and integrated waste-related management are introduced and the role of energy recycling in the hierarchy is established. A special focus is given to the current and future waste-related products to energy technologies and challenges.

Chapter 3: Canadian Sustainable and Integrated Waste-Related Management Policy

Will explore the various Canadian policies regarding waste-related management on a national and provincial scale. The Canadian performance is compared against other developed countries.

Chapter 4: Greenhouse Gas Emissions from Waste-Related Management

In this chapter a model is developed to estimate the GHG emissions related to various waste-related management activities. Using this model, seven scenarios with varying degrees of diversion and energy recycling are analysed for the Canadian environment.

Chapter 5: Conclusions and Recommendations

Summarises the results from the previous chapters and concludes on the sustainability, policy and GHG emission situation in Canada. Recommendations are made for Canada to achieve an optimal sustainable and integrated waste-related management scheme.

1.2 Background

The United Nations Development Program collects data on the Municipal Waste & Recoverable Products (MW&RP) generated for countries around the world [7]. Figure 1-1 shows the estimated MW&RP generated. Some adjustments were made since not all countries reported data [2]. This represents a total in excess of 1.5 billion tons of MW&RP produced each year. Assuming an average density of 100 kg/m^3 [8], this represents almost 15.5 billion m^3 of W&RP. Furthermore, consider that if the rest of the world was as wasteful as North Americans (592 kg/capita), we would produce approximately 3.7 billion tons of MW&RP each year, enough to cover the country of Taiwan in one (1) meter of garbage.

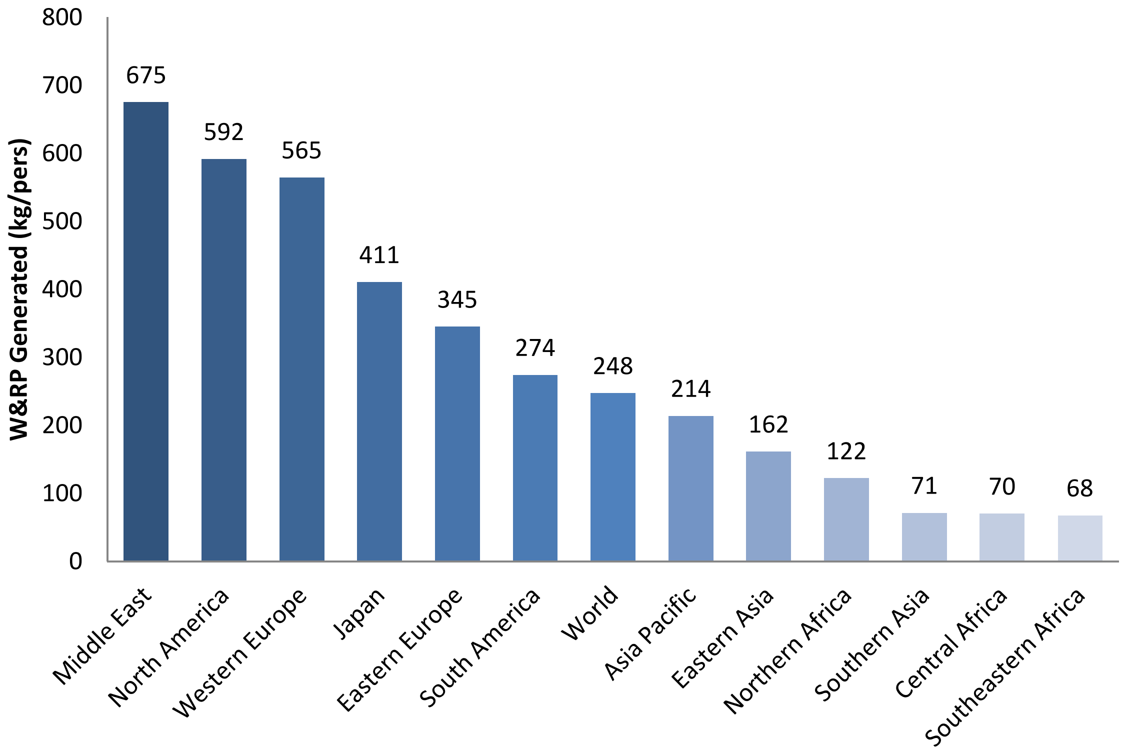

Figure 1-1: Municipal W&RP generated per person around the world (2002)

Although MW&RP is a valid measure used to compare wastefulness, it is only a small part of the story. In Western Europe (WE) MW&RP accounts for only 14% of the total *waste* produced (excluding agricultural W&RP), see Figure 1-2 [3]. If we included the other 86%, each resident in WE is responsible, on average, for 3.8 tons of W&RP generated annually, considerably larger than 565 kg/person noted in Figure 1-1.

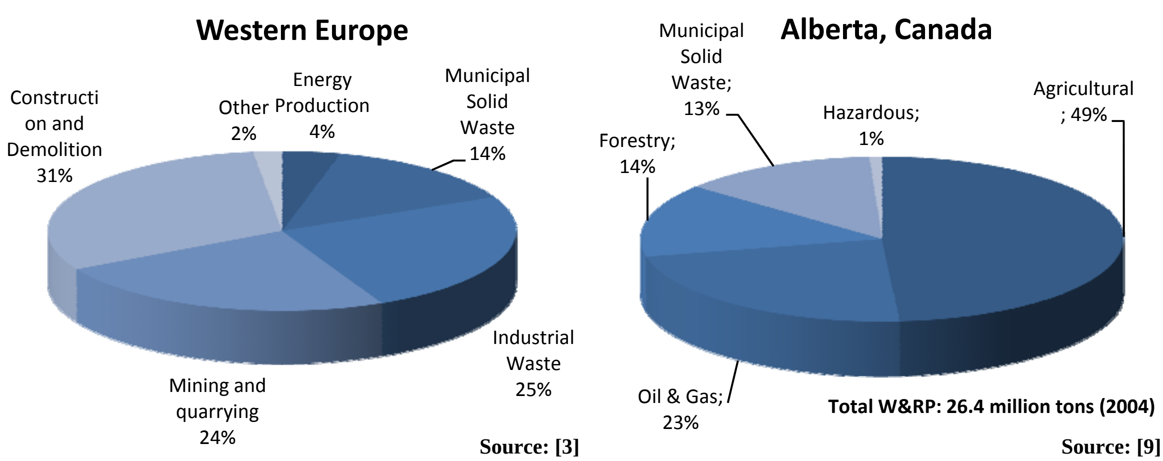

Figure 1-2: Waste Produced in Western Europe (left) and in Alberta, Canada (right)

The WE figures coincide well with the province of Alberta in Canada [9], where MW&RP accounts for 13% of the total, Figure 1-2 (however agricultural W&RP is included in Alberta's totals). This means that each Albertan is responsible for 8,251 kg/yr of W&RP. If the agriculture component is removed from the equation (to compare with WE), Alberta MW&RP would represent 26% of the total mix and each resident would be responsible for producing 4.2 tons of W&RP per year. This tends to imply that Albertans do not have as much industry as Western Europeans have or Albertans generate much more municipal waste than Western Europeans.

At the other end of the spectrum, in Central & Eastern Europe (CEE) the figures tell a different tale. There, each person is responsible for 4.4 tons per year of waste [3]. Although more overall than for Western Europe, only 5% of this accounts for MW&RP [3], see Figure 1-3. Almost half the waste generated in CEE is from the mining and quarrying sector, giving the reader an indication of the type of regional economy.

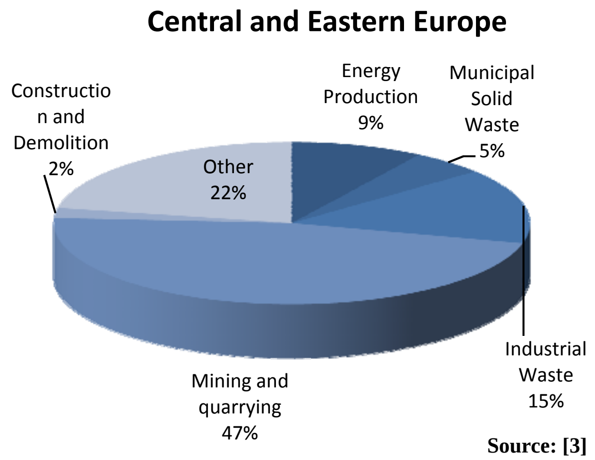

Figure 1-3: Waste Produced in Central and Eastern Europe

To summarise the last three figures, they have shown that MW&RP accounts for 5% to 26% of the total, excluding agricultural W&RP, and these figures seem to be linked to the type of economy within the country. That said, if we assume that MW&RP in most developed countries accounts for only 15% on average of the total, it seems that in reality we produce approximately 7.3 billion tons of W&RP annually. Following the same logic as above, if the rest of the world was as wasteful as North America the numbers are staggering: 24.6 billion tons of W&RP would be generated per year, enough to cover Taiwan in seven (7) meters deep of garbage.

Luckily, this is not the case...yet.

Although shocking, these numbers represent total generated W&RP and do not account for any diversion efforts. Since diversion figures vary greatly depending on the country, they are not considered in the above calculations. These elements will be discussed later in chapter 3. However, it is clear from Figure 1-1 that North Americans are amongst the most wasteful in the world and recent figures show that our diversion efforts are fairly poor. Canada diverted 24% of its W&RP generated from landfill in 2004 [10] and the USA 33% (2006) [11] compared to the EU-25 39% (2004) [12].

These numbers only show what was actually achieved, but what about the potential for diverting W&RP? In Canada, Figure 1-4 shows the breakdown of MW&RP that was sent to landfill or incinerated in 2002. Out of 30.7 million tons of MW&RP generated, only 6.6 million tons (21%) were diverted from landfill either by recycling or composting [13]. Of the material that was sent for disposal, 46% is considered recyclable, 28% is kitchen and yard residues and the remaining 26% can be classified as non-recoverable matter. This means that 74% of the MW&RP sent for disposal (landfill or incineration) in 2002 was compostable or recyclable. There is much room for improvement.

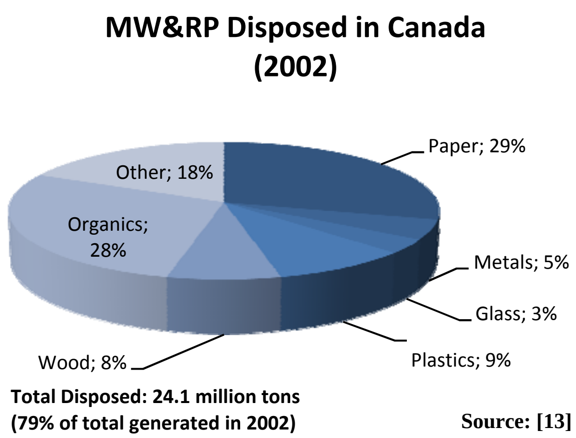

Figure 1-4: MW&RP sent for disposal in Canada (2002)

To make matters worse, the amount of W&RP being generated (per capita) is on the rise, despite increasing diversion efforts. According to the OECD (2004) MW&RP produced was up by approximately 54% between 1980 and 2000 in OECD countries [14]. Even though the report suggests that this trend is slowing down, the point remains that we continue to generate more W&RP.

Another study estimated that each year only 6% of all raw materials consumed in the USA end up as usable products [15]. Of this, only 1% actually ends up as durable products [16]. What is not transformed is “waste” in one form or another. When considering that 99% of all raw materials used are wasted in an economy the size of the United States, the magnitude of the problem becomes clear. [17].

In the Canadian example above, of the 30.7 million tons generated in 2002; 0.7 were incinerated, 1.6 were exported to the US and 21.8 were landfilled, most of which was recoverable [10]. Three things are very troubling about these statistics:

- First, only 21% of the potentially 80% recoverable materials were diverted from disposal,
- Second, a country such as Canada with large amounts of land, still finds a need to export 5% of its W&RP,
- Third, 97% of W&RP disposal was buried in the ground.

As a nation that prides itself on its natural beauty, Canada cannot be proud of this performance.

What does the analysis above reveal?

- The developed world generates too much W&RP,
- This trend is rising (the developing world is adopting our bad habits),
- We send the majority of recoverable materials for disposal,
- We still believe that a landfill is an acceptable solution for W&RP disposal.

Something needs to be done. The purpose of this paper is to identify what are the best practices in general, with a focus on the Canadian situation.

Let's begin with our current, misuse of the word *waste*.

1.3 Definitions

This section explores and defines the key terms used in this paper. Special focus is given to the definition of *waste* as it is fundamental to any discussion on the topic.

1.3.1 Waste – Uses of the word

What is the definition of *waste*? The dictionary defines waste as something "regarded or discarded as worthless or useless". This seems to fit quite well with our current use and understanding of the word. Now consider the use of *waste* in *municipal solid waste (MSW).* Does MSW not include recyclables and compostable material? Paper, for example, is not useless or worthless. On the contrary it is a resource, not a *waste*. Globally, and certainly in Canada, the term seems to be applied liberally, arbitrarily and inconsistently.

Perhaps the most widely accepted definition of *waste* today is that of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, which Canada ratified in 1992. It proposes the following; "*Wastes* are substances or objects which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law." [21].

The United Nations defines *municipal waste* as follows;

> "*Municipal waste* includes household waste and similar waste. The definition also includes bulky waste (e.g. white goods, old furniture, mattresses) and yard waste, leaves, grass clippings, street sweepings, the content of litter containers, and market cleansing waste, if managed as waste. It includes waste originating from: households, commerce and trade, small businesses, office buildings and institutions (schools, hospitals, government buildings). It also includes waste from selected municipal services, e.g. waste from park and garden maintenance, waste from street cleaning services (street sweepings, the content of litter containers, market cleansing waste), if managed as waste. The definition excludes waste from municipal sewage network and treatment, municipal construction and demolition waste."

Another example is Environment Canada, which refers to *municipal solid waste* as; "recyclables and compostable materials, as well as garbage from homes, businesses, institutions, and construction and demolition sites" [22].

The EU Waste Framework Directive (European Directive 2006/12/EC) defines *waste* as; "Any substance or object the holder discards, intends to discard or is required to discard" [23]. This implies anything that is thrown out, including recoverable materials.

In all these examples, *waste* is used to describe both unusable and recoverable materials. The appropriate definition of the word *waste* should mean only materials that are useless. Clearly the word *waste* is being applied inappropriately in our every day terminology.

CEPA the Canadian Environmental Protection Act on the other hand, bases itself on the Basel Convection but clarifies that; "W*aste* means any material that is disposed, destined for disposal, or is required to be disposed, and does not include recyclable material or any material used for its original purpose" [24]. It's troubling, that many other Canadian publications still include recyclables within their description of waste.

Our current misuse of the word may be contributing to our wasteful habits. Consider that many publications refer to materials that are recovered as *diverted waste*. There are two major problems with this;

- Firstly, it reinforces the concept that everything we choose to get rid of is automatically *waste*. Something that is *recoverable* should never be referred to as a *waste*, since it precludes that it is useless.
- Secondly, it promotes the perception that not sending *waste* for disposal is a positive. Whereas the opposite should be our goal – preventing *recoverables* from being disposed.

Hence, *diverted waste* could be referred to as *recovered recyclables*, for example. It is a nuance but consider the impact of using the term *disposed recyclables* for recoverable materials sent for disposal and hence a negative thing. It is far more representative of what is taking place, and is an important step towards our next stage of *waste & recoverable products management*.

For all the examples above, additional definitions are provided for recyclables, diverted materials, compostable and recoverable materials to name a few, but they are still defined as *waste* at the outset.

Many critics believe that this is a part of the problem. Pongrácz and Pohjola [25] write that the current definition of *waste* at the European Union level is inappropriate and actually prevents the EU from attaining a sustainable *waste* management structure. They argue that current legislative definitions of *waste* dictate the manner in which *waste* must be handled. And although the European legislations are there to monitor and control the safe de-evolution of *waste*, they can in many cases inhibit recyclables, compostable and potentially hazardous materials, from their optimum treatment, simply because they are labelled *waste*. They continue to say;

> "By accepting that the way waste is described, prescribes the way it is handled; waste related activities need to be based on radical new waste definitions: Purpose readjustment without Structure manipulation to make Performance satisfactory, or readjustment of Structure by accepting current Purpose. *Waste management* can now

be defined as control of waste-related activities with the aim of protecting the environment and human health, and encouraging resource conservation."

This alters mainly the perception one must have towards *waste* management in a sustainable context, and will be explored later in this paper. The point is that if something is labelled *waste*, then it is assumed (intentional or not) that it is destined for disposal.

It is clear that the word *waste* can be improperly used and needs to be applied with purpose.

1.3.2 Waste-Related Definitions

Some of the current definitions used in *waste management* are prohibitive to the development of a sustainable system. More importantly, using improper definitions dilutes the focus and impact of this paper. The following intuitive definitions will be used throughout this paper.

Waste has been defined by other experts on the topic as: "a man-made thing, which in a given time and place, in its actual Structure and State, is not useful to its owner, or an output that does not have any owner." [25]. In this case, the concept of ownership is quite important. However, for simplicity the following definition will be used;

Unrecoverable Materials or Waste: materials that cannot be reused for any other means, in other words *residual waste*.

Waste & Recoverable Products (W&RP): All that is the by-product of a process or activity and refers to both recoverable materials and residual waste. This consciously includes all materials and is used instead of the traditional term *waste*. For example, agriculture waste & recoverable products (instead of agricultural waste) or waste & recoverable products generated (instead of waste generated).

Waste-related products or activities: is used synonymously with waste & recoverable products.

Municipal Waste & Recoverable Products (MW&RP): Formally known as Municipal Solid Waste (MSW) or municipal waste. The definition for MW&RP is the same as MSW, but the name is revised to be more accurate. MW&RP refers to waste and recoverable products collected by or on behalf of municipalities as well as those collected by the private sector. MW&RP includes household, light industrial, commercial and institutional waste, recyclables, compostable and recoverable materials that enter the municipal streams (may also include construction and demolition). The waste and recoverable products managed onsite and privately are not included, such as: agricultural, large industry, mining, quarrying, energy production, etc.

Waste-Related Management: The management of waste-related activities, which includes: public education, collection, transport, material recovery and residual waste disposal (for as long as the material is still considered *waste)*.

Sustainable & Integrated Waste-Related Management (SIWRM): waste-related management practices that protect human health and the environment by meeting the needs of today, without compromising the ability of future generations to meet their own needs (adapted from The World Commission on Environment and Development, Brundtland Commission 1987).

1.4 Methodology

The following section is a brief description of the methodology used to research for and write this paper.

1.4.1 Literature Review

The present paper is mainly a literary review of previously published papers, articles, reports, websites, books, etc. However, chapter 4 develops and discusses a model used to estimate GHG emissions; the methodology used is explained there. The purpose of this paper is to analytically review the topic of waste-related activities, in particular the context of sustainability, waste & recoverable products to energy (WRPtE) technologies and policy. All information referred to is properly referenced at the end of this paper.

1.4.2 Basis for Comparison

Throughout this paper, information is analysed and compared in order to draw educated conclusions on waste-related activities in Canada and the world. As is often the case, there are discrepancies between the data from independent studies. Within the context of waste-related information the differences are even more pronounced [26].

As a matter of comparison, Statistics Canada[i] reported that in 2004 Canadians generated an average 1,037 kg/person of Municipal Waste & Recoverable Products (MW&RP) [27].

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[i] Statistics Canada is the national body responsible for Canadian Statistics

Another figure based on the OECD Environmental Data Compendium: 2002 places Canada at 640 kg/person per year [28]. A third compilation from The United Nations Statistics Division places Canada at 423 kg/person [7], using Statistics Canada information.

Why are these numbers so drastically different? At first let's compare the definitions of "municipal waste". All three use the definition[ii] of MW&RP as stated in the previous section as a baseline, except that Statistics Canada includes construction and demolition waste-related products whereas the others do not. In the UN report, it is unclear if recoverable materials are excluded. With regard to the age of the data, the OECD Compendium information is based on Canadian data from the 1990's, whereas the other two are from 2004.

Hence it could be argued that the Statistics Canada data is higher since it includes construction and demolition waste-related products. By removing this content, the numbers would be closer to the OECD information. However, the actual contribution of this sector to the W&RP is unclear. As for the OECD information, it could easily be out of date and unusable. Finally for the UN figures, if construction and demolition products are excluded, as well as recovered materials then the figures may match up with the ones from Statistics Canada of the same year, however this is also not clear.

This is just an example of the issues facing this industry. Information is scattered, definitions are inconsistent, which consequently impacts the conclusions. On the other hand, this

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[ii] Statistics Canada: Includes residential and not-residential waste "Residential waste includes solid waste from residential sources, which includes all households, and includes waste that is picked up by the municipality (either using its own staff or through contracting firms) and waste from residential sources that is taken by the generator to depots, transfer stations and disposal facilities. Non-residential waste includes municipal solid non-hazardous waste generated by industrial, commercial and institutional sources as well as waste generated by construction and demolition activities.

OECD Compendium: "Municipal waste is waste collected by or on the order of municipalities. It includes waste originating from households, commercial activities, office buildings, institutions such as schools and government buildings, and small businesses that dispose of waste at the same facilities used for municipally collected waste. Household waste is waste generated by the domestic activity of households. It includes garbage, bulky waste and separately collected waste. National definitions may differ. Amounts per capita are rounded."

United Nations: "Municipal waste includes household waste and similar waste. The definition also includes bulky waste (e.g. white goods, old furniture, mattresses) and yard waste, leaves, grass clippings, street sweepings, the content of litter containers, and market cleansing waste, if managed as waste. It includes waste originating from: households, commerce and trade, small businesses, office buildings and institutions (schools, hospitals, government buildings). It also includes waste from selected municipal services, e.g. waste from park and garden maintenance, waste from street cleaning services (street sweepings, the content of litter containers, market cleansing waste), if managed as waste. The definition excludes waste from municipal sewage network and treatment, municipal construction and demolition waste."

example shows that with a little reasoning, the differences can be explained to a certain degree. But the point remains that finding the exact information is not easy. Even within Canadian data, things are contradictory and often hard to confirm. Municipal, provincial and national reports can differ by large amounts, depending on the method of measure used.

Fortunately the purpose of this paper is not to qualify the accuracy of this data and the conclusions do not hinge on their accuracy. The figures and tables used here are for comparative and discussion purposes. Whenever possible, the same source will be used as a consistent means for comparison and in all cases, the assumptions made and context of the information are elaborated throughout.

1.5 Summary

The following chapters are intended to elaborate on the topics of sustainable and integrated waste-related management, waste-related products to energy technology, Canadian waste-related policy and greenhouse gas emissions associated with waster-related activities. Ultimately, this paper will demonstrate how Canada compares to other countries in this field, what their potential for diversion is and the associated greenhouse gas emissions for various scenarios. Subsequently, recommendations are made to help Canada establish targets and policies towards a sustainable future.

CHAPTER 2: SUSTAINABLE AND INTEGRATED WASTE RELATED MANAGEMENT

2.1 Introduction

Waste-related management is a very broad topic with many components and avenues to explore. The concepts and goals have changed over time, mainly out of need, to address new types of waste-related products and increasing volumes. In general the prime movers in this field have been financial with the environmental as a side effect.

Today, the environment is of growing concern and traditional waste-related management systems are inadequate. To address these needs the concept of Sustainable & Integrated Waste-Related Management (SIWRM) is explored. SIWRM is the implementation of waste-related management practices that protect human health and the environment by meeting the needs of today, without compromising the ability of future generations to meet their own needs. The first part of this chapter will deal with this.

The second part of this chapter investigates the role of energy recycling or Waste-Related Products to Energy (WRPtE) in the SIWRM scheme. Although not desirable, the reality is that we currently and for the foreseeable future require the permanent disposal of some Waste & Recoverable Products (W&RP). Since it is the most environmentally questionable element of any waste-related management strategy it deserves special attention. Therefore a large portion of this chapter is dedicated to exploring the various disposal and energy recycling strategies and technologies.

The main goals of this chapter are for the reader to understand why sustainable and integrated waste-related management is important and the role that energy recycling plays in all this.

2.2 Current Waste-Related Management Systems

2.2.1 A brief History

The activities of waste-related management were started as early as 9000 BCE with the rise of the great Mesopotamia and Egyptian civilizations. It was recognized that waste was a growing concern in urban centers. Dumps were created away from the settlements in an effort to keep animals, insects and bacteria from the people. Even in 14 CE, the Romans commissioned a common workforce to collect and transport the waste, which had previously been done by the inhabitants themselves [1].

Over the years, *waste management* followed the rise and fall of great empires and cities. It has been an issue since man has roamed the earth. Nomadic tribes would live on a piece of land until the waste built up and would then move to another location. These practices had little environmental effects since the waste generated was generally biodegradable, reusable or recyclable [29].

Up until the industrial revolution, reuse and recycling of products was commonplace. Before this time, materials were more difficult to obtain than labour, hence items were built to last, conserved, repaired and reused as much as possible. In the UK at the time, the main wastes generated were ash from fires, wood, bones, bodies and vegetable waste. These were routinely composted or tilled back into the soil. With the industrial revolution, machinery made it possible to extract much more raw materials than required, which subsequently led to the wasteful use of resources and reduced reuse [29]. This can be considered as the turning point from *waste activities* to *waste-related activities*.

Next, the discovery of oil enabled humanity to create a myriad of wonderful synthetic products such as plastics, lubricants, wax, ink, crayons, bubble gum, dishwashing liquids, deodorant, eyeglasses, records, tires, ammonia, heart valves, etc. The combination of these non-renewable products with our increasingly wasteful habits created problems for disposal. The generation of non-reusable waste in growing quantities meant more and larger disposal facilities.

Throughout the past century, governments have battled to gain control over their *waste management* strategies. Most cities that have collection and disposal infrastructures are today faced with urban sprawl, loss of suitable landfill sites, environmental concerns and public opinion. To say that these latter factors have contributed to the adoption of the 3R's (reduce, reuse and recycle) would not be totally accurate. The waste diversion policies have mostly been implemented based on material shortages and depletion of waste disposal land [30].

In essence, waste-related management strategies have been developed and modified out of need, not necessarily due to environmental concern. It should be noted however, that civilizations have always been aware that resources are precious and that waste is an undesirable thing. Yet it seems that the extent of the environmental impacts resulting from our modern activities are only now being quantified and acknowledged.

2.2.2 Waste-Related Management

Waste-related management (WRM) covers the collection, transport, transfer, diversion and disposal of waste & recoverable products (W&RP). Public education and participation should also be part of this process. The main concern of this practice is towards Municipal Waste & Recoverable Products (residential, some industrial, commercial, institutional, construction and demolition). In most jurisdictions around the world this task is bestowed upon the cities, municipalities or regional authorities to develop implement and maintain their WRM strategies. The waste from larger producers (paper mills, forestry, agricultural, mining, etc.) does not generally enter the municipal stream. It is either treated onsite or through private companies. It is up to higher levels of government to set targets and environmental guidelines.

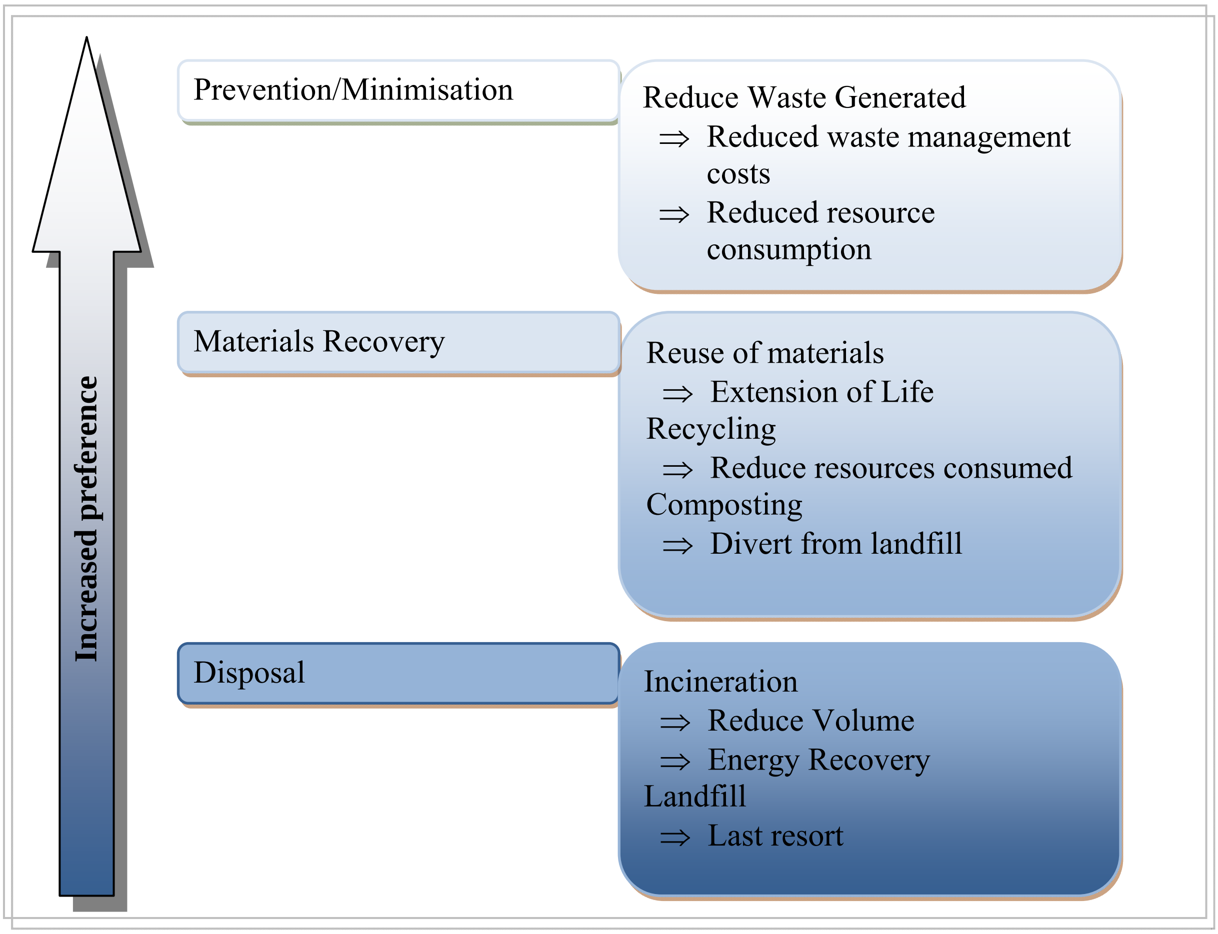


Figure 2-1: Traditional *Waste Management* Hierarchy

In most industrialised countries the following waste-related management hierarchy has been adopted to help develop their strategies: 1) prevention/minimization, 2) materials recovery and 3) disposal (see Figure 2-1) [26]. The implementation of these varies greatly based on regional requirements (population density, geography, available land, waste-related product characteristics, etc.) but the basic concept remains the same. One of the big regional differences is of course, the definition of waste-related activities [26]. As discussed in the previous chapter, definition is everything, and it is in fact a major hurdle with regard to accurate data collection, comparing information and achieving a truly sustainable structure.

2.2.2.1 Prevention/Minimization

The first step in any *waste management* strategy is to reduce the W&RP being produced. Ever since the Community Strategy for Waste Management (SEC (89) 934) was adopted in the EU, prevention and minimization has been at the top of the priority list in Europe [31]. Reducing the W&RP generated, reduces handling and management costs for the municipalities [26]. This is mainly achieved by the higher levels of government involved in targeting the manufacturing sectors.

An example of this is the Extended Producer Responsibility (EPR) concept, where the producers assume full responsibility for disposing the packaging of their products. Consequently, the jurisdictions do not assume the bill. In Canada, the National Packaging Protocol asked the producers to reduce their packaging by 50% from 1990 to 2000, on a voluntary basis with successful results [32].

2.2.2.2 Material Recovery

The concept of material recovery can be further broken into three activities; reuse, recycling and composting. Reuse and recycling are often used synonymously, but in fact the reuse of a product implies leaving in its original state. Recycling is better defined as the use of otherwise waste materials as raw materials for another product.

The reuse of materials is a novel concept since it assumes that a waste-related product is still useful in its original form. For example, an automobile that is no longer useful by one owner (for whatever reason) might be exactly what someone else needs. A W&RP for one person becomes a product for another with very little additional energy and resources. Unfortunately, for this exchange to have any merit, it’s assumed that products are made in a durable fashion with quality components, which is not necessarily the case with everything. In this day and age, it’s often simpler to buy a new car than to try and fix a reused one.

Recycling has been promoted as a means to minimize the use of natural resources and by doing so the amount of ultimate waste generated is reduced. In general these activities have been successful in reducing the amount of waste-related products for disposal. However, the efforts have been highly influenced by the fluctuating market for such materials. Entire recycling programs have been shut down due to lack of infrastructure and funding (Nipawin, SK, Canada [33]).

About 30% of municipal waste and recoverable products (MW&RP) in developed countries are organic materials [9, 34], so the potential for diverting these from disposal is huge. Organics decompose relatively fast and are the main source of methane in a landfill. They can be composted (aerobic digestion) or processed in an environment without oxygen (anaerobic digestion) to extract energy. Composting has gained a lot of attention over the recent years as a cost effective means to divert W&RP from landfill.

2.2.2.3 Disposal

After prevention/minimization and recovery has occurred, the remaining product is in theory *waste*. The residual waste has traditionally been sent to either landfill or incineration. This dates back to early man. Incineration has been developed to reduce the volume and/or sterilize *waste* (e.g. hospital). Concerns with air emissions and related health hazards have forced many governments to instate strict laws on acceptable contaminants released into the environment. Consequently the incineration process has become, in some cases, cost prohibitive. However, growing aversion to landfills, lack of land and transport costs are allowing new cleaner technologies to emerge.

2.2.3 Recap of Current Waste-Related Management Systems

Waste-related management has been around for thousands of years. Innovations in the practice have occurred out of need (e.g. health problems associated with waste in the proximity of people created central landfills) or financial motivation (e.g. to reduce operating costs - prevention/minimization and recovery practices divert waste-related materials form the waste stream). Unfortunately the environmental impacts have not been the primary drivers of policy changes.

It is important to distinguish that the traditional hierarchy has its merits and typically it’s the waste-related management system that does not apply the concepts properly. There are three main items that are commonly misused in many WRM plans or policies [6]:

- First, the hierarchy should be used as a guideline, it is not the law. Many governments have adopted it as the law. The decision makers need to account for local needs and tailor the concept accordingly [35].

- Secondly, the hierarchy is lacking in the area of reducing demand. There is emphasis on waste prevention/minimization, but the focus is on reducing the quantity of W&RP produced, without necessarily trying to change the consumption patterns. The prioritisation needs to be more explicit at the top if any measurable changes are to occur. Reducing the demand for products is the first step.
- Thirdly, recycling is a measure to divert materials from disposal and hence should be a last resort. However, recycling seems to take have taken precedence in policy makers diversion priorities. The role of recycling in the hierarchy needs to be viewed as a step prior to disposal.

Therefore some changes could be made to the traditional hierarchy in an effort to better highlight the intentions of a good waste-related management system, especially considering that environmental impacts are becoming key indicators. Consequently, sustainable practices must be integrated. Improvements to the hierarchy and the waste-related management concepts will be discussed in the next section.

2.3 Sustainable and Integrated Waste-Related Management

In the previous section, the traditional waste-related management structures were described. This need based and financially motivated structure is no longer sufficient. We must move towards a proactive, Sustainable and Integrated Waste-Related Management (SIWRM) approach. The waste-related practices must be able to fit within the concept of a sustainable development[iii]; "Sustainable practices are becoming an actual requirement rather than simply a theoretical principle. Integrated waste management must be a fundamental part of the policy built into any strategy for sustainability." [6].

A truly SIWRM system would minimise environmental impacts and consider all stakeholders involved and affected by the process and respect economic, social and cultural elements [35].

The following section explores the concept of integrated waste-related management.

[iii] Sustainable Development: One that "meets the needs of the present generation without compromising the ability of future generations to meet their own needs." (Brundtland Commission 1987) [27].

2.3.1 The Concept

When discussing sustainability in any context, it typically implies looking at the big picture, or expanding the boundaries of the existing system[iv]. The total impacts on the environment, society and economy of any activity must be considered. In other words, the concept of applying a life cycle analysis (LCA) model should be used. For example, the cost of producing an incandescent light bulb should consider the resources and energy consumed and human and environmental impacts during the entire life of the product including extraction of materials, production, transportation, operation and disposal. Only in this way can the true cost of something be quantified.

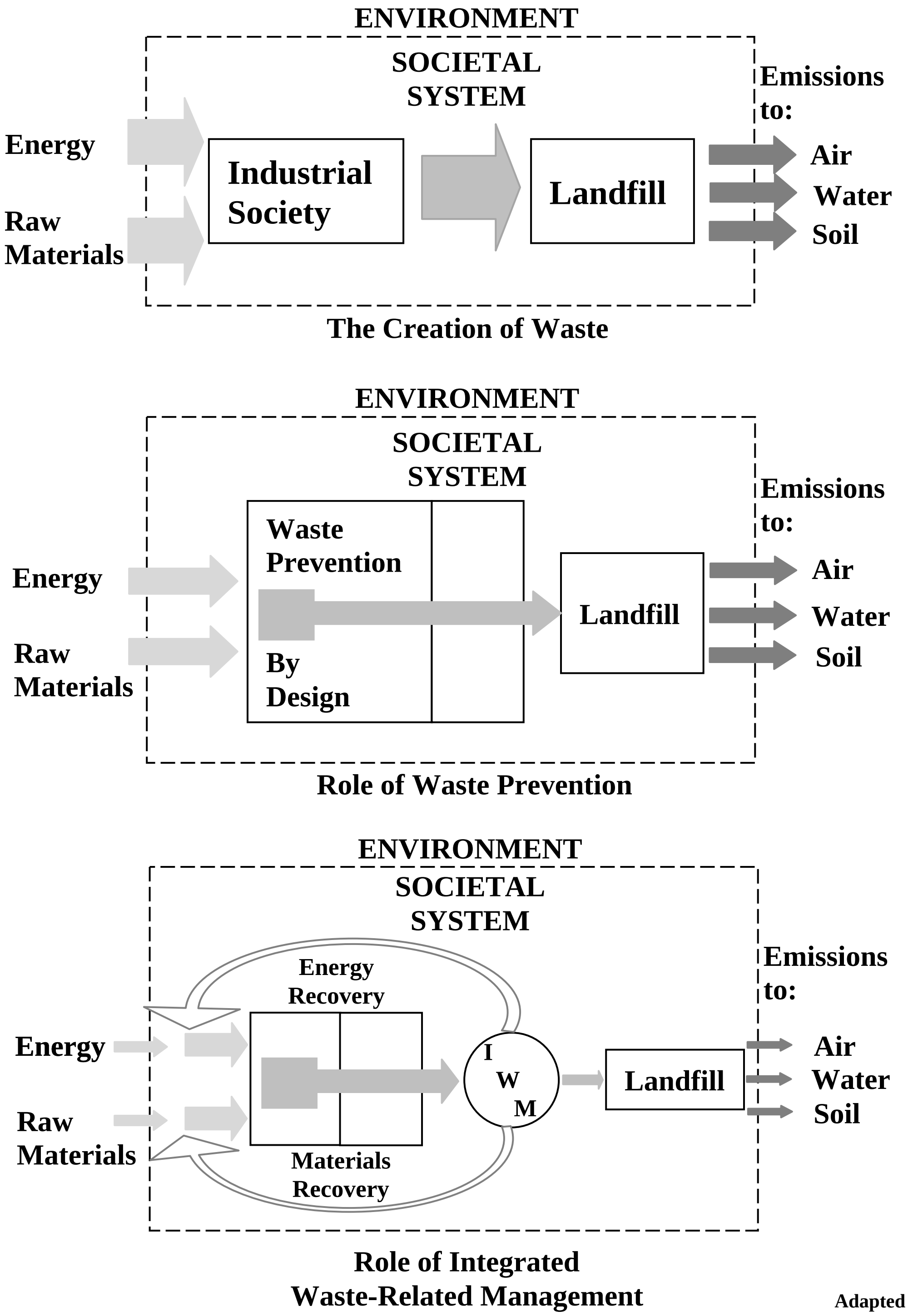
To achieve a sustainable waste-related management system, one should consider what is known as Integrated Waste Management (IWM). IWM is the industry accepted term, but as discussed previously the term should be modified to Integrated Waste-Relate Management (IWRM) or sustainable & integrated waste-related management (SIWRM), and will be used as such henceforth. SIWRM is a holistic approach to the process, in-line with sustainable development. Decision makers should not simply be concerned with making their existing waste-related infrastructure more cost effective and environmentally friendly; it requires the expansion and understanding of the entire W&RP life cycle, and not just solid waste, but all waste-related products. IWRM is a series of complimentary actions that help reduce the quantity of waste-related material generated [35].

The United Nations Environmental Programme (UNEP) in 1996 defined integrated waste-related management as: "a framework of reference for designing and implementing new waste-related management systems and for analysing and optimising existing systems" [17]. Expanding on this, SIWRM follows the traditional WRM hierarchy (Figure 2-1) but also considers the "direct impacts (transportation, collection, treatment and disposal of waste) and indirect impacts (use of waste materials and energy outside the waste management system)." [36].

Take for example the New Zealand Waste Strategy. They define *waste* as ''any material, solid, liquid or gas, that is unwanted and/or unvalued, and discarded or discharged by its owner'' [37]. The purpose behind this definition is to allow policy makers the possibility of integrating all the types of waste streams in their strategies. When treated separately, the total

[iv] A system is a: ''set of interacting units or elements that form an integrated whole intended to perform some function'' [38].

waste produced will be greater. Seadon (2006) writes that with SIWRM, “There is wider scope for users to fully integrate media, agents and tools to provide a waste management system that reduces the need for virgin materials, utilizes energy more efficiently, produces fewer emissions and thus has a lower environmental impact.” [17].



Adapted from: [47]

Figure 2-2: Integrated waste-related management system

Overall, the concept of integrated waste-related management, summarised in Figure 2-2, is crucial to sustainable development. Some of the concepts that form an SIWRM system are, in no particular order, as follows [6], [35]:

- Comprehensive waste-related policies need to consider the social, environmental and economical impacts of their strategies. The ecological footprint and life cycle analysis of resources should be at the top of the priority list. The traditional hierarchy needs to be used as a tool and not a rule.
- A more synergetic approach between consumer needs and market demand in policy development.
- Education of the public to reduce consumption, purchase durable products and lead a sustainable lifestyle.
- Increased pressure on the manufacturing industry to design more durable products and minimal packaging, which enhance reuse and recycling. Design of products should include life cycle analyses.
- Initiatives to reduce the quantity of waste generated at all levels.
- Capital investment and continuous funding on behalf of the various levels of government to promote new initiatives.
- Continuous management and operation to implement the SIWRM plans, dynamically adapt to changing conditions, investigate best available technologies and oversee private sector service providers.
- Selection of waste & recoverable facility location and available service which do not discriminate based on racial, ethical, cultural or economic characteristics.
- Processing schemes to include; recycling, putrescible material treatment, energy recovery from W&RP and sanitary landfills.

2.3.2 Improving the traditional WRM hierarchy

By considering the SIWRM principles, policy makers should be able to develop comprehensive strategies which will contribute to a sustainable development. The importance of waste prevention is re-emphasized and expanded to included lifestyle education. Recycling and disposal are still considered a last resort in the hierarchy.

2.3.2.1 Prevention/Minimisation

At the outset, there needs to be more emphasis on prevention and minimization. Current strategies have included the Extended Producer Responsibility (EPR) or User-Pay structures, with some success. These tend to minimize packaging and promote sorting. They have minimal impacts on the consumers' attitude towards minimizing W&RP. Lifestyle and consumption habits need to be revisited in addition to EPR and User-Pay systems.

Reducing demand is at the top of the list. The main reason that we currently produce so much *waste* is that we choose to consume more than is required. Consider all the frivolities that one is privileged to enjoy in the developed world. How much is really necessary? An author on the topic of climate change once said that; to avoid a global collapse of the environment we would have to lead a lifestyle that is similar to that of the Stone Age [40]. Without going that far, it is our responsibility to make educated choices about the things we purchase and consume. Moreover it is the responsibility of our leaders to support and give us direction in that respect; because it might go against the economic expansion paradigm we now follow. Supporting local products is one way to reduce the overall life cycle cost of items.

In terms of prevention, we need to manufacture things that are less wasteful. This means less packaging, using recycled materials and creating reusable products. In part governments must set targets and require that manufacturers meet these goals and penalize those who don't. The responsibility also falls on the consumer to make educated choices about what they buy.

The durability of the items we create and buy also goes hand in hand with preventing the waste we produce. It is the consumer that must consider what to buy. But the government should also participate by enforcing manufacturers to; for example, have minimum warranty periods on their products. The variations are numerous, but the point is still made: cooperation is needed between government and consumers.

Consider that if we purchase only what we need, and those items have minimal associated waste and are durable, then the residual waste should be reduced. However, there will surely be waste & recoverable products despite our best efforts. In this case, a User-Pay system should be used to discourage disposing of potential resources. Typically the cost for MW&RP management is lumped into property taxes, and consequently does not reward one's ability to cut *waste* or to separate recoverable products. Many jurisdictions that have implemented full or partial pay-as-you-go type systems have seen drastic reductions in the quantity of waste being sent for disposal and an increase in recycling [41]. Table 2-1 displays the positive effects of a user-pay structure for six Canadian cities. All show reductions in W&RP sent for disposal and increased diversion.

Table 2-1: Effects of Bag Limits and Unit Pricing on Material Recycled and Waste Disposed in Six Canadian Municipalities

City of Unit Pricing and bag limit introduction	Change in amount of residential W&RP disposed	Change in amount of residential recycling	Base year before bag limits and unit pricing introduced	Comparison year after bag limits and unit pricing introduced
Peterborough, Ontario	-21%	49%	1993	2000
Markham, Ontario	-8%	6%	1997	2000
Georgina, Ontario	-38%	46%	1996	1999
Barrie, Ontario	-16%	22%	1996	1999
Orillia, Ontario	-23%	31%	1996	1999
St. Albert, Alberta	-38%	51%	1995	2000
Peel, Ontario	-4%	12%	2002	2003

Source: [42]

Going one step further, the typical NIMBY or Not in My Back Yard mentally, should be challenged. Wastes & recoverables should not be carted away from the source. Imagine the effect of living near the refuse you create. A drastic change of attitude, in this case, would be inevitable.

In conclusion, preventing and minimising W&RP generation involves public education and awareness, policies that regulate products being sold, penalisation of wastefulness and rewards for efforts to minimise W&RP.

2.3.2.2 Diversion

Compared to the traditional equivalent in the hierarchy (Material Recovery), Diversion is much broader in what it attempts to achieve, i.e. divert W&RP from disposal. Anything from this point on implies that the owner abandons ownership over his possession. Here in the hierarchy it is crucial to properly name objects. Just because ownership has been dismissed the item is not automatically *WASTE*.

Reusing is the simplest and most environmentally sound solution to diversion. By keeping something in the same state and finding a new use for it requires little additional energy and no new resources. A flea market or a garage sale, are great examples. An old saying comes to mind: One man's trash is another man's gold. Conceding ownership of an object does not imply that it has lost its value. Society has a large role to play in this, by accepting the possibility that something previously used still has importance. The local governments can help by allowing and making room for flea markets to operate in urban centers where people can buy, sell and trade their goods.

The next logical steps are to compost and recycle. Although composting is commonly accepted as “recycling” since the organics are turned into fertiliser, organics represent 1/3 of our MW&RP stream and hence should be listed as a separate category in the hierarchy. The traditional breakdown does not draw specific attention to organics, but it is of equal or greater importance to recycling.

Organics will decompose no matter what. During their decay they will release CO_2, methane and heat so why not capture some energy from this process? This is intuitive; however the technologies to do so are expensive and must be applied on large scales. Hence, governments at all levels must step in to support the infrastructure and the technology. If energy recovery is not possible or does not make sense in a given system, at the very least composting should be considered if only to minimize the volume of materials being disposed.

As a last method of diversion, recyclables must be removed from discarded goods instead of being sent for disposal. Ideally materials are reused as opposed to recycled, since it does require a large amount of energy to sort, transport and convert these into usable raw materials. Also, recycled materials tend to degrade the more they are recycled, rendering them eventually unusable. The alternative however, of consuming new resources for the same product is even more undesirable from a life cycle perspective. The local governments must provide the collection, sorting and transportation infrastructure and the higher levels of government must promote and sustain a market to buy recyclables.

At any rate, recycling should be as last resort, before disposal.

2.3.2.3 Disposal

Once a product or material has been rendered unusable, it must then be disposed. Ideally nothing should make it this far if all the previous steps of the hierarchy are followed. But alas, unless we revert to the Stone Age, we will always have waste requiring disposal.

The first step would be to extract whatever useful energy is left in the wasted products. The only items that could be used for this must contain carbon, which would convert to CO_2, methane and heat if left to rot in open air. Instead, if they are placed in a controlled environment, energy can be extracted. This is known as energy recycling. The advantage of this is to produce useful energy from something that would otherwise be *waste*. In addition, GHG’s are controlled before being released into the atmosphere, as opposed to decomposing outdoors (e.g. landfills). By-products of this energy recycling are typically inert solids, liquids and flue gases. First, local governments need to assess some of the newer options. The upper levels of government must implement laws and regulations that allow newer technologies to be explored, in addition to providing funding for start-up projects.

Landfill is the last resort for *wastes*. These *wastes* are buried in the ground where they slowly decompose.

2.3.2.4 Conclusion of SIWRM

Figure 2-3 is a summary of the recommend sustainable and integrated waste-related management hierarchy discussed above. Compared to the traditional hierarchy, the preference flow has been changed. In Figure 2-1, the treatment preference increases from disposal to prevention. But as discussed in chapter 1, the mentality that diverting *waste* is a good thing as opposed to discarding recoverables being a bad thing needs to change. Therefore it is proposed that the decision flow be reversed, decreasing in preference as you work down the hierarchy.

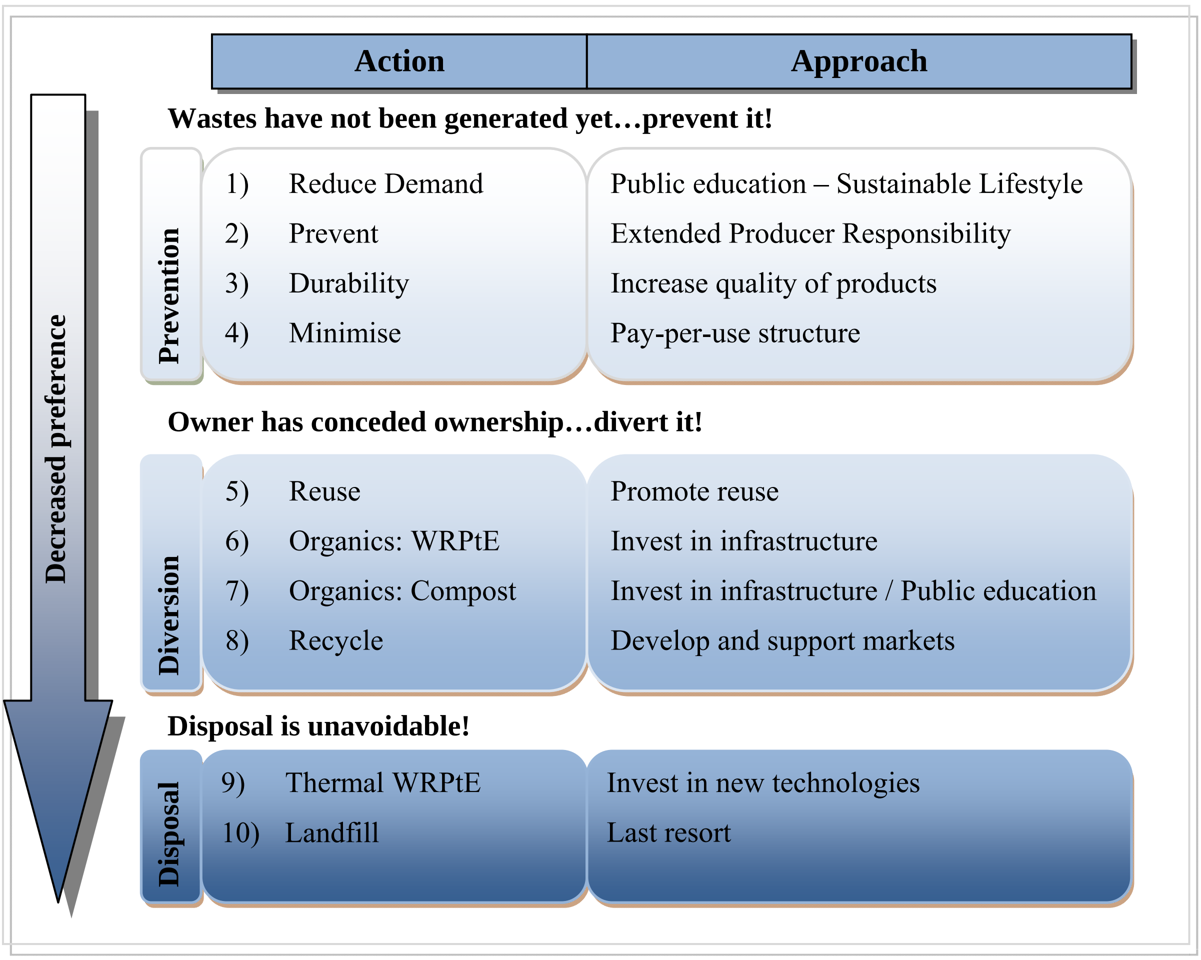


Figure 2-3: Sustainable & Integrated Waste-Related Management Hierarchy

2.3.3 Environmental Concerns

Waste-related management is plagued with environmental concerns. The very concept itself of ‘waste’ has negative environmental connotation. The following section is a brief description of some of these.

2.3.3.1 Resource depletion

The first big environmental issue is resource depletion. If we did not have such a consumption driven attitude, then our resources would be cherished as opposed to ravaged. The sheer scale at which we extract materials from the ground is staggering. Since our economies are consumption driven, we continuously exploit new ways to find and extract more resources, as other sources diminish. The amount of energy spent, the ecosystems compromised and resources wasted leave unchangeable scars on our planet. So long as we consume, new materials are required. At which point will there be no more? Is there a limit to ecological devastation?

In essence, waste-related management must have as a primary goal to minimize the new resources required, as seen in Figure 2-3.

2.3.3.2 Transportation

The transportation of waste-related products from where it’s generated to a processing site is part of most waste-related management strategies [43]. Typically people are against having waste-related facilities near urban centers. So it is easier to transport the products away where land has always been cheaper.

This mentality however, is changing. Adequately located land is harder to obtain due to urban sprawl and growing public opposition. Transportation costs are also going up and in some cases is the most expensive part of a WRM system [45]. The GHG impact is also of concern and there are additional issues such as potential traffic accidents which put the environment and public safety at risk.

The role of transportation in a SIWRM system will depend on many factors such as: what is being collected and how often (this depends on the SIWRM strategy itself) and location factors such as population density, geography, topography and environmental conditions [45]. For example, in hot climates where unsorted W&RP is being collected, the system may require more frequent pickups (such as multiple times a week) in order to keep the odours from decomposing organics to a minimum [43]. Whereas if waste streams are being sorted at the source and organics composted on site or collected separately, the balance of the waste and recyclables can be stored and collected once a week or every second week.

From a cost perspective, it can in general be argued that the method used to collect W&RP (i.e. source separated vs bulk and frequency) does not affect the overall transportation costs [43]. Assuming that all trucks are filled near capacity, the cost of transporting 10 tons of mixed W&RP compared to 5 tons of refuse and 5 tons recyclables is relatively the same. Or if 100 tons of W&RP are collected once per week vs. 20 tons per day, the cost per ton is the same. The same logic can be applied to the other associated environmental and social implications. The only way to minimize the impacts associated with transportation is to reduce the quantity transported and the distances required. For example the treatment of organics at the source (e.g. composting) would reduce the quantity of material being transported by 1/3.

Materials that can be recycled on the other hand may require transportation over long distances [47]. Re-processing facilities can be few and far between. Transportation from collection or sorting facilities to these plants can be very significant and in many cases affect the economics of the process. And so the locations of these facilities are important, near railways for example, where large quantities can be shipped for relatively low costs and environmental impacts.

In essence, transportation is part of most WRM systems and the environmental, social and economical side effects must therefore be considered. The only way to mitigate their impact is to reduce the quantity and distance that W&RP must travel. So it's crucial to start accepting new strategies and technologies that will allow W&RP to be treated near the source. Doing so, society will be faced with the W&RP they generate and arguably this would have the positive effect of reducing the quantity. The 'out of sight, out of mind' mentality cannot be part of a SIWRM.

2.3.3.3 Disposal

Disposal is the worst of all environmentally unsafe aspects of waste-related management. Although it has been previously argued that residual waste should in fact be free of all hazardous, organic, recyclable and reusable materials, it is rarely so. Today, the majority of all W&RP are sent to landfill or incinerated. In Canada, landfill accounts for 97% of the residual W&RP disposal. Either of the two options however, have their drawbacks.

Landfills produce methane as the organics decompose but due to the environmental conditions and mainly a lack of humidity, this takes decades. Furthermore, some organics (10 to 20% [43]) dissolve into a complex mixture of organic acids, aldehydes, alcohols and simple sugars. These are combined with other liquids, rain water, hazardous materials present in the W&RP to form what is called leachate. Leachate is a lethal mix, as discussed later, that can seep into the ground and reach the water table. The effects are devastating and this occurs over decades, even after a landfill is closed.

Incinerators, or other thermal processing technologies, are notorious for their emissions, hazardous liquid and solid by-products. However, if managed and treated properly, the impacts are far less than landfills since emissions and by-products are created in a controlled environment.

2.3.4 The Role of Waste-Related Products to Energy

Waste and recoverable products can be thermally treated as a final means to help divert them from landfill. The main goal is to extract useful energy and reduce the volume of the residual waste. Although good in concept, there are many opposed to such practices for two main reasons: 1) harmful emissions and other by-products are generated and 2) the activity competes with recycling [44]. Both these issues have been successfully addressed in many cases and are mainly focused on thermal processes (e.g. incineration) and not biochemical (e.g. composting). There are many different WRP-to-Energy (WRPtE) technologies, some that have been proven for many years and others that are cutting edge. The chosen approach depends mainly on the feedstock composition and the desired output.

The opposition to WRPtE technology with regards to pollution comes from three major issues [46];

- Incinerators and other thermal processes are said to be the largest producers of dioxins and furans,
- Some of the by-products of the process are toxic,
- Even the best available technologies will pollute.

Although these statements are true to a certain extent, each technology must be viewed in context and state of the art technologies are far superior with respect to their predecessors. WRPtE plants are strictly regulated by governments, and air emissions comply and often surpass these requirements (see Table 2-16, for example). The emissions from newer facilities are far better than oil and coal fired power stations and is slightly worse than natural gas [48]. In Germany, WRPtE plants accounted for 1/3 of all dioxin emissions in 1990. By using better technology, applying flue cleaning processes and improved waste-related material quality, these figures were less than 1% in 2000 [49]. These dioxin control measures are expensive to implement and reduce the financial viability of such facilities but in certain cases, the protection of human health and the environment is more important.

In addition, many supporters say that WRPtE will reduce the methane that is currently emitted by landfills. In Europe, it is estimated that new directives will cut 74 million tonnes of CO_{2eq} by 2016 [50] and WRPtE technology will play a role in diminishing our reliance on fossil fuels.

With regards to WRPtE inhibiting the recycling process, there are good arguments on both sides. Opponents such as Greenpeace, say that if thermal processes are used it would reduce the willingness of the public to recycle. Also, it is true that these technologies are looking for organics, paper, plastics and rubber to increase the energy content and consequently their energy output. These are all recoverable materials. Furthermore, the amount of energy produced via these processes is only a fraction of the energy required to manufacture the same product [46].

However, achieving 100% diversion of waste is not practical in the foreseeable future due to the ailing recyclable material market. Even in Canada, in 2004 only 23.7% of materials were diverted from disposal [27], so there is a long way to go before eliminating disposal. Also, as discussed previously, the quality of the recycled material degrades overtime and becomes un-recyclable. In other words, WRPtE is a useful tool in the interim to reduce waste to landfill and has potential in the future to eliminate obsolete recyclable materials.

Moreover, European experiences have shown that the countries with the highest recycling rates also show the strongest WRPtE growth [44] (also see Figure 3-10 and Figure 3-11). In the UK, a municipal council stated;

> "Experience in a number of other European countries shows that EfW incineration underpins schemes with high recycling rates. EfW gives the opportunity to recover value (energy) from waste which cannot be recycled, provides an opportunity for the recycling of bottom ash (thus contributing to a more sustainable use of aggregates), and provides a treatment option for recyclable waste when markets for recyclables are poor." [51].

In essence, WRPtE is an integral part of a sustainable development for the following reason;

- Emissions are far less toxic than they used to be, and surpass those of other power generating technologies with the proper flue gas cleaning equipment.
- WRPtE goes hand in hand with recycling.
- There will always be (at least for the foreseeable future) a portion of residual waste requiring disposal.
- WRPtE is better than landfill (as will be seen later on).

2.4 Material Recycling

Within the scope of a SIWRM system, recycling is slightly better than disposal and worst than re-use. Additional energy and resources are required to convert the recyclables into raw materials for other processes. However, we currently generate a large quantity of W&RP and at the moment not all can be re-used. Recycling is part of most waste-related management schemes and will continue to do so in the foreseeable future. At the root, many of the modern day products that are suitable for recycling cannot be reused as is (e.g. packaging materials, cans, newspapers, bottles, etc). Many of these are suitable and must be considered for recycling or disposal (as a last resort).

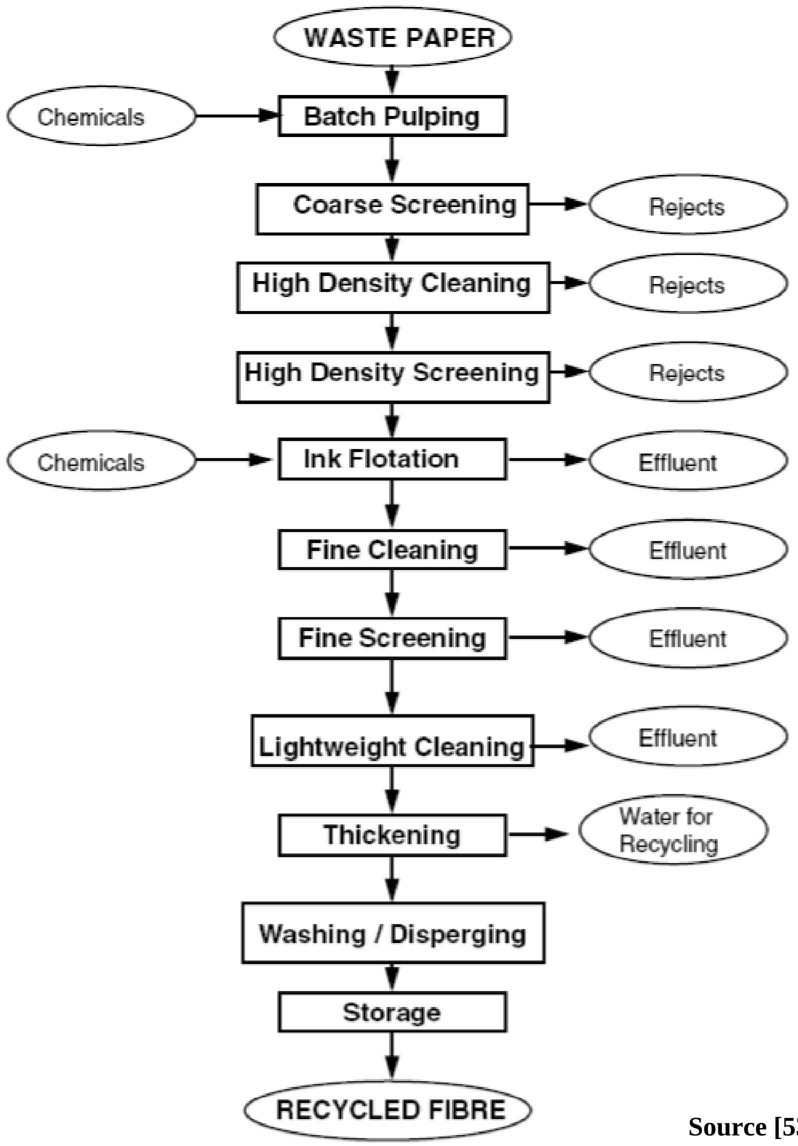
The quantity and type of materials being recycled depends on its financial viability within a waste-related management system. Consequently it varies quite drastically in the different regions of the world based on the type of material being recycled, population density, system infrastructure, available resources, technology, market value of raw and recycled materials, etc [47]. However, as the cost of landfills increase and the amount of suitable land is diminishing, recycling is more prevalent in waste-related management systems [52]. In general, the benefit of reducing the amount of raw materials being extracted is a secondary benefit of recycling.

The typical recycling scheme involves collection, sorting/bulking and reprocessing [43]. The cost of reprocessing depends largely on the scale of the process, complexity of the technology and quality of the feedstock. The quality of recycled materials is directly dependant on the quality of the sorting and separation, either at the source and/or at central sorting facilities. Therefore the role of sorting in any SIWRM system if very important and requires special attention.

Different types of recycling processes are applicable depending on the material. The following is a brief summary of the various recyclable categories. Organics can also be recycled (e.g. composting) and are discussed later on in this chapter.

2.4.1 Paper and Cardboard

Paper and cardboard are amongst the easiest and most cost effective household materials to recycle. They represent about 30% of the municipal solid waste-related stream and consequently have a significant impact on the quantity of material sent for disposal. However, it is estimated that about 30% of this resource is not recoverable because it is destroyed (e.g. toilette paper), contaminated (e.g. pizza boxes), permanent (e.g. books) or in areas where the population density is too low to warrant collection [43].



Source [53]

Figure 2-4: Production of recycled paper fiber

Current paper and cardboard recycling technologies and processes create some wastes. It is estimated that about 15% of the original material is not recycled [47], as is shown in Figure 2-4 for bulk recycling of paper.

The industry produces a wide variety of paper type and grade. As a result, most can contain a portion of recycled materials. Even most commodity grade paper can be made almost entirely of recycled paper [43]. Considering the quantity of paper and cardboard sent for disposal and the ease of recycling, this resource plays an important role in most waster-related management schemes.

2.4.2 Glass

Recycled glass is typically in the form of bottles and jars. It is collected and sent to sorting and reprocessing facilities, where various steps occur. Typically, all foreign objects are removed, starting with manual separation (e.g. plastic bottles, lead wine bottle collars), then the mechanical removal of ferrous metals and low density materials such as paper and aluminum caps [47]. The sorted glass is then crushed into cutlets for use in new products.

The glass cutlets are typically mixed with raw materials to make new bottles and jars, but can also have other applications like in fiberglass or as additives in building materials such as asphalt, bricks, insulation, ceramics, etc [43].

2.4.3 Metals

Metals are usually separated into ferrous (steel) and non-ferrous metals (mainly aluminum), each are treated and recycled separately.

The recycling of ferrous metals to make steel is a well established industry [43]. Steel is a principal construction material due to its low cost and the widespread availability of iron ore. However, processing raw iron oxide is very energy intensive compared to reprocessing recycled steel. So since the large increases in energy costs of the 1960’s, production has incorporated recycled steel by using more flexible processes, in an effort to remain more competitive [47]. Although most recycled steel comes from the construction/demolition industry and the industrial sector, about 4% of MW&RP is ferrous metal. These materials are easily removed from other recyclables by using magnets at sorting facilities.

Aluminum is a typical non-ferrous metal collected in the MW&RP stream (approximately 1%) in the form of cans, foil and containers. Similar to steel, aluminum is a highly valuable recycled material because of the high energy costs required to process raw bauxite into aluminum. One source estimates the relative energy cost of processing raw and scrap aluminum to be 183 GJ/ton and 8 GJ/ton, respectively [47]. Even though it is only a small part of the MW&RP generated, its value warrants recycling.

2.4.4 Plastics

Plastics are particular materials that are difficult to recycle because they are produced in many different types of polymers, such as: high and low density polyethylene (HDPE, LDPE), polyethylene terephthalate (PET), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC) and many more. Because of the various types of plastic, proper sorting becomes the most important part in the recycling loop [52]. Additionally, plastics have a relatively low density which makes transportation problematic.

Plastics are amongst the least sustainable elements of the waste-related products. 90% of the plastics used are created from non-renewable fossil fuels [52]. Many plastics enter the waste-related stream after only one use, for example packaging materials, which represent 35% of all plastics consumed worldwide [52]. Therefore plastics required special attention in a SIWRM scheme.

Plastics can either be mechanically or chemically reprocessed. The simplest method being mechanical, where plastics are shredded and cleaned to remove paper and other soluble residues. Typically this forms low quality or contaminated raw plastics for products designed for this material (e.g. fencing, traffic cones, etc) [43]. Obviously the quality of the recycled plastic is dependent on the sorting performance.

The chemical processing of plastic involves breaking down the polymers into their monomer form [47]. This process is more complex than mechanical processing and requires much more energy. Doing so allows the recycled plastic to be re-formed in a much wider range of products.

Plastics can also be thermally converted as feedstock for energy production (energy recycling) and this is discussed later in this chapter.

2.4.5 Textiles

Textiles come from clothing, carpets, curtains, etc. Many of these can be typically re-used via second hand stores. But in some cases the wear is excessive and these materials must be reprocessed. The recycled product can be split into various categories depending on the desired product (e.g. cotton, wool, synthetics, etc). They can be re-processed to produce new fabrics or stuffing materials, for example. The process to recycle and produce textiles is similar to that of the pulp and paper industry [47].

2.4.6 Waste Electrical and Electronic Equipment (WEEE)

Waste electrical and electronic equipment (WEEE) covers a wide range of household products (e.g. computers, TV's, appliances). In Canada, WEEE is estimated at less than 4% of the MW&RP stream. However, studies have shown that the quantity being generated is growing at a rate 3 times faster than MW&RP [43].

These products are generally sent to landfill because it's difficult to separate all the various components (plastics, ferrous and non-ferrous metals, glass and other non-recyclables). In some cases it's possible to refurbish some of these products and put them back into the market, but this is not a prevalent trend. The infrastructure to reuse and recycle these materials needs to be developed and must form part of any SIWRM strategy. Trends show that they are gaining importance in the WRM stream and cannot simply be sent to landfill.

2.5 Disposal and Energy Recycling

The current reality, and foreseeable future, includes waste-related disposal as part of any SIWRM. This would include landfills and Waste-Related Products to Energy (WRPtE) or Energy Recycling. The following section will describe these various methods with a special focus on energy recycling.

As a starting point, some of the basic principles and concepts are reviewed to better understand the processes.

2.5.1 The basics

There are three main sources of biomass feedstock for energy conversion: waste & recoverable products, agriculture residues and energy crops. When using biomass[v] (such as MW&RP) as a feedstock[vi] for energy production it is important to understand its

[v] Renewable organic materials such as; wood, agricultural crops or wastes, and municipal W&RP.

[vi] Raw material required for an industrial process.

characteristics, i.e. moisture content, heating value, fixed carbon and volatile mater proportions, ash content, alkali metal content and cellulose and lignin ratio [54].

The interest in agricultural waste and energy crops is that they can be mixed with W&RP in an effort to normalize the heating value and improve the supply stability of the feedstock. In addition, it is good SIWRM practice to consider other waste streams. Sanitary waste-related products can also be considered as feedstock.

2.5.1.1 Agricultural Waste

Agricultural waste is of interest because it's exactly that, *waste*. In some cases it's tilled back into the ground or used as animal bedding. Sometimes it's burned or sent to landfill, and hence a valuable source of energy is being discarded.

Agricultural waste can be divided into; wood, manure, temperate and tropical crop W&RP. Wood by-products are an important source of energy and they are often ignored. Mill wastes, trimmings and forest residues are commonly left to rot or go to landfill. Manure is produced from farm animals and is a very good energy source due to its high volatility. Collecting it also helps reduce the green house effect since it captures the otherwise released methane.

The main problem with agricultural waste/resources is collection. It's produced in a dispersed fashion. Moreover, the density is low which increases transportation costs and further puts into question the economics of such an energy source. The most beneficial biomass to energy facilities are placed on site where the waste/resource is produced, such as large farms, saw mills, sugar refineries or olive oil pressing factories, as some examples.

2.5.1.2 Energy crops

Energy crops are grown for the sole purpose of being converted to energy. The interest is intertwined with mitigating greenhouse gas emissions. Energy crops are considered CO_2-neutral, when they are harvested sustainably, since they consume as much during growth as they release during the energy conversion process. They can be converted to heat, electricity or biofuels. Other benefits are usage of surplus agricultural land and reducing the dependence on oil. Energy crops however, do raise certain environmental concerns such as excessive land use, soil desertification, water table contamination due to fertilizers and loss of biodiversity.

2.5.1.3 Refuse

Refuse is basically *waste*, that is not agricultural, which consists of MW&RP. Refuse is a complex mix of things, as shown in Figure 2-5.

Table 2-2 also gives a description of the typical composition of MW&RP depending on the income of a country. From Figure 2-5 it is clear that up to 80% is easily recoverable (compost, reuse, recycle). Over 65% of the MW&RP is biodegradable material or plastics suitable for energy conversion, although reuse and recycling would represent higher uses for MW&RP. However, consider only the biodegradable products, which account for about 1/3 (excluding paper and cardboard) of the W&RP. This organic material will decompose regardless and release energy in one form or another. There is great potential to capture this otherwise wasted energy. In Canada this represents an estimated 11 million tons of biodegradable products produced each year (based on 2004).

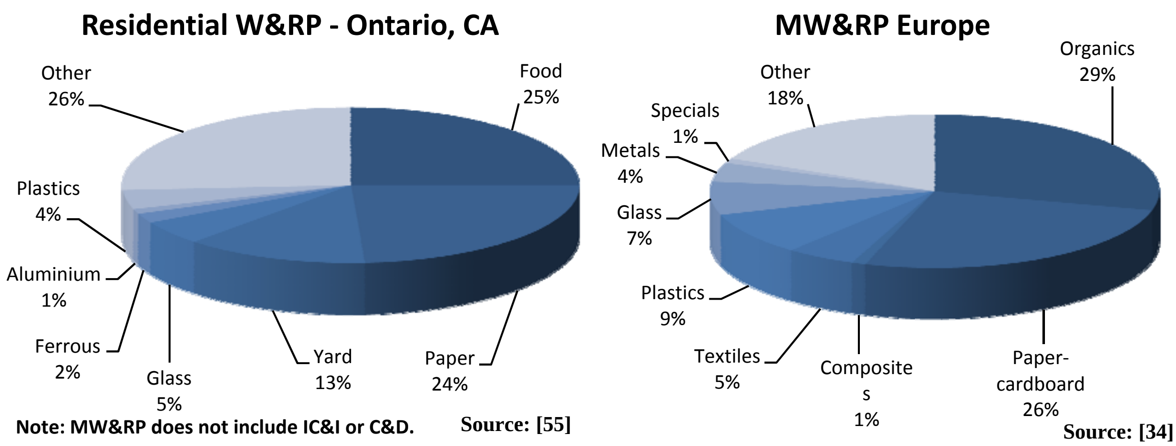


Figure 2-5: Composition of MW&RP in Ontario, Canada (left) and in Europe (right)

Table 2-2: Typical composition of municipal solid wastes from high and low income countries

Category	**MW&RP (%) (low-income countries)**	**MW&RP (%) (high-income countries)**
Paper	3–10	30–46
Plastics	2–7	7–13
Compostable	36–80	23–38
Glass and ceramics	1–8	4–10
Metals	1–4	4–9
Others	14–54	8–22

Source: [57]

One of the most important factors when dealing with biomass or W&RP as a feedstock is the heating value or energy content of that fuel, which is obviously related to the heating value of its components. This is required to assess the energy producing potential and consequently the feasibility of implementing WRPtE facilities. Table 2-3 gives the ultimate analysis for Canadian MW&RP and its constituents, including the calculated higher heating value (HHV) which is typical for developed countries [56]. It is clear that plastics have a much greater HHV than other materials present in MW&RP. This is due to their high level of fixed carbon and lower volatility. Hence they are much better as feedstock for thermal WRPtE conversion than other materials.

Table 2-3: Composition and heating value of MSW

Material	Canada Share	Ultimate Analysis C	H	O	N	S	Ash	Cl	MC	HHV (MJ/kg)	LHV (MJ/kg)
Paper / cardboard	29.0%	34.7%	4.7%	32.5%	0.2%	0.2%	6.5%	0.2%	21.0%	14.1	12.5
Yard Trimming	7.6%	23.3%	2.9%	17.5%	0.9%	0.2%	10.1%	0.1%	45.0%	9.7	8.0
Organics	28.2%	17.9%	2.6%	12.9%	1.1%	0.1%	5.1%	0.4%	60.0%	8.0	5.9
Plastics	9.2%	56.4%	7.8%	8.1%	0.9%	0.3%	8.6%	3.0%	15.0%	29.3	27.2
Glass	3.4%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Metals [a]	4.6%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Textiles	2.4%	37.2%	5.0%	27.1%	3.1%	0.3%	2.0%	0.3%	25.0%	16.1	14.4
Other [b]	15.7%	24%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	10.0	8.4
MW&RP-Unsorted	**100.0%**	**27%**	**3%**	**16%**	**1%**	**0%**	**5%**	**0%**	**28%**	**11.7**	**10.1**

a Metals are comprised of 4% ferrous and 1% non-ferrous metals. Information based on [58].
b Other is assumed to be 7% misc. combustibles, 2% misc. non-combustibles and 6% fines (dust). Information based on [58].
c Carbon content and Heating values extrapolated for paper, cardboard, wood and plastics taken from [56]. All others were taken from Waste Management Option & Climate Change [43].

Going one step further, Table 2-4 compares the ultimate analysis of MW&RP for high and low income countries with other known fuels such as methane. Clearly the energy content of W&RP is comparatively low. It is important to remember that other biomass can be combined with the MW&RP to improve the heating value and stability of the W&RP as a feedstock.

Table 2-4: Characteristics of the waste feedstocks (dry mass basis)

Waste type	C (%)	H (%)	O (%)	Ash (%)	HHV (MJ/kg)
MSW[a]	36.7	7.2	31.1	25.4	8.4
RDF[b]	44	8	30	18	16
MSW[c]	47.6	6	32.9	12	19.9
Waste oil	83	17	0	0	34
Landfill gas	47	11	42	0	28.2
Methane	75	25	0	0	55.7

[A] Low-income countries
[B] Refuse Derived Fuel from [a]
[C] High-income countries

Source: [57]

The energy content is only part of the required information, however. The major drawback of MW&RP as a fuel source is the inherent heavy metals, toxins, hazardous and potentially hazardous materials in unsorted MW&RP. Table 2-5 gives a summary of W&RP molecules found in Austria and UK refuse.

Table 2-5: Comparison of Austrian and UK W&RP data

Source	C (%)	Fe (%)	Cl (%)	S (%)	F (%)	Zn (%)	Pb (%)	Cu (%)	Cd (ppm)	Hg (ppm)
Austria household	24	5	0.8	0.4	0.2	0.1	0.06	0.04	9	2.5
Austria municipal	26	5.6	0.9	0.4	0.2	0.1	0.08	0.05	11	1.4
UK household	34	6.6	1	0.2	0.03	0.1	0.04	0.1	5	0.5

Source: [59]

Going into greater detail, Table 2-6 breaks down some of the heavy metals found in common W&RP. The harmful chemicals present in the fuel are problematic regardless of the disposal method, meaning that they need to be accounted for during landfill just as much as for WRPtE. It is important to note however, that WRPtE occurs in a controlled environment, which allows these molecules and their by-products to be captured and managed appropriately, unlike landfills.

Table 2-6: Comparison of heavy metal data by fraction

	As (ppm)			Cd (ppm)			Cr (ppm)			Hg (ppm)			Pb (ppm)		
Category	**UK**	**Nl**	**D**	**UK**	**Nl**	**D**	**UK**	**Nl**	**D**	**UK**	**Nl**	**D**	**UK**	**Nl**	**D**
Paper/card	2	2	<5	1	11	1	20	67	10	0.1	<0.1	0.2	42	127	23
Organic waste	5	67	30	1	5	1	25	310	55	0.1	<0.1	0.5	76	188	90
Total plastics		3			388			853			<0.1			302	
Dense plastics	2			32			181			0.1			879		
Film plastics	4			4			195			0.1			1595		
PVC			<5			66			29			0.2			50
Wood		6	<5		12	<1		231	5		1	<0.1		277	21
Textiles	2	2	<5	1	16	1	25	934	17	0.1	<0.1	<0.1	35	30	35
Glass	6	287	0	1	<1	0	454	253	1	<0.1	<0.1	0	168	381	329
Miscellaneous non-combustible	11			3			118			<0.1			999		
Stone/ceramics		91	10		341	1		822	80		<0.1	0		1967	50
Total metals			20			21			156			nd			582
Ferrous metal	32	539		15	<1		1571	1730		nd	nd		1300	520	
Non-Fe metal	4	48		16	19		221	331		nd	nd		4000	11,635	
Batteries			12			53			18			127			10,800
Electrical goods			71			361			1304			17			11,000
Fines	16			1			97			0.2			706		

UK: United Kingdom
Nl: Netherlands
D: Germany

Source: [59]

The effects that these constituents have on the liquid, solid and gaseous emissions depend on the process used to convert the W&RP to energy. This will be discussed in the following sections as we focus on the WRPtE technologies.

A final thing to consider before embarking on the WRPtE technology journey is that not all biomass is suitable for every conversion process. Depending on the characteristics of the feedstock (HHV, moisture content, toxins, etc.) and the desired output (heat, electricity, liquid fuels, etc.) different processes are more appropriate than others. This holds true for all the various materials in W&RP. For example, organics that are volatile and have higher moisture content are better suited for biochemical conversions (e.g. Anaerobes digestion). MW&RP can be treated physically, in order to prepare it for recycling or further processing. Subsequently, waste-related products can be converted either by thermochemical or biochemical processes to produce useful energy. Table 2-7 is a summary of the potential applicable processes for the multitude of products found in MW&RP.

Table 2-7: MW&RP conversion processes

Type	Example	Conversion Process
Biodegradable products	Food, yard, wood, paper	Biochemical and thermal processing
Recyclable materials	Paper, glass, bottles, cans, metals, certain plastics	All are good for recycling, Plastics and paper are good for thermal processing
Inert materials	Construction and demolition waste, dirt, rocks	Recycling or landfill
Composite products	Clothing, Tetra Paks products, waste plastics	Thermal conversion
Domestic Hazardous Waste	Medication, paints, chemicals, light bulbs, fluorescent tubes, spray cans, fertilizer and pesticide containers, batteries, shoe polish	Recycling and often need to be sterilized via thermal processes

Source: [60]

2.5.2 Physical Processing

MW&RP can and should be physically manipulated prior to energy conversion. The W&RP can be separated, compacted or shredded. The first would separate any compostable, recyclable or hazardous materials for further processing. Then if energy conversion is to take place, the quality and characteristics of the feedstock are better known and controlled. Separation can be done manually, mechanically or both. Compaction and shredding are used to reduce the volume and size respectively.

Refuse Derived Fuel (RDF), can be made by either shredding or steam pressure treating MW&RP. It is comprised of mainly plastics and biodegradables. Non-combustibles must be removed. The RDF can be compressed into bricks, pellets or logs for transportation to industrial plants or WRPtE facilities.

Physical separation should occur in any SIWRM scheme to ensure compostable and recyclable materials are not sent to landfill, especially if materials are not separated at the source.

2.5.3 Biochemical Conversion

Biochemical conversion is the decomposition of organics into combustible hydrocarbons (e.g. methane). Decomposition happens naturally, if left in the presence of oxygen (e.g. composting) or the process can be accelerated in a controlled environment in the absence of oxygen (anaerobic digestion (AD) or fermentation) to produce gas or liquid biofuels.

2.5.3.1 Aerobic Digestion (Composting)

Aerobic digestion (also known as composting) is the natural decomposition of organic matter in the presence of oxygen. Aerobic bacteria such as yeast and fungi do most of the work with larger creatures such as ants and insects also helping the process. During the process aerobic bacteria convert the carbon in the form of cellulose to heat, CO_2 and water. Nitrogen trapped in the form of protein is also required to provide nutrients to the bacteria [61].

The type of material preferred for composting has high carbon content such as leafs, sawdust and paper, mixed with high nitrogen materials (e.g. grass clippings, manure, fruits and vegetables). The preferred Carbon/Nitrogen ratio is between 25 and 30 on dry mass basis [61]. Guides are available for household composters. In commercial and industrial composters, the C:N ratio is closely monitored.

Aerobic digestion can occur either actively or passively. The process requires carbon, nitrogen, water, heat and oxygen to function. The first two and often water are present in the feedstock. Heat occurs as a by-product of the decomposition process. As the temperature increases, so does the metabolism of the bacteria, which accelerates the process, creating more bacteria and heat. This part is self sufficient. Oxygen on the other can be introduced naturally or actively. Larger composting facilities will periodically mix the feedstock pile to stimulate oxygen penetration. Mixing sticks, wood chips and small rocks will also allow oxygen to migrate through the pile passively. If the compost is left to sit, without new oxygen, the process will switch to anaerobic digestion and produce odours. Methane will also be created in the absence of oxygen, which is a lot more harmful than CO_2 as a greenhouse gas (GHG), and this is undesirable.

Aerobic digestion can either occur at mesophilic (20 to 44°C) or thermophilic (above 45°C) temperatures. In general, a higher temperature promotes a faster bacteria metabolism and consequently faster decomposition. However different bacteria are active at the different temperature ranges. Consequently, the composting temperatures must be kept relatively consistent. At temperatures above 55^{o}C for several days, would kill most bacteria [61]. When a significant portion of the colony is killed, the process takes longer to restart.

Another form of composting would be by worm or vermicomposting. Worms are used to decompose the organics into a nutrient rich fertilizer. The process can occur indoors, hence year-round [61].

Although aerobic digestion is not a method to produce energy from waste-related products, it does play an important role in the integrated waste-related management strategy. The importance of diverting biodegradable materials form landfill is crucial to sustainable development. Composting provides a diversion option which creates CO_2 as opposed to methane (being better from a GHG perspective). In addition biomass can be considered carbon neutral since it generates as much CO_2 during decomposition as it consumes during growth.

On the other hand, there has been success in producing energy from composting. It has been shown that aerobic digestion piles can reach up to 68^{o}C. By running coils through a compost pile, hot water can be heated for domestic purposes [62]. This might be interesting for smaller homes in warm climates and may require more research since it may kill most bacteria needed for the decomposition.

2.5.3.2 Anaerobic Digestion (Landfill Gas)

Anaerobic digestion is similar to aerobic digestion, except the whole process occurs in the absence of oxygen. Using bacterial action in a warm and wet environment this process produces mainly methane (50-75% of total gas vol.) and CO_2 with traces of hydrogen sulphide. In general the process occurs at mesophilic temperatures (~35^{o}C), and higher temperatures yield higher biogas rates and shorter residence times in the digester. Unfortunately higher digester temperatures are not always economical since most of the methane gas produced must be used to heat the digester tank, depending on the external environmental conditions.

The moisture content of the feedstock 'slurry' should also be between 80-95%. This is why manure is a great feedstock for such systems. MW&RP and sewer sludge (solid by-product from sewage treatment plants) can also be used to help decontaminate the waste and reduce landfill. The potential methane release to atmosphere is also mitigated. Any other biomass can also be used. The solid by-product of the process can be sold as a fertiliser, depending on the contaminants of the initial feedstock.

The gas can be then used in an IC engine or in a micro-turbine to produce electricity. The waste heat can be used to heat the digester or for other process heating. The gas can also be stored and redistributed as needed. Except for storage, compression equipment and energy requirements are high, which significantly reduces the benefits of such systems. The conversion efficiency from feedstock to gas is 20-50% of the initial energy content. Electrical conversion efficiency from feedstock is then 10-16% of the initial energy content [63].

The process of anaerobic digestion is what occurs in landfills. Within a controlled environment (e.g. digester) the methane gas and odours can be collected, eliminated and turned into useful energy. In this case, controlled conditions allow for a much faster decomposition process. A landfill on the other hand, causes the same decay except over years rather than weeks compared to the controlled environment [64].

2.5.3.3 Fermentation

Fermentation is another anaerobic process by which microbes convert sugars to alcohol. The process then produces ethanol that can be used as an additive to gasoline in normal engines or as the primary fuel in converted engines such as in Brazil. The ethanol can also be used in the esterification process used to create bio-diesel from bio-oils. Sugar crops (sugar cane, sugar beet) or starch crops (maize, wheat) are best suited for this. Corn will yield about 450 l of ethanol from one dry ton [63]. The by-products can be used as cow feed or in the case of bagasse, it can be further converted using a combustor or a gasifier [65].

Once again, this biochemical process is not necessarily pertinent to the WRPtE conversion. However, in an SIWRM system, the by-product could be combined with another waste-related stream for further thermochemical processing to energy.

2.5.4 Thermochemical Conversion

This type of conversion requires heat to extract the energy trapped in the feedstock. Typical end-products are heat, electricity, producer gas or bio-oil. Sub-categories of this conversion are direct combustion or upgrading the fuel via gasification or pyrolysis.

In contrast to biochemical treatments, thermal conversions can deal with a much larger variety of materials such as plastics and hazardous waste. However, as a result of the higher temperatures there are far more environmental considerations. The inherent composition of MW&RP, as shown in Figure 2-5, makes it such that emissions and by-products must be properly assessed. Unsorted MW&RP can contain metals, plastics, organics, wood and hazardous products.

In addition, the solid and liquid by-products of thermochemical conversions can also be environmentally unsafe. Only those of the incineration process are discussed here, since pyrolysis and gasification facilities are faced with similar environmental concerns [46]. The specifics of the other processes are discussed along with the technology itself in subsequent sections.

2.5.4.1.1 Emissions

W&RP can produce emissions during combustion containing “various hazardous substances such as mercury and other toxic metals, particulate matter (PM), hydrogen chloride, chlorine gas, undesirable hydrocarbons (VOC’s), and, most notoriously, dioxins and furans.” [44].

Firstly, during combustion metals are not destroyed, and are released in a more concentrated form. At the higher temperatures toxic metals contained in batteries, paints and certain plastics, for example, are released in their airborne form. This makes capture and mitigation more difficult. The metals can include: lead, cadmium, arsenic, mercury and chromium [46].

Second, unburned toxic chemicals are often emitted in the flue gas. Since incinerators do not operate at 100% efficiency, certain amounts of toxic chemical are not combusted and are emitted to the environment [46].

Thirdly, there is the creation of new pollutants which were not initially present, e.g. dioxins and furans (chlorodibenzodioxins and chlorodibenzofurans). “Dioxins and furans are chlorinated organic compounds which are generally considered to be among the most acutely toxic carcinogens known to man.” [66]. They are associated with a “…wide range of health impacts including; cancer, altered sexual development, male and female reproductive problems, suppression of the immune system, diabetes, organ toxicity and a wide range of effects on hormones." [46].

In Canada the CCME (Canadian Council of Ministers of the Environment) has published a study analyzing the sources of dioxins and furans. Table 2-8 summarizes the sources of these emissions and their concentrations. It concludes that W&RP incinerators account for 21% of the total emission.

Table 2-8: Atmospheric releases of dioxins and furans by source, 1999

Source	Quantity TEQ g/yr	Share of total %
Conical waste burners	44	22.6
Waste incinerators	41	21
On-site burning of household waste	20 to 40	15.4
Open burning of municipal waste	13 to 24	9.7
Electric arc furnace steel manufacturing	11	5.6
Diesel fuel combustion	9	4.6
Residential and agricultural fuel combustion	7	3.6
Iron sintering	6	3.1
Burning saltladen wood	5	2.6
Electric power generation	5	2.6
Residential wood burning	3	1.5
Base metals smelting	3	1.5
Beehive burners	3	1.5
Cement kilns	2	1
Other releases	7	3.6
Total	**195**	**100**

Source: [67]

However, many other studies have found that the relative danger of these to human health is small. For example, the Johnston Island W&RP incinerator in the pacific emitted 22.9 pg TEQ[vii]/second whereas a Norwegian study showed that a diesel truck travelling at an average speed of 40 miles/hour emits 89 pg TEQ/second [68]. This means, a single truck releases 4 times more dioxins and furans than an incinerator, in this case. A case study by the US EPA showed that a single family using a burn barrel for household and garden waste produced more dioxins and furans than a plant disposing of 200 tons of waste per day [69]. Furthermore, according to the UK Environment Agency a 15 minute spectacle of fireworks held at the millennia released more dioxins and furans than the WRPtE plant in South-East London would over 100 years [70].

The opposition however, argues that there is still little information known about these substances, and that many others have not even been identified yet [46]. This may be the

[vii]TEQ = Toxicity equivalent

"Achilles' heel" of the incineration process [44]. However, a report from the UK says that "98% of people's exposure to dioxins comes through the food chain (direct inhalation accounts for the remaining 2%)" [71]. Another study shows that "modern (WRPtE) plants may contribute 0.039% of tolerable daily intake of dioxins for a maximally exposed individual. This is a negligible amount." [72]. The issue might not be so much with MW&RP incinerators, as with every process of combustions.

In general, any thermochemical process of MW&RP is likely to produce unwanted by-products. However, there exist many methods to clean the flue gas before it is released into the atmosphere. Furthermore, some contaminants have negative effects on the process or the equipment, and must be removed in any case. Table 2-9 gives a summary of the major contaminants present in the flue gases and the problems they cause.

Another interesting point is that energy created by WRPtE facilities offsets that created by other power or thermal stations. In other words, the emissions from a WRPtE facility are actually causing a reduction from another source. It has been shown that this displacement actually has a positive effect on the overall emissions generated. When considering the atmospheric emissions as a whole, reducing the fuel consumption of traditional thermal and power plants, more than compensates for the emissions caused by the entire waste-related management system [73].

Table 2-9: Contaminant presence in the gas and relative problems

Contaminant	Presence	Problems
Particulates	Derived from ash, char, condensing compounds and bed material for the fluidized bed reactor.	Cause erosion of metallic components and environmental pollution.
Alkali metals	Alkali metals compounds, especially sodium and potassium, exist in vapour phase.	Alkali metals cause high-temperature corrosion of metal, because of the stripping off of their protective oxide layer.
Fuel-bound and combustion air nitrogen	Cause potential emissions problems by forming NO_x during combustion.	NO_x pollution, acid rain.
Sulphur and chlorine	Usual sulphur and chlorine content of biomass and waste is not considered to be a problem.	Could cause dangerous pollutants and acid corrosion of metals.
Tar	It is bituminous oil constituted by a complex mixture of oxygenated hydrocarbons existing in vapour phase in the producer gas; it is difficult to remove by simple condensation.	Clog filters and valves and produce metallic corrosion.

Source: [39]

2.5.4.1.2 Solid and Liquid By-products

Although incinerators are intended to burn waste-related products, liquid (e.g. from flue gas scrubbing) and solid (e.g. ash, inert materials) by-products are still produced. The ash and liquid from the process contain some of the same pollutants emitted in the flue gas. Up to 43 different semi-volatile organic chemicals have been found up until now in incinerator ash and a minimum of 16 organic chemicals in waste water [46].

Solid by-products from the incineration process contain fly ash and bottom ash. Fly ash from MW&RP is by far the most hazardous since it can contain heavy metals and traces of dioxins and furans [74]. Bottom ash is typically non-hazardous. Generally these ashes are sent to landfill where they must abide by the same environmental restriction that regular MW&RP are subject to. Ash can also be used as an additive in asphalt and concrete, to prevent these toxic chemicals from going to landfill. However, some samples taken of asphalt and concrete containing incinerator ash was noted to have “unacceptably high levels of heavy metals and dioxins.” [46].

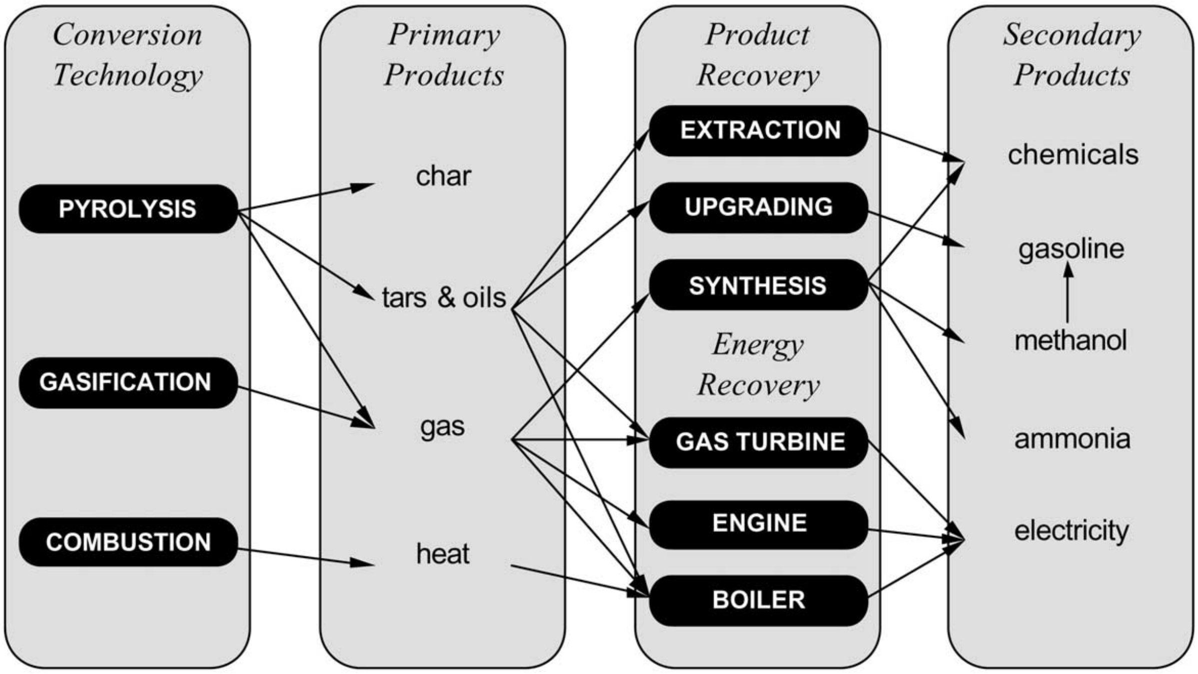
Water is used in the flue gas cleaning scrubbers. This wastewater can contain acids, sulphur, heavy metals, dioxins, furans and other toxic chemicals. The effluent must be sent to a treatment facility to have the harmful chemicals removed. After treatment to acceptable levels, the waste water is re-introduced into the lakes and rivers, but the removed hazardous chemicals still need to be disposed [46].

2.5.4.1.3 Conclusion

There are good arguments for and against energy recycling. Perhaps the compromise would be to not incinerate or landfill any waste-related products. This goes back to the primary objective of SIWRM, prevention of waste-related products, with disposal as a last resort.

But in reality, residual waste is not going to disappear in the near future. Hence, considering the advancement in thermochemical processing technology and flue gas cleaning, it seems favourable to create useful energy before sending the waste to landfill. The problematic chemicals inherent in the MW&RP would go to landfill either way. We may as well reduce the volume, do ‘energy recycling’ and promote the recycling of some of the by-products. In addition, it is much easier to deal with toxic chemicals in a controlled environment than in a landfill.

Figure 2-6 shows some of the main thermochemical conversion technologies, their by-products and ultimately what can be extracted from the processes.



Source: [39]

Figure 2-6: Thermal conversion process and products

2.5.4.2 Combustion (Incineration)

Combustion is the most cost effective and wide-spread method to extract useful energy from biomass [64]. The process is common for heating in developing countries or in rural areas. Larger facilities use the heat from combustion to produce steam and run turbine generators for electricity. Modern facilities do both, using steam for electricity and the waste heat for heating, which greatly improves the overall efficiency of the system.

Waste-related products with moisture contents (MC) greater than 50% are generally not suitable for combustion since the energy required to evaporate the water reduces the efficiency. Feedstock should be dried as much as possible prior to combustion. Combustion gases range in temperature from 800 to 1000^{o}C.

Typically the combustion process will produce about 25% bottom ash by weight of the input [72] and 1-2% fly ash [75]. This ash can contain heavy metals, hazardous materials and dioxins and furans and should be treated accordingly. In fact, as discussed previously, these elements can also be present in the flue gases. However, the system operation has a lot to do with finding these products in the flue gas or not. For incineration to occur properly;

sufficient temperature and sufficient residence time at that temperature, maximum turbulence and excess oxygen are crucial [76].

Higher temperature helps prevent un-burnt W&RP and hazardous by-products [75];

- Temperatures above 1200°C will break the molecular bonds
- Temperatures of 1100 to 1300°C are necessary to incinerate chlorinated solvents and other difficult wastes
- Temperatures of 900 to 1100°C will destroy hydrocarbons
- Below 900°C, hazardous by-products (dioxins and furans) are more likely to form
- Below 800°C, incomplete combustion is more likely which will contribute to soot formation

Typically incinerators operate around 1000°C to ensure high-efficiency combustion and destruction, and the systems are designed to operate continuously at 100°C over the normal operating temperature [76].

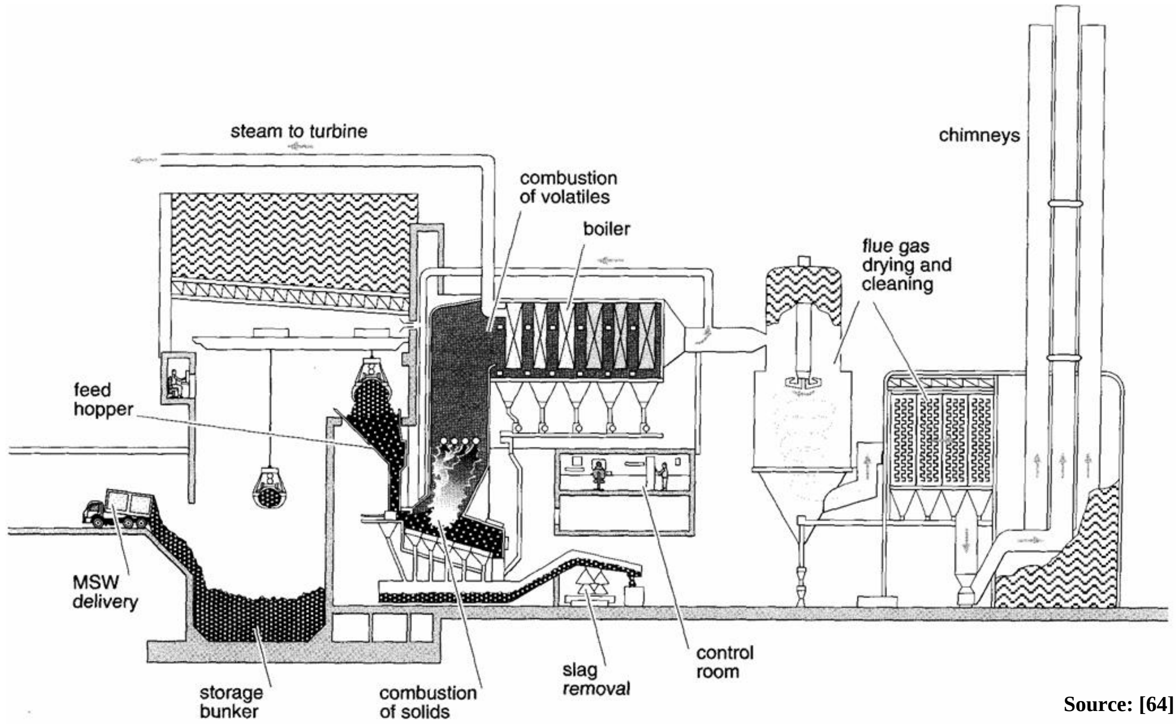
Residence time in the combustion chamber is intertwined with the temperature. Complete incineration is only possible at high heat over a duration of time, the longer the better [75]. The European Waste Directive (2000/76/EC) states that; incinerators must keep the flue gases at no less than 850°C for a period of 2 seconds to ensure adequate breakdown of organic toxins [74].

Air distribution is also crucial. Turbulence helps ensure that waste and oxygen are properly mixed to increase combustion efficiency [75]. The air distribution should also be adjustable, to ensure the proper residual oxygen concentration in the flue gases.

Oxygen quantity is also crucial. Typically an incinerator is designed to operate with 6% excess oxygen in the combustion chamber [76]. Excess oxygen ensures that oxidative processes can occur. If the oxygen concentration is less than 6% (by volume) in the combustion chamber, CO emissions will be high [75]. On the other hand, oxygen concentrations higher than 9% (by volume) will promote the creation of NO_x, dioxins and furans [75]. For these reasons, CO and oxygen monitoring is very important.

There are various types of incineration systems such as pile burning, grate fired (stationary, travelling, vibrating), suspension fired, rotary kiln and fluidized bed (bubbling (BFB) and circulating (CFB)). Each has its advantages and disadvantages based on efficiency and quality of combustion, leading to reduced un-burnt fuel emissions. In general going from pile burning through to fluidized bed combustion implies increased efficiency, quality of combustion and price.

Figure 2-7 shows an example of an incineration facility for MW&RP with energy recovery via a steam turbine. In addition, flue gas cleaners are shown since no modern day facility would be without them; they will be discussed in a later section.



Source: [64]

Figure 2-7: A Large MW&RP incineration facility

As stated earlier, when burning MW&RP the emissions can contain "various hazardous substances such as mercury and other toxic metals, particulate matter (PM), hydrogen chloride, chlorine gas, undesirable hydrocarbons (VOC's), and, most notoriously, dioxins and furans." [44]. Table 2-10 gives the distribution of pollutants found in the by-products of an incineration process. 97% of the sulphur, 99% of the chlorine, 99% of the lead and 98% of the cadmium is captured either in the bottom ash or through abatement methods, such as flue gas cleaning. Furthermore, Table 2-11 compares the European mean and the UK best practice emissions. The values are compared to 1991 levels. It can be noticed that the percent emission reduction is 89% and above for all and most are near 99%. It can be concluded from these tables that technologies are improving and although the emissions are present in MW&RP incineration, they are controllable, and surpass environmental requirements.

Table 2-10: Percentage distribution of pollutants in incineration

	S	Cl	Pb	Cd
Abatement residue	60	88	30	83
Bottom ash	37	12	70	15
Atmosphere	<3	<0.7	<1	<2.5

Source: [59]

Table 2-11: A comparison of UK (best practice) and European mean WRPtE incineration emissions and percentage improvement over UK 1991 performance

	Emission to air in mg/Nm^3 – dioxins in ng/Nm^3 – dry gas 11% O_2			**UK 1991**	**% Reduction**	**Emission burden**
Component	**Measured (UK) (best practice) (1)**	**Europea n (mean) (2)**	**Waste incineration Directive (3)**	**Mean emissions mg/Nm3 (4)**	**(4)-(1) / (4) (5)**	**Best practice emissions [a] g/te (6)**
Particulates	0.9	2.2	10	500	99.8	4.95
HC1	20	1.6	10	689	97.1	55
HF	<0.1	0.03	1	N.A.	–	0.55
SO2	36	7.2	50	338	89	198
NOx as NO2	274	29	200 (plant >3 tph)	N.A.	–	1100
CO	5	–	50	220	98	27.5
VOC	<5	–	10	NA	–	<27.5
Hg	<0.02	<0.001	0.05	0.26	99	0.11
Cd	<0.001	<0.001	0.05 (Cd & TI)	0.6	99.8	0.0055
Heavy metal summation	R7	R12	0.5	>11.0	99	<0.55
	<0.1	0.16				
Dioxin I-TEQ (ng/Nm3)	0.006	<0.01	0.1	>225	99.9	33 ng
NH3	–	–	<0.1	–	–	–
Non-biogenic CO_2 = 132 kg						

[a](based on (1)) plus NOx of 200 mg/Nm3 and HCl of 10 mg/Nm3

Source: [72]

2.5.4.2.1 Combustion vs. Gasification and Pyrolysis

Although combustion of MW&RP is the most widespread WRPtE technology, it does have its limitations. How does it compare to gasification and pyrolysis?

Some advantages of gasification and pyrolysis over combustion [75]:

- Better emission control, since gas cleaning can occur prior to combustion
- By-products can be sold
- No oxygen implies no dioxins or furans
- Higher thermal efficiency
- Metals are not oxidized
- Smaller amounts of gas to clean (syngas vs. flue gas after combustion)

Some advantages of combustion over gasification and pyrolysis [75]:

- Combustion technology has been around for longer, especially for W&RP

- Capital costs are lower
- Air is cheaper than oxygen
- High pressures may be required especially for hydro-conversion
- Chlorine can cause some problems
- Market may not be developed to purchase by-products steadily
- Corrosion of ash
- Gas cleaning has its challenges (NH_3, H_2S)

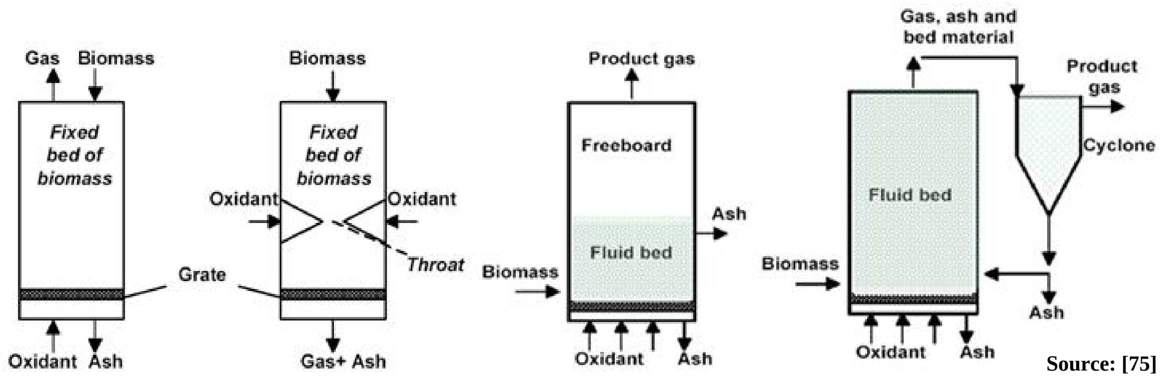
2.5.4.3 Gasification

Gasification involves partially oxidizing the fuel using air or oxygen and steam. The process takes place between 800 and 1000^{o}C and from 0 up to some 30 atmospheres of pressure [64]. The advantage of such conversion process is to upgrade the quality of the fuel. By gasifying the feedstock, gas cleaning is possible and it can then be used for many other purposes other than simply direct heat. The gaseous product of this process is called producer gas and is a mix of combustibles (carbon monoxide and hydrogen with methane and other HC's and condensable tars) along with CO_2 and water [64]. The producer gas is then combusted in a gas turbine, hydrogen and other HC's can be separated or synthetic gas made. Inert, non-combustibles are also present such as small char particles, ash and tars. There are three main types of gasifiers; fixed, fluidized bed and indirect gasifier.

Fixed-bed gasifiers are the traditional technology and can be further differentiated by the direction of the air flow; Updraft, downdraft and cross-flow. For more detailed information see [77]. The energy content of the resulting gas is about 75% of the initial feedstock, but initial moisture content should be less that 20% [77].

Fluidized bed (FB) gasifiers have been used for many years with coal. Their main advantage over the fixed bed type is the uniform temperature distribution in the gas chamber. This leads to more complete gasification of the fuel and hence higher efficiencies. There are 2 main types of fluidized bed gasifiers; circulating (CFB) and bubbling (BFB).

Indirect gasification does not use an oxidizing agent whereas direct gasification does, Figure 2-9. In the case of indirect gasification, heat must be provided from external sources.



A) Updraft B) Downdraft C) Bubbling Fluidized Bed D) Circulating Fluidized

Figure 2-8: Fixed and fluidized bed gasification

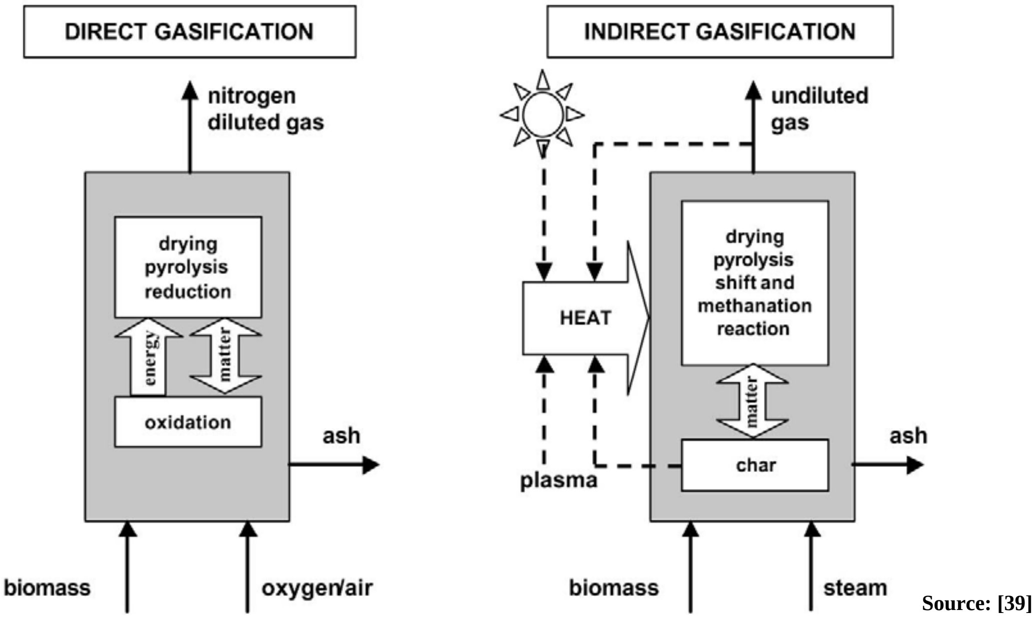


Figure 2-9: Direct and indirect gasification

One major factor which contributes to the quality of the produced gas is the gasifying agent, see Table 2-12. It should be noted however, that there is a sharp rise in cost as the quality is increased. Direct gasification with pure oxygen compared to indirect with steam is comparable in performance, but the cost of pure oxygen is much higher. It is estimated that for the former, oxygen production costs over 20% of the overall electricity production [78]. For this reason, most gasifiers use air and steam since other agents are not economical with current technologies.

Not all W&RP are suitable for gasification. Typically, the feedstock must be sorted prior to gasification, to leave only paper mills *waste*, mixed plastic *waste*, forest industry *waste* and agricultural residues [79]. Even sorted waste-related fuel can cause problems in the reaction chamber, which requires scheduled shutdowns every few months for cleaning. This compromises the availability of this process as a source of energy [80].

Table 2-12: Effect of gasifying agent on producer gas quality

Process	Heating Value of the producer gas (MJ/Nm^3)	Gasifying Agent
Direct gasification	4-7	Air
Pure oxygen gasification	10-12	Oxygen
Indirect gasification	15-20	Steam
Hydrogen gasification [77]	40	Hydrogen and hydrogenation

Source: [39]

2.5.4.3.1 Pollutants

Like combustion, there is a certain amount of pollutants created as by-products to W&RP gasification. However, gasifying the feedstock prior to combustion allows for better control of CO, NO_X, dioxins and un-burnt compound emissions [39]. In addition, pre-treating the gas helps remove potential pollutants such as chlorine and nitrogen [39]. Table 2-9 shows some of the contaminants that could cause problems. In Table 2-13 the requirements for certain energy conversions end products are shown. This table clearly indicates that if electricity is desired from the producer gas it must be cleaned up in any case, regardless of the source.

Table 2-13: Gas quality requirements/energy recovery system

	Boiler			
	Stand alone	**Co-firing**	**Engine**	**Gas turbine**
LHV (MJ/Nm3)	>4	None	>4	>4
Particulate (mg/Nm3)	None	None	<5–50	<5–7
Tars (g/Nm3)	None	None	<0.5	<0.1–0.5
Alkali metals (ppm)	None	None	<1–2	<0.2–1

Source: [39]

Even if the gasification of waste is better than combustion in terms of emissions, there still needs to be some gas cleanup prior to combustion. One of the advantages of gasification over combustion is the ability to do just that. As a result, the volume of gas being cleaned is much smaller for the gasification process, since it does not include combustion air, not to mention many of the harmful emissions have not had a chance to oxidize yet. Nevertheless, the producer gas still has some contaminants that must be removed prior to combustion. Table 2-14 gives a list of some of these problems and the recommended clean-up method.

Solid residues such as char and ash still contain heavy metals and should be disposed in landfills [39]. The char and ash is collected in three main parts of the process; 2-9% in the gasifier, 5-10% in the particulate control equipment and 3-6% in the boiler (if used) of the initial feedstock mass [39].

Table 2-14: Fuel gas contaminants: problems and cleanup processes

Contaminant	Range	Examples	Problems	Cleanup method
Particulate (g/Nm3)	3–70	Ash, char, fluid bed material	Erosion, emission	Filtration, scrubbing
Alkali metals (g/Nm3)		Sodium and potassium compounds	Hot corrosion	Condensation and filtration
Fuel nitrogen (g/Nm3)	1.5–3.0	Mainly NH3 and HCN	NOx formation	Scrubbing, SCR
Tars (g/Nm3)	10–100	Refractory aromatics	Clog filters, deposit internally	Tar cracking, scrubbing
Sulphur, chlorine (g/Nm3)	2.5–3.5	H_2S, HCl	Corrosion, emission	Lime scrubbing

Source: [39]

Wastewater is produced from various equipment, such as gas coolers and wet scrubbers. Included in this waste water are soluble and insoluble pollutants (mainly tar); acetic acid, sulphur, phenols and other oxygenated organic compounds [81]. Tar removal can be difficult and expensive to do, Table 2-15 compares three (3) methods.

Table 2-15: Advantages and disadvantages of tar removal systems

System	Advantages	Disadvantages
Thermal cracking	Simple control Low cost	LHV losses Low efficiency
Catalytic cracking	LHV unchanged Upgrade too No gas cooled	Catalyser cost Difficult control
Scrubber	Easy control Air pollution control	LHV losses Gas cooled Wastewater production

Source: [39]

2.5.4.4 Pyrolysis

Pyrolysis is a form of indirect gasification (Figure 2-9) that uses an inert gas as the gasifying agent [39]. The process takes place around 500-600^{o}C in the absence of oxygen [56]. The process produces syngas, char and tar, in fractions that are dependent on the temperature, residence time and heating rate [56]. Traditionally wood was used to produce charcoal via this process, except the volatiles were not collected. Since biomass is comprised of mostly volatiles this was very wasteful. Present day technology condenses the gas to produce bio-oil, a substitute for petrol products. This oil can then be used for heating or in a gas turbine for electricity or treated and used in vehicles. McKendry [63] reports that if flash pyrolysis is used bio-oil can contain as much as 80% of the initial feedstock energy. Fast pyrolysis (short residence time, high heating rate) can be used to have a higher tar yield, whereas slow pyrolysis (long residence time, low heating rate) will maximize syngas and char production [56].

The syngas produced depends on the MW&RP composition and has a heating value much lower than natural gas [56]. The char is comprised of unconverted organic solid and ash resulting from inorganic materials. It has a heating value equivalent to lignite and coke [56]. The tar fraction is a liquid mixture containing resins, acids, alcohols, intermediate carbohydrates, phenols, aromatics and aldehydes [56].

There is still little practical information on using MW&RP in the pyrolysis process, but it is clear that it still has the same environmental issues as combustion and gasification, including dioxins and furans, mercury and other heavy metals, particulate matter, carbon monoxide, hydrogen chloride, sulphur dioxide, and more, as well as toxic contaminants in the char or ash residues, and contaminated waste water [82]. However, pyrolysis is being used in combination with gasification in newer technologies, as is seen in plasma gasification.

2.5.4.5 Plasma Gasification

Plasma gasification is an interesting emerging technology for WRPtE conversion. It is "a drastic non-incineration thermal process, which uses extremely high temperatures in an oxygen-starved environment to completely decompose input waste material into very simple molecules." [83]. It combines indirect gasification, pyrolysis and plasma[viii] arc torches to disassociate the molecules. The plasma torch can reach temperatures up to 15,000^{o}C and it can control temperature independent from the feed quality and supply of air, oxygen and steam [84]. Plasma gasification generates two products: syngas and vitrified slag [84]. At the high temperatures, all the inert materials (glass, metal, silicates and heavy metals) are fused into a volcano lava type fluid, and then hardened to form a silica matrix [84]. The vitrified slag can be used as an aggregate in concrete [83], as a sub-base in road construction, for sand blasting [85] and even as raw material for ceramic products [84]. Even more important, dioxins and furans are reliably destroyed along with other organic contaminants during the gaseous and liquid phases of the process [85]. A facility for plasma gasification and vitrification of MW&RP is composed of four main sub-processes;

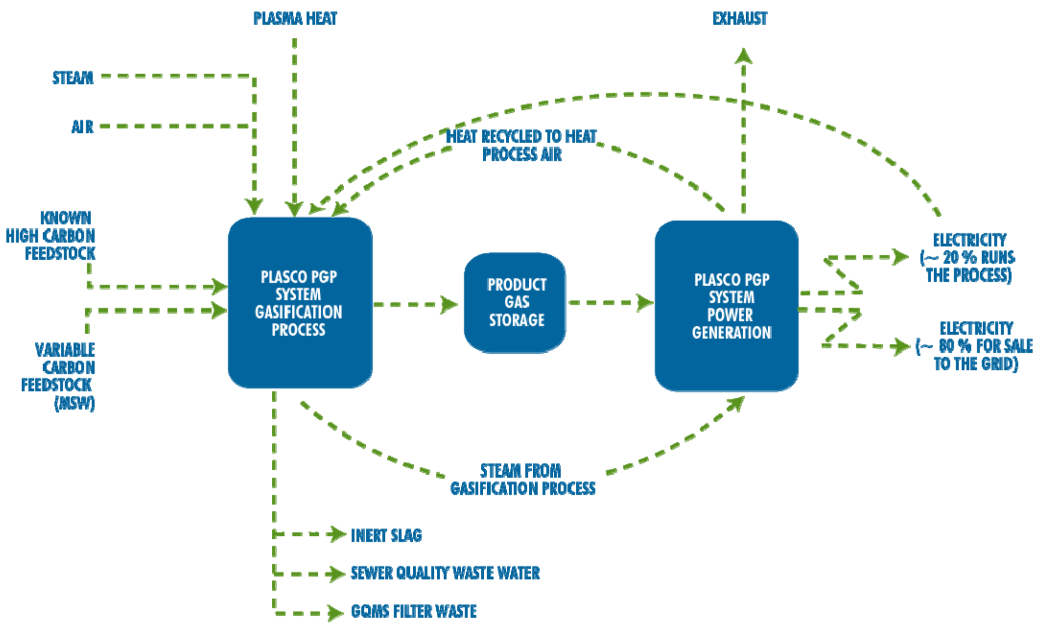
1. Pre-treating the MW&RP;

[viii] "Plasma refers to every gas of which at least a percentage of its atoms or molecules are partially or totally ionized." [83]

- Separating out low caloric value waste (glass, grit, metal),
- Coarse shredding.

2. Syngas and Inert slag production;
    - Pyrolysis,
    - Gasification,
    - Vitrification.
3. Syngas Scrubbing (cleaning);
    - Particulate matter (PM),
    - Acid gases,
    - Heavy metals.
4. Power generation;
    - Electricity,
    - Combined Heat and Power (CHP).

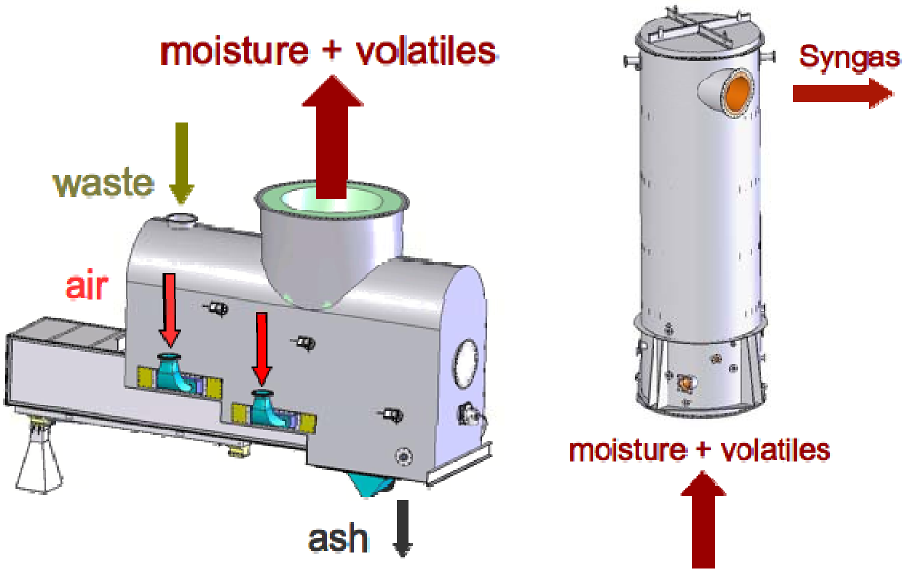
A pilot project of this technology is in the last stages of commissioning (at time of writing). The Plasco Energy Group [86] is using sorted MW&RP to produce electricity. The following description follows their process, Figure 2-10.



Source: [86]

Figure 2-10: Overview of the Plasco plasma gasification process

Pyrolysis involves the exposure of organic materials to temperatures in excess of 400°C in an oxygen-starved environment. The foremost products of the process are moisture and volatiles in the form of large HC, H_2O, H_2, N_2, CO, and CO_2, ash or tares, and fixed carbon, mostly the inorganic fraction of the waste. Plasco's approach utilizes a three stage primary reactor vessel (Figure 2-11) that allows for full control of fuel feed rate and mixing, temperature, and air flow rate. The incoming air is preheated to approximately 600°C using a heat exchanger that allows it to extract heat from the Syngas farther downstream (that is operating between 1000-1100°C). Both pyrolysis and gasification occur here.



Source: [86]

Figure 2-11: Primary (left) and Secondary (right) Reaction Vessels for Plasma Gasification Process

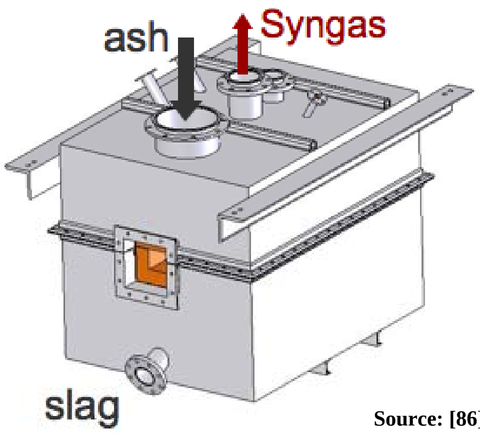
The refractory lined reactor vessel features an open-core downdraft-like design in that the MW&RP enter from the top, the moisture and volatiles exit from the top, the air enters from the sides, and the ash exits from the bottom of the chamber. An extendable grate that promotes mixing moves the feedstock between stages at a controllable rate.

The product gas from the first chamber (mainly CO, H_2, tars and un-reacted carbon) continue to the second stage (Figure 2-11), where plasma gasification occurs. The gas and process air are combined with the plasma heat to destroy all long chain hydrocarbons. The plasma torches are never in contact with the MW&RP, they are just used as a highly efficient way to refine the syngas [86].

Two 300kW Phoenix DC plasma torches with copper electrodes are inserted along the top of the vessel. The torches are aerodynamically controlled such that the arcs are located closer to the center of the reaction vessel. This promotes greater interaction with the Syngas which is heated to 1000-1100°C.

Contrary to most processes that rely on direct plasma heating of the fuel for gasification, Plasco uses the ionization cascade in plasma as a catalyst to gasification. The high reactivity of electrons and positively charged ions accelerate molecular dissociation. The long hydrocarbon molecules that remain after the primary (pyrolysis) are then destroyed and refined, leaving a cleaner and lighter Syngas. The Syngas is mainly composed of CO and H_2, however N_2, CO_2, HCl, NOx, CH_4, HCN, and COS can also be present.

The inorganic components remaining after pyrolysis/gasification move onto the third stage (Figure 2-12) where they are vitrified into an inert slag in the form of a silica matrix. Of recent interest, is the improvement of the remaining slag for applications such as those mentioned above. In addition studies have shown that with the addition of SiO_2 and MgO, leaching of heavy metal ions is significantly reduced [87]. Furthermore, these glasses showed an increase in Vickers hardness, bending strength, and toughness [87].



Source: [86]

Figure 2-12: Vitrification Vessel for Slag Melting

Plasco's vitrification vessel is shown in Figure 2-12, utilizes a single 300kW Phoenix DC plasma torch to apply direct heat to the fly ash that remains after the primary and secondary vessels. Unlike the approach for gasification, this process relies on direct heat from plasma to melt the ash. The remaining volatiles and fixed carbon are further converted to Syngas by setting the temperature to 1300^{o}C in order to promote carbon-monoxide formation.

The residue is then vitrified to form inert slag at a rate of 150kg/tonne of MW&RP. Silica, glass, and aluminum require 1300^{o}C whereas steel is heated to 1650^{o}C. Preliminary results have shown a 5-10 fold volume reduction of ash and effective destruction of dioxins, furans, and inertisation of heavy metals.

The syngas is then cleaned before storage and power generation.

2.5.4.5.1 Pollutants

Plasco uses an activated carbon filter that removes particulate matter and heavy metals, particularly mercury, simultaneously. The residue is collected at a rate of 1.3kg/tonne of MW&RP and accumulates in a baghouse (the only non-reusable waste produced by the entire process). A flow chart of the fuel scrubbing and separation processes is presented in Figure 2-13, and shows the pre-cooling of the Syngas with a dry quench. This avoids unnecessary filter damage due to high temperature and also filters Cl^-. The process also includes an activate carbon bed that acts as a second mercury filter further downstream. It has been suggested that the particulates and heavy metals recovered could be re-injected into the slag once dewatered and dried for further vitrification [84], however Plasco has not attempted to do so. HCl, HF and NH_3 can be removed with an acid scrubber. A venturi type scrubber is ideal because it eliminates dust as well [84].

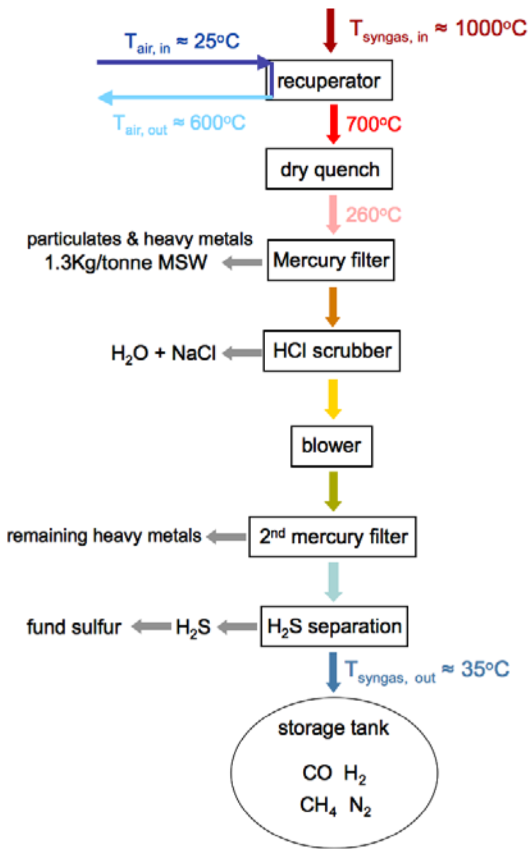


Figure 2-13: Syngas Scrubbing and Separation Flow Diagram

An H_2O spray is used to convert Cl^- to HCl such that no chlorine remains bonded to large molecules. The H_2O + HCl mix is neutralized with caustic soda and forms an NaOH + H_2O mix. The NaOH is reused as road salt once filtered from the water which is said to be "suitable for irrigation or for use in industrial processes" [86] once cleaned. How much cleaning is necessary, or the amount of energy required to power this process, has yet to be determined.

HCN, SO_2, H_2S can be removed with an alkaline scrubber. An alternative is wet lime sorption, where CaSO3, $Ca(CN)_2$ and CaS are formed [84]. Plasco removes the H_2S using a bacterial filter from Shell/pacques called the Thiopaq. The H_2S dissolves in an NaOH caustic solution and is re-converted to sulphur [88]. The process can remove >96.5% H_2S [89]. SO_2 is not produced.

Dioxins and furans can be limited by high temperature removal of dust because it is a precursor to their formation when the Syngas cools [84]. Emission testing has shown no traces of dioxins or furans in the Plasco process.

Most important to consider when designing a cleaning system for plasma gasification is that it include heat recovery to cool the Syngas, dry scrubbers for particulate matter and heavy metal removal, and wet scrubbers for acid gas removal.

Pollutant air emission measurements were taken by Liu and Liu for a pyrolysis/gasification pilot plant [90]. Measurements were taken for particulate matter (PM), CO, SO_2, NOx, HCL, HF, and dioxins. All pollutant levels were below Chinese EPA, EU, and US EPA limits except for HF, which exceeded the EU standard. Another study found the exhaust gas composition for both gas phases to have particulate values all below Korean emission standards [91].

Table 2-16: Projected Emission data for Plasco Energy

Item	Ontario - Current Limit	Limits Agreed to by Plasco Energy	Expected Performance Under Local Conditions	Units
Carbon Monoxide	55	-	34	mg/m3
HCl	18	13	1	ppmv
Nitrogen Oxides	110	110	20	ppmv
SO2	21	14	4	ppmv
Organic Matter	100	75	25	ppmv
Particulate Matter	17	12	2.5	pg/ m^3
Mercury	20	20	0.5	µg/ m^3
Cadmium	14	14	1	µg/ m^3
Lead	142	142	12	µg/ m^3
Dioxins and furans	80	40	0	pg/m^3

Source: [86]

Table 2-16 compares Ontario's operational limits to the predicted performance of the Plasco plant. Although no actual data has been published (still in commissioning phase), based on the results from comparable processes, emission concentrations should be within the provincial limits.

2.5.5 Engineered Landfill

Landfill is still a major part of our waste-related management system. Although it should only be used as a last resort, it seems that there is still a need for it. Thermal and chemical treatments of W&RP are not the only processes to have seen technological growth. Landfills have vastly improved in terms of their environmental impacts. Engineered landfill sites are designed to dispose of residual waste in a secure manner, which keeps the impacts on the environment to a minimum [92], Figure 2-14.

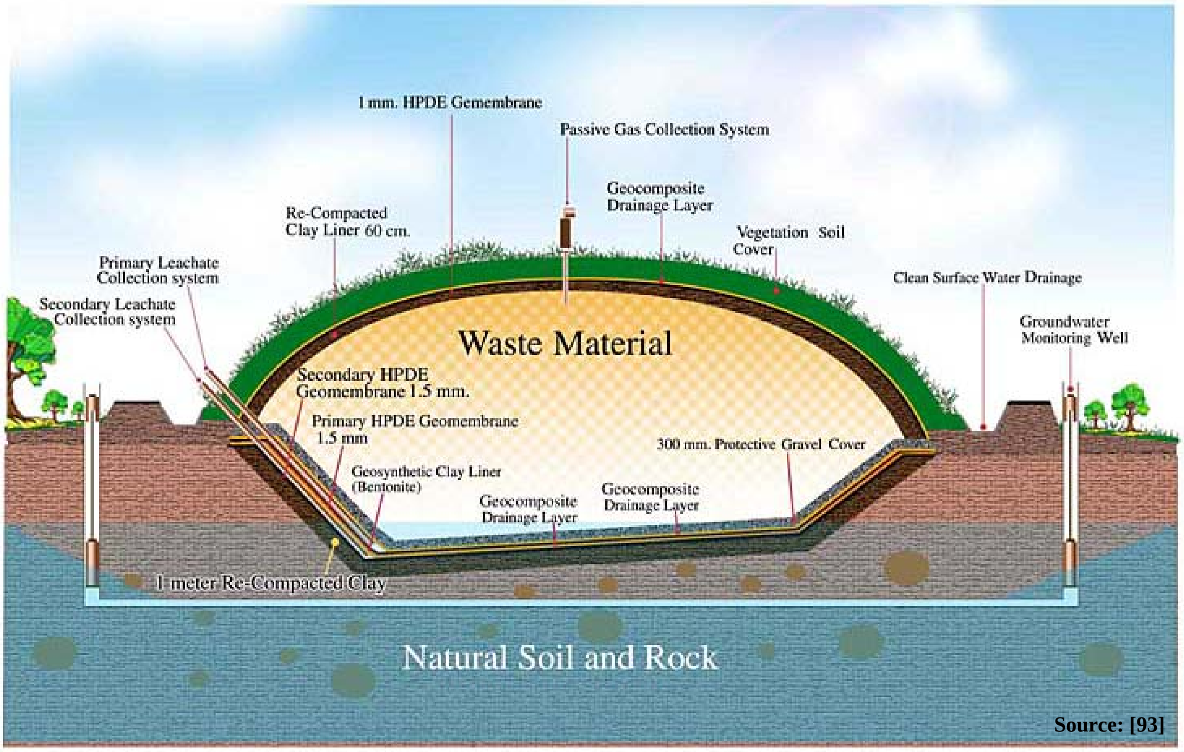


Figure 2-14: Engineered Landfill

The waste & recoverable products are placed in a waterproof cell (lined with a rubber geo-membrane), levelled, compacted and periodically covered with soil to keep odours and vermin to a minimum. At the bottom of each cell is a network of perforated pipes to capture the leachate. Leachate is water that infiltrated into the cells and mixes with the W&RP. Evidently, the percolating rain water captures contaminants from the W&RP as it passes. The resulting leachate can be comprised of the following (but not limited to) [94]:

- Dissolved organic matter (alcohols, acids, aldehydes, short chain sugars etc.)

- Inorganic macro components (common cations and anions including sulphate chloride, Iron, aluminum, zinc and ammonia)
- Heavy metals (Pb, Ni, Cu, Hg)
- Xenobiotic organic compounds such as halogenated organics (PCBs, dioxins etc.)

The leachate is collected in a pond and treated before being released back into the environment. Surface water is also collected in trenches around the landfill site and sent to the same pond for treatment.

Once these cells are full, they are covered with a rubber membrane and gas wells are installed. These wells remove the gas produced from the natural decomposition of organic matter (see anaerobic digestion above). The produced gas is mainly methane (50-75% of total gas vol.) and CO_2 with traces of hydrogen sulphide. But due to the nature of the landfill waste (MW&RP, IC&I, construction and demolition), many other harmful gases are created. The collected gas can then be flared or combusted to produce energy.

However, the decay of the biodegradables happens over a long period of time. So long that it takes 20 years for the majority of the gas to be produced (although this varies quite drastically), and can continue for 50 years [95]. For this reason, critics say that only a small percentage of the gas is actually captured and hence it is a flawed environmental mitigation measure. The US EPA had stated that 75% of the landfill gas could be collected over the lifetime of a site [96]. After closer inspection however, these figures are way off. Table 2-17 shows that in fact, the collection efficiency of the landfill gas is more like 19% over the 100 year time horizon. This translates into a reduction of 0.01 ton CO_{2eq}/wet ton of MW&RP, or 5.1% over the lifetime of the landfill [96]…Hardly worth the effort. It is by far more effective to ban biodegradables from landfills than to try and capture the gas.

Table 2-17: Collection of landfill gas

Phase	Time Interval (years)	Portion of Gas Produced in Time Period	Collection Efficiency in Time Period	Weighted Collection Efficiency
Before Pipes	0 to 5	6.0%	0.0%	0.0%
Before Cover	6 to 10	11.9%	25.0%	3.0%
Functioning	11 to 30	32.1%	50.0%	16.1%
After shutoff	31 to 100	50.0%	0.0%	0.0%
Total		100.0%		19.0%

Source: [96]

In an effort to address some of the escaping methane after a site has been closed, a restoration layer can be added above the rubber membrane, identified in Figure 2-14 as the soil cover.

This has two effects; one to improve the appearance of the landfill and two to convert some of the methane into CO_2. As escaping methane passes through the restoration layer, it comes in contact with methanogens which then create CO_2 [43]. Although logical, this option is not always practical or financially feasible.

Another area for malfunction is the liners. Ultimately, over time they will fail [97]. A truly sustainable landfill would ensure that W&RP products are safely assimilated into the environment [97]. Although this might not be possible in the long term (gas release and geo-membrane failures), it is at the political level where criteria need to be established and enforced to ensure that the environmental impacts are minimal [97]. Fundamentally, there are plenty of existing, operating landfills which need to be “cleaned up” and engineered landfills can offer some help in this respect. Also, the new and innovative WRPtE technologies (clean incineration or plasma gasification) still do produce a certain amount of waste as by-product, which require landfill. Hence, landfills may still be required in the foreseeable future.

2.5.6 Conclusions – Energy Recycling

In summary, waste-related products to energy technologies are far from perfect. However newer conversion and emission cleaning technologies have shown to be leagues ahead of their predecessors. Furthermore, when it comes down to the disposal of W&RP, the alternatives are WRPtE vs. landfill. Both have their pros and cons, but the reality remains:

- WRPtE is a form of ‘energy recycling’, where landfills represent wasted resources and energy
- Landfill gas capture has been proven flawed at best
- Both processes produce solid, liquids and gaseous by-products that require treatment however, WRPtE is performed in controlled environments where these things can be mitigated

Furthermore, within the hierarchy of WRPtE, incineration is the least desirable (less efficient, more problems with emissions) and newer, higher temperature process are better (such as plasma gasification). For some of the more traditional technologies, the electrical conversion efficiencies are included in Table 2-18.

Table 2-18: Conversion efficiency of electricity generation processes

Conversion Process	Power Cycle	Size (MWe)	Efficiency (%)	Efficiency Formula (%)
Combustion				
Grate firing	Steam cycle	0.11 - 150	17 - 37%	eff = 2.3365*Ln(MWe) + 21.642
Fluidized bed combustion	Steam cycle	0.5 – 200	17 - 33%	eff = 2.3383*Ln(MWe) + 20.204
Gasification				
Downdraft-gasification	Gas engine	<5	20 - 30%	-
Updraft-gasification	Gas engine	0.5 - 50	25 - 30%	-
Fluidized bed gasification—atmospheric	Gas engine	0.5 – 200	20 - 35%	eff = 1.7021*Ln(MWe) + 24.298
Fluidized bed gasification—atmospheric	Combined cycle	5 – 200	30 - 45%	eff = 3.8902*Ln(MWe) + 23.423
Fluidized bed gasification—pressurized	Combined cycle	5 – 300	40 - 50%	eff = 1.2537*Ln(MWe) + 39.981
Anaerobic Digestion				
Digester	Gas	-	20 - 50%	-
Digester	Gas engine	0.05 - 30	10 - 16%	-

Source: [98]

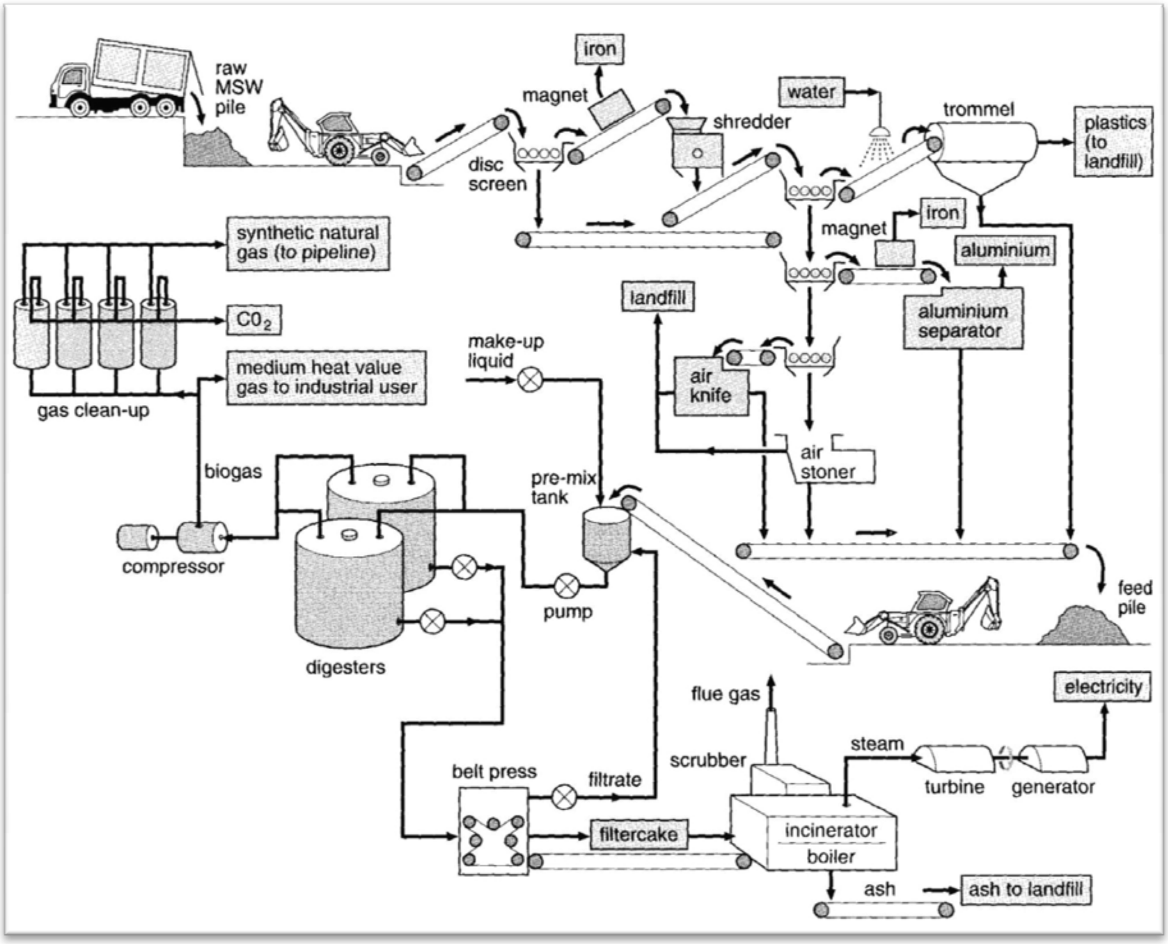


Figure 2-15: Example of a sorting and WRPtE facility

In general organics are better suited for biochemical conversions and more complex hydrocarbons (e.g. plastics) for thermochemical processes. In almost all cases, physical processing is required in order to sort out the required products. Within an SIWRM scheme, this can actually promote recycling, reuse and ensure that W&RP are being used as they should. Figure 2-15 gives an example of a sorting and biochemical WRPtE facility. It should be noted however, that the plastics and metals being sent to 'landfill', and should in fact be going to recycling or further thermal processing.

2.6 Conclusions

In this chapter, the concept of sustainable & integrated waste-related management was presented. From this discussion it has become clear that waste-related management has been around for centuries, and it has evolved out need for survival (keeping disease, rodents and animals away from cities). However, since the industrial revolution we have been extracting resources and wasting them at exponentially increasing rates. This has caused a stress on our environment and we are now faced with the dilemma of dealing with the effects of our "progress". For this reason, modern waste-related management strategies are needed more than ever.

The traditional waste-related management hierarchy has gotten us to this point, but it is no longer enough, primarily because it's misused and secondly because it does not address the bigger picture inherent in the sustainable development context. A major shift is required in the way we perceive and generate waste-related products. The first step is minimisation and prevention. This can only be achieved by changing our habits, i.e. consuming less and buying durable products with minimal packaging. Inevitably, some waste and recoverable products will always be generated and diversion from disposal is essential, i.e. reusing, composting and recycling. Recycling is a last diversion resort since it is energy intensive and degrades the quality of the materials the more it gets recycled. Finally, there will always be certain amounts of residual waste and recoverable products requiring disposal.

There are two ways to dispose of these residual materials: waste-related products to energy or landfill. It has been shown that landfills offer few benefits over energy recycling. Considering transportation and land costs, environmental accidents, operating lifetime and clear overstatement of the landfill gas capture potential, landfills have become less and less popular. Waste-related products to energy facilities on the other hand are not ideal either. They can produce toxic emissions, solid and liquid hazardous by-products and they are expensive. However, these unwanted elements are produced in closed environments with emission cleaning technologies and hence are more readily controllable. In addition, useful energy is created which actually has a positive effect on the environment since the atmospheric emissions as a whole caused by WRPtE facilities offset those from other power generation. For the same energy generated, WRPtE facilities have proven to be better in terms of global warming, human toxicity, acidification and photochemical oxidation.

WRPtE facilities offer a tangible solution for our residual waste issues. Depending on the inputs and desired outputs there exist many different technologies, ranging from anaerobic digestion, basic incineration to newer plasma gasification processes.

Each technology has its merits and drawbacks, which depend a lot on how the facilities are operated. But in general, the higher temperature processes offer the best energy conversion and pollution control. Plasma gasification is proving to be a cost effective, environmentally sound and innovative solution to our residual waste problems.

Anaerobic digestion (with energy production) or aerobic digestion (composting) should happen in any case, regardless of one's position on WRPtE. Organics comprise over 1/3 of our municipal waste and recoverable products and are the main drivers of landfill gas and odours. They should never be sent to landfill. Simply by excluding these from the W&RP stream, the disposal system is significantly reduced.

In essence this chapter has shown that current waste-related management systems are flawed and need revision. We can never achieve a sustainable development without applying a new hierarchy and a broader spectrum of initiatives that encompass the entire waste-related stream. At the forefront is reduction. The concepts of ownership and accountability should be rigorously applied, i.e. if you produce it, buy it or throw it away, you should be responsible for it.

CHAPTER 3: CANADIAN SUSTAINABLE AND INTEGRATED WASTE-RELATED MANAGEMENT POLICY

3.1 Introduction

Canada is a vast country, with a low population density. Each province and territory is responsible to set its own waste-related management policy and the regions or municipalities must develop their own plans based on their local needs. As a result it is difficult to have unified and consolidated targets across the nation.

As described in the previous chapter, many of the modern day applications of Sustainable and Integrated Waste-Related Management (SIWRM) require strong leadership, public education, inter-departmental cooperation and public funding. This chapter will investigate these elements in Canada by discussing federal and provincial strategies and policies relating to this topic.

Canada is also one of the greatest producers of waste & recoverable products in the world, as seen in chapter 1. The details of the current MW&RP situation in Canada are explored in this chapter with comparisons made between the provinces and territories. Canada's performance is also compared with other countries in the world.

The goal of this chapter is to elaborate on the current Canadian geo-political climate regarding waste-related management and give some recommendations on how things could be improved based on the hierarchy discussed in chapter 2. The conclusions of which will be combined with those of chapter 4 to help guide Canada towards a more sustainable future.

3.2 Canadian Performance

Canada is blessed with a large amount of land and a low population density. The country covers 9,017,699 km^2 with a population of 31,612,897 (2006), hence a population density of 3.5 people/km^2. Only six metropolitan areas in the country have over 1 million inhabitants, which account for more than half the country's population, living on less than 0.5% of the land (average urban population density of 375 per km^2). Many areas of the country are remote and sparsely populated. For example, the Yukon, Nunavut and Northwest Territories (NWT) have less than 0.03 inhabitants per km^2. Removing the 3 territories and the major metropolises from the calculations, the balance of rural Canada is populated by 2.8 people per km^2. Table 3-1 shows a breakdown of Canada's pertinent population statistics.

Table 3-1: Population across Canada

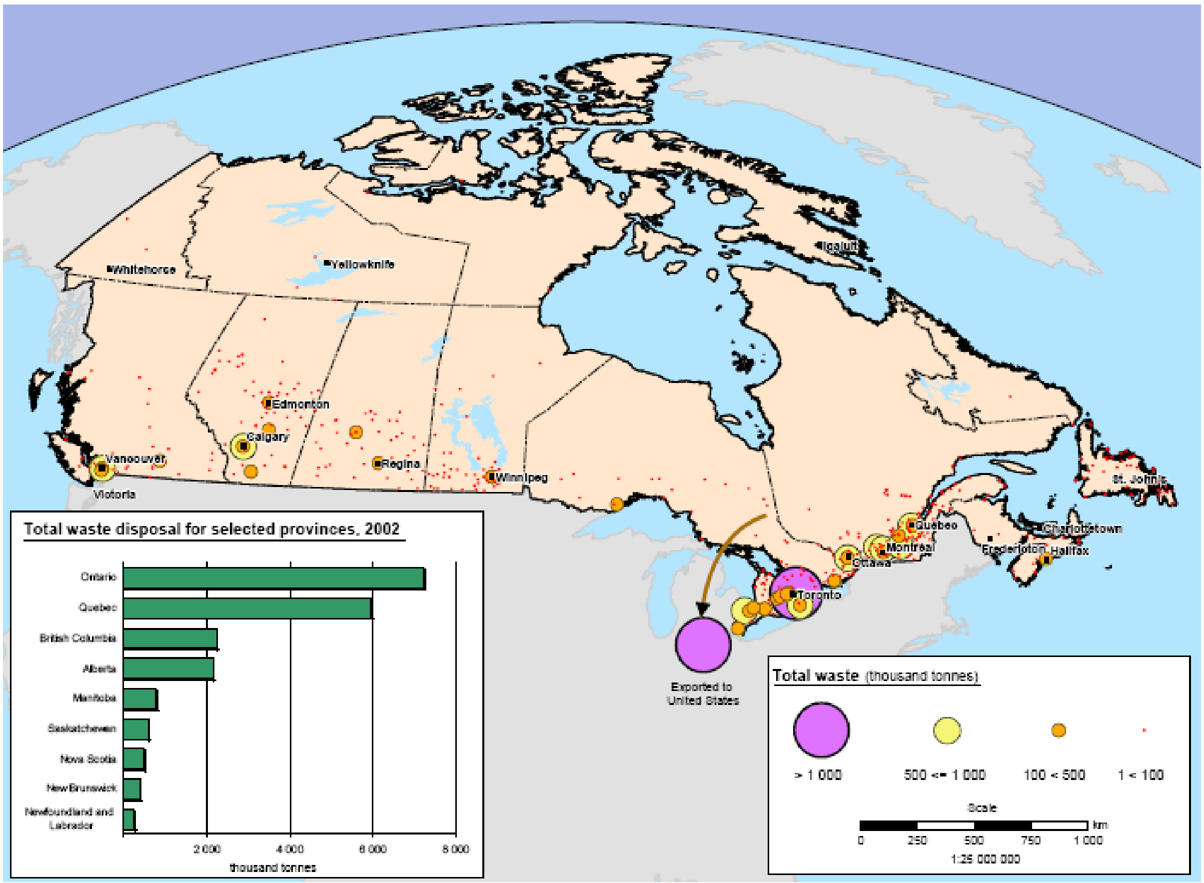
City	Population[a]	Area (km^2)[b]	Population Density
Major Cities			
Toronto, Ontario	2,503,281	630	3,972.4
Montreal, Quebec	1,854,442	499	3,714.9
Calgary, Alberta	988,193	727	1,360.2
Ottawa, Ontario	846,802	3,274	258.7
Edmonton, Alberta	730,372	684	1,067.2
Winnipeg, Manitoba	633,451	464	1,365.2
Vancouver, British Columbia	578,041	115	5,039.0
Hamilton, Ontario	504,559	1,117	451.6
Quebec City, Quebec	491,142	454	1,081.2
Total	**9,130,283**	**7,964**	**1,146.4**
	28.9%	**0.1%**	
Major Metropolitan Areas			
Toronto, Ontario	5,113,149	5,904	866.1
Montreal, Quebec	3,635,571	4,259	853.6
Vancouver, British Columbia	2,116,581	2,877	735.6
Ottawa, Ontario & Gatineau, Quebec	1,130,761	5,716	197.8
Edmonton, Alberta	1,034,945	9,418	109.9
Calgary, Alberta	1,079,310	5,107	211.3
Quebec City, Quebec	715,515	3,277	218.4
Winnipeg, Manitoba	694,668	5,303	131.0
Hamilton, Ontario	692,911	1,372	505.1
Total	**16,213,411**	**43,233**	**375.0**
	51.3%	**0.5%**	
Rest of Canada			
Yukon, Nunavut and NWT	101,310	3,547,801	0.03
	0.3%	**39.3%**	
Rest of Canada	15,298,176	5,426,665	2.8
	48.4%	**60.2%**	
Canada	**31,612,897**	**9,017,699**	**3.5**

[a] Population excludes census data for one or more incompletely enumerated Indian reserves or Indian settlements.
[b] Area does not include lakes and river.

Source: Statistics Canada Census 2006 [99]

This dispersed population over such a varying geography makes it difficult to manage municipal services with common, set guidelines. In terms of waste-related management, the problem is quite evident. As an indicator of the urban centers in Canada, Figure 3-1 is a map displaying the generation of total waste & recoverable products. This figure further emphasises the need for local attention to W&RP management. Take note of the large portion of W&RP being exported to the United States. Even with Canada's large amount of land, approximately 3 million tonnes of non-hazardous W&RP generated in Canada is exported to the United States each year [104].

Canada's population is dispersed. For this reason, waste-related management is no easy task especially outside of the major metropolises. The majority of Canada's waste is sent to landfill, which is also as a result of this low population density. Of the 33.2 million tons of municipal waste and recoverable products (MW&RP) generated (Figure 3-2); 24% is diverted, 74% is sent to landfill and 2% is incinerated, see Figure 3-3. On average the other OECD countries landfill about 58% of the generated W&RP [41]. The figure also shows the waste & recoverable products composition. From this, it is clear that 46% of the WRP is recyclable (paper, plastic, metal and glass), 28% compostable and 8% wood. In essence, without knowing what the ‘other’ WRP are, 82% of the total could be diverted and the remaining 18% would need to be disposed. Canada is diverting only 24% when it could conceivably reach 82%...there’s much room for improvement.

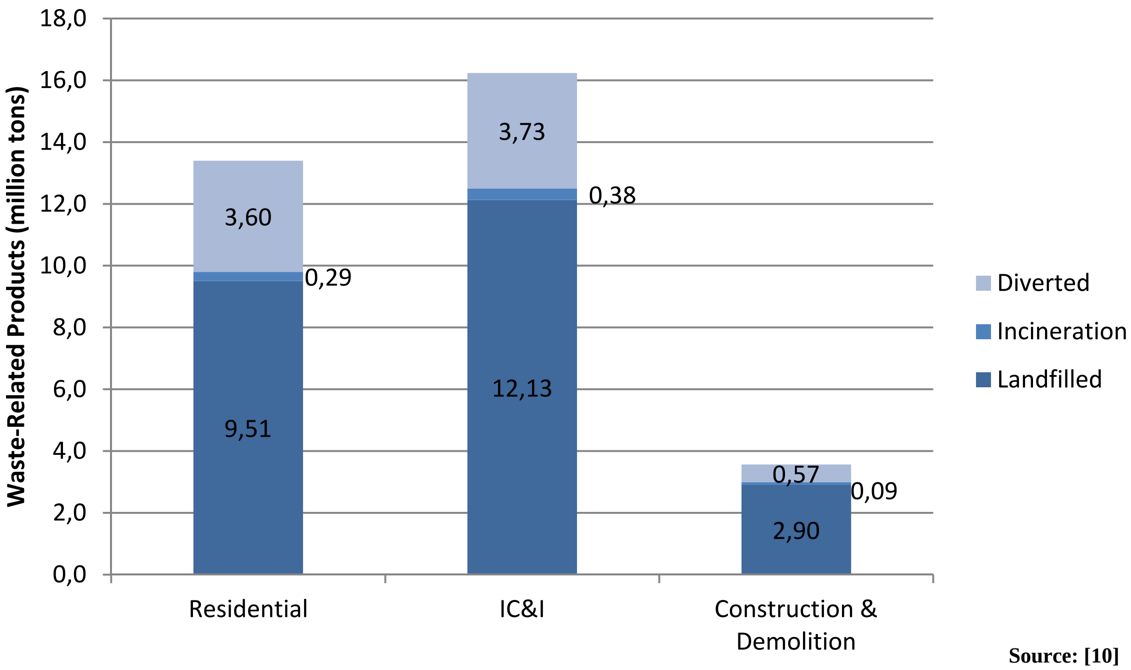


Source: [10]

Figure 3-1: Landfills across Canada

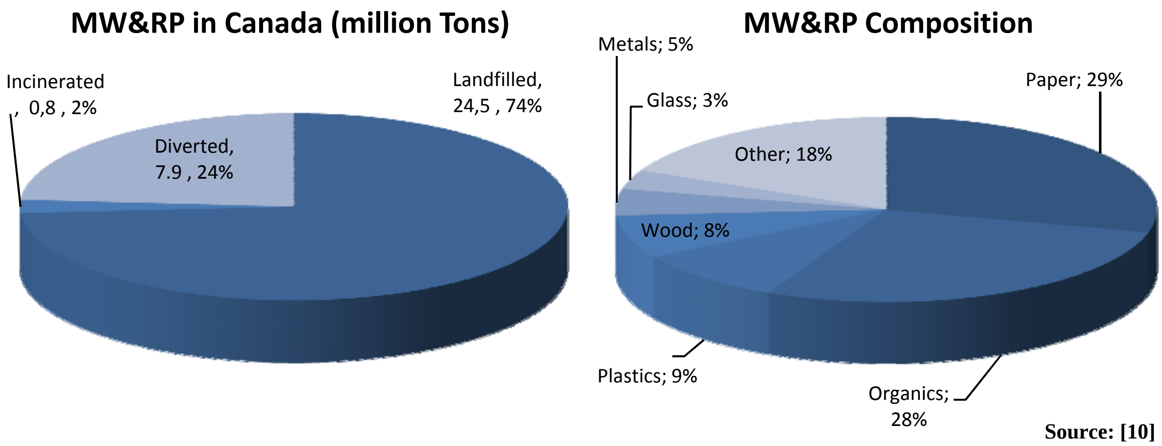
Canada only has 7 main W&RP incineration facilities, 5 of which have energy recovery. The total throughput of these 7 facilities is 763,000 tons of W&RP per year [13]. Two newer technology facilities are being built, a Plasma gasification plant in Ottawa, ON and a gasification plant in Edmonton, AB. Unfortunately, statistics show that the existing facilities are heavy polluters, which release dioxins and furans, see Table 2-8. However, it is estimated that Canada’s landfills are responsible for about 38% of the country’s total methane emissions [67].

The country also has a total of 351 (2002) centralized composting facilities [100]. Up to 1.2 million tons of organic materials were composted in these facilities in 2002 [10]. These figures exclude residential composting.



Source: [10]

Figure 3-2: Municipal Waste & Recoverable Products Generated in Canada (2004)



Source: [10]

Figure 3-3: Landfill, Incineration, Diversion of MW&RP (left, 2004) and Composition in Canada (right, 2002)

Canada has made some advancement but there is room for improvement. The following will discuss the political situation in Canada regarding waste-related activities.

3.3 Canadian waste policy

Before understanding the direction Canada's policy makers have chosen with regards to waste-relate management, it is important to have an overview of the current organisational structure.

In general, waste disposal and diversion in Canada is a shared responsibility among all levels of government. The Federal government regulates international and interprovincial/territorial exchanges of waste and recyclables. Provinces and territories regulate the intra-provincial/intra-territorial movement of waste and recyclables in addition to licensing the producers, transporters and treatment facilities within their authority. Furthermore, the provinces/territories are responsible to set out minimum environmental guidelines with respect to the handling and disposal of this waste.

It is bestowed upon the municipalities to develop their own waste-related management plans to align with the respective provincial or territorial guidelines. It's acceptable and even encouraged to develop inter-municipal agreements to help bear the burden of waste-related diversion, transportation and disposal infrastructures.

In this structure lies the problem. The national government leaves it up to each municipality to develop its own plans for waste disposal. This allows for many different approaches to the problem, some of which are excellent examples of technology that meet the most stringent sustainable values of WRM, whereas some barely achieve minimum environmental standards set out by the provincial/territorial governments.

3.3.1 Federal

The Canadian federal government has two main departments which set and regulate environmental initiatives and regulations, Environment Canada (EC) and the Canadian Council of Ministers of the Environment (CCME). EC is a federal agency which mainly sets out general goals for the country. For WRM it is engaged in such activities as sustainable development, GHG emission cuts, toxic substances, international movement and funding. The CCME is a collective of provincial and territorial ministers of the environment which set out minimum environmental criteria, produces reports and sets guidelines for a multitude of environmental issues.

3.3.1.1 Canadian Environmental Protection Act, 1999

Environment Canada has legislated the Canadian Environmental Protection Act, 1999 (CEPA 1999) [101], which is aimed at preventing pollution and protecting the environment and human health. The guiding principles are Sustainable Development, Pollution Prevention, Virtual Elimination of substances that take a long time to break down, Ecosystem Approach (not political boundaries), Precautionary Principle, Intergovernmental Cooperation, National Standards, Polluter Pays Principle and Science-based Decision-Making. They have also been involved in landfill gas capture strategies.

More pertinent to this topic is EC's Waste Prevention Program which focuses mainly on the sustainable management of solid non-hazardous waste-related products. Some of the initiatives are to develop national waste-related prevention programs and landfill gas capture and utilization (up 17% from 1997 to 2001) [10].

It is also EC's role to oversee and regulate the interprovincial/territorial and international import and export of WRP, which includes waste disposal at sea. Some of the CEPA 1999 Federal regulation initiatives on waste are as follows;

3.3.1.1.1 Export and Import of Hazardous Waste and Hazardous Recyclable Material Regulations

CEPA 1999 ensures that all transboundary hazardous waste and hazardous recyclable materials are handled in an environmentally sound manner. Any movement of hazardous waste and recyclables must be reported to the ministry of Environment which has regulatory and permit issuing powers over this issue. The regulations ensure that all hazardous waste is collected, transported and disposed of by approved facilities which deal with these substances with human health and environmental sensitivity in mind.

The Export and Import Regulations are in line with Canada's other agreements such as;

- the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, 1989 (ratified by Canada in 1992) [21]
- the Organisation for Economic Co-operation and Development (OECD) Decision of Council on the Control of Transboundary Movements of Wastes Destined for Recovery Operations, C(2001)107, June 2001 [102]
- the Canada-U.S.A. Agreement on the Transboundary Movement of Hazardous Wastes, 1986(as amended in 1992) [103]

3.3.1.1.2 Development of regulatory framework for the Export and Import of Non-Hazardous Wastes

Although still in the works, Environment Canada is developing a framework for the Regulation of the Export and Import of non-hazardous wastes, which mainly consists of municipal solid waste. The regulations will be consistent with Canada's international obligations and focus on a similar approval and tracking program as for the hazardous waste.

At the moment the government has published its "Development of Regulatory Options for the Export and Import of Prescribed Non-Hazardous Wastes Destined for Final Disposal: Options Paper" [24] in 2000 for consultation. The subsequent stakeholder meetings have been held and the "Proposed Regulatory Provisions for the Export and Import of Non-Hazardous Waste: Consultation Document" [104] was published in 2005. The conclusions are still awaited.

In these documents, it was found that presently information on transboundary non-hazardous waste for disposal is difficult to obtain, due mainly to the utilisation of private WRM firms which do not report their activities. Furthermore, it was observed that the provinces of Newfoundland, Prince Edward Island, Nova Scotia, Quebec, Manitoba and Alberta reported no waste being exported or imported, although confirming data was scarce. It is clear that regulations are needed.

3.3.1.1.3 Regulations for the Inter-Provincial Movements of Hazardous Waste and Hazardous Recyclable Material

The Interprovincial Movement of Hazardous Waste Regulations [105] is set in place to monitor the movement of hazardous waste between provinces and territories. The regulations are currently being revised to be in line with the Import Export Regulations and with regard to the definition of hazardous waste. Unfortunately the main focus of this legislation oversees the movement of hazardous waste only.

3.3.1.1.4 Regulate waste disposal at sea

CEPA 1999 prohibits the disposal of waste by Canadian ships in national and international waters and the disposal of waste from other ships in Canadian waters unless given a permit to do so. The only substances allowed for disposal at sea are dredged material from waterways, fisheries waste, ships, inert geological matter, uncontaminated organic matter and bulky substances that are primarily composed of iron, steel, concrete or other similar matter.

Incineration at sea is also prohibited except under emergency situations or if the waste is generated on the ship in question or a structure such as an off-shore oil platform.

3.3.1.2 Canadian Council of Ministers of the Environment

The Canadian Council of Ministers of the Environment (CCME) has a potentially more tangible role when it comes to WRM since its work is at both national and inter-provincial levels. The related initiatives of the CCME include guidelines for compost quality, principles for extended producer responsibilities including national packaging protocols, principles for electronic products stewardship, several guidelines on hazardous waste and recyclables and emission guidelines for waste incinerators.

One of the most important initiatives of the CCME, which fits into the sustainable WRM principles, is the National Packaging Protocol [32]. The goal was to reduce packaging waste by 50% from 1990 to 2000. The voluntary goal was achieved by reducing packaging and using recyclable materials at the producer level and encouraging recycling programs at the consumer level. The initiative was a success, but highlighted the difficulties in having a unified national plan with regard to WRM.

Unfortunately, the CCME has a broad mandate that encompasses a large variety of needs in a vast country, and it can only focus on a small number of items every year. Hence, the duty falls upon the provinces and territories to dictate more accurately the minimal environmental requirements for WRM.

3.3.1.3 Waste-Related Products to Energy

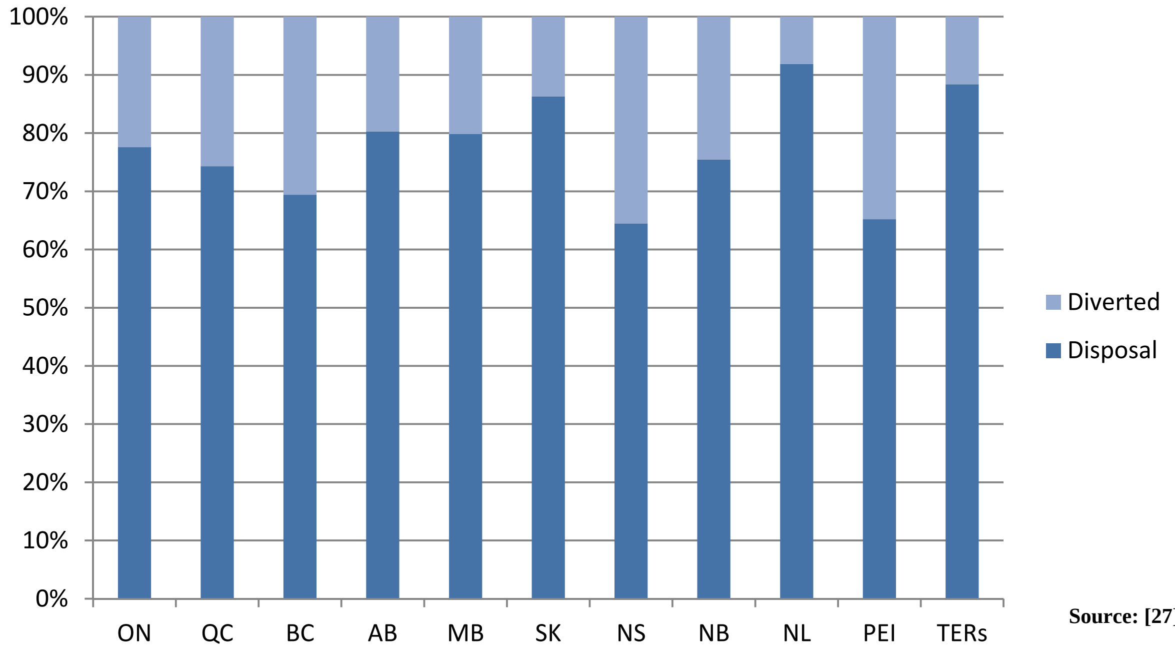
With regards to WRPtE facilities, the federal government gives grants, produces environmental studies on certain technologies but does not layout any comprehensive waste-to-energy policies. This topic is still under great discussion and has been passed on to the provinces and territories.

3.3.2 Provincial and Territorial

Canada has 10 provinces and 3 territories in just under 10 million km^2 of territory with a vast variety in climate, geography, resources and lifestyles. For this reason each province/territory has jurisdiction over its own environmental standards and minimum waste-related management guidelines with regard to the environment in order to better suit local needs. Understandably, this can be a lot of information to digest. This section will summarise the highlights for each province and territory. They are summarised by geographical region: Atlantic, Central, Prairies, Western and Northern Canada.

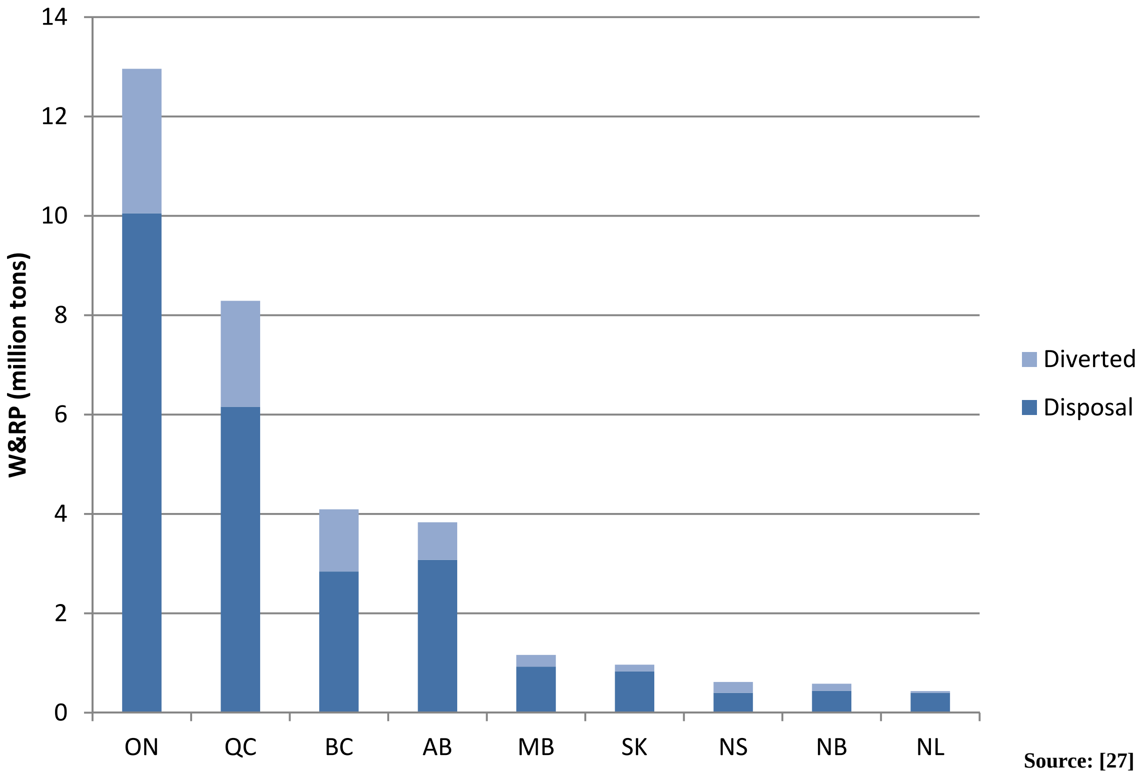
As a matter of comparison, Figure 3-4, Figure 3-5 and Figure 3-6 present the disposal and diversion of MW&RP for each province and territory by ratio, total and per capita, respectively. These tables consider only municipal waste & recoverable products, which include; residential, IC&I and construction & demolition sources. They do not include hazardous waste or materials not entering the waste stream (e.g. paper mill waste which is processed by the company itself). Unfortunately it's difficult to compare the exact numbers since each level of government has its own figures derived from varying base points and measuring methods. These figures may vary in the later text, but for comparison purposes the information presented is from Statistics Canada, the national body on the topic of statistics, so the relative performance of each province/territory is still valid.

Table 3-2 gives the generated and diversion tonnage of W&RP per province and territory in Canada for 2004. Once again these figures consider only waste entering the waste-related stream (residential, IC&I, construction & demolition). Canadians generate on average about 1 ton per capita each year of W&RP and divert only 23.7%. The bad news is that projections show that we are generating more W&RP. The good news is that Canadians are also increasing their diversion rates.



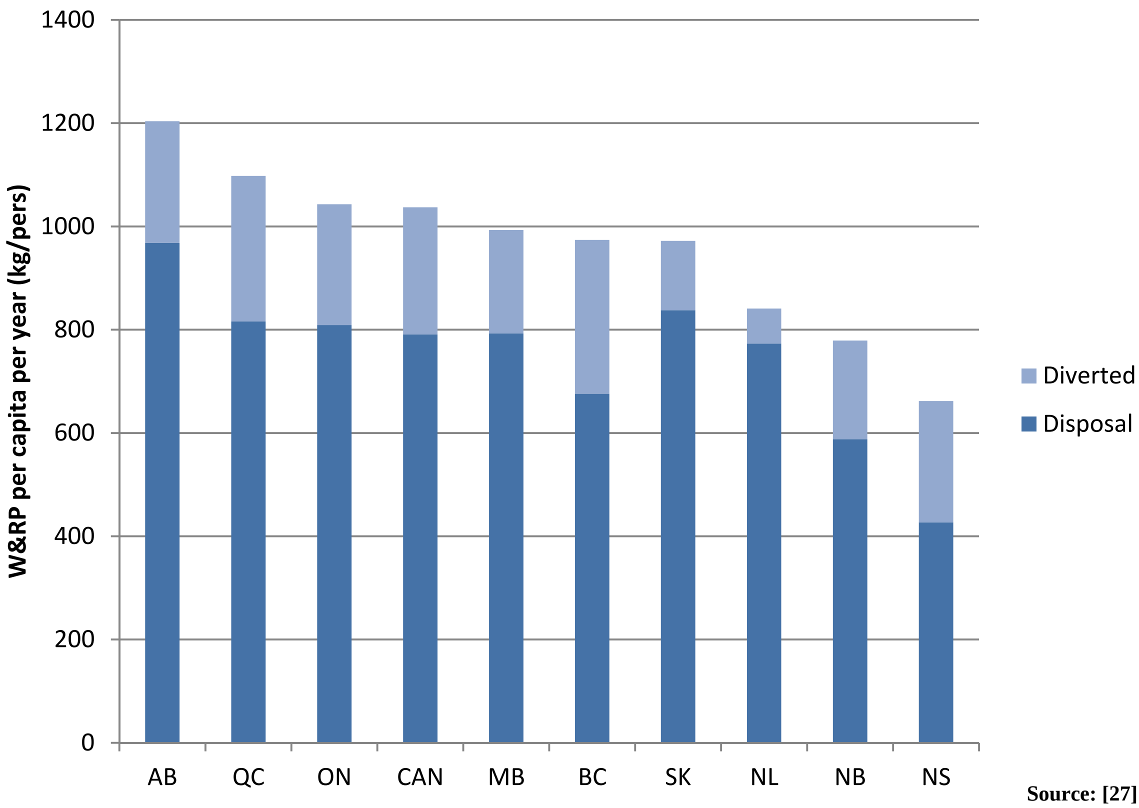
Source: [27]

Figure 3-4: Diversion and disposal of MW&RP, by province (2004)



Source: [27]

Figure 3-5: Total municipal waste & recoverable products generated by province[ix] (2004)



Source: [27]

Figure 3-6: MW&RP generation per capita, by province (2004)

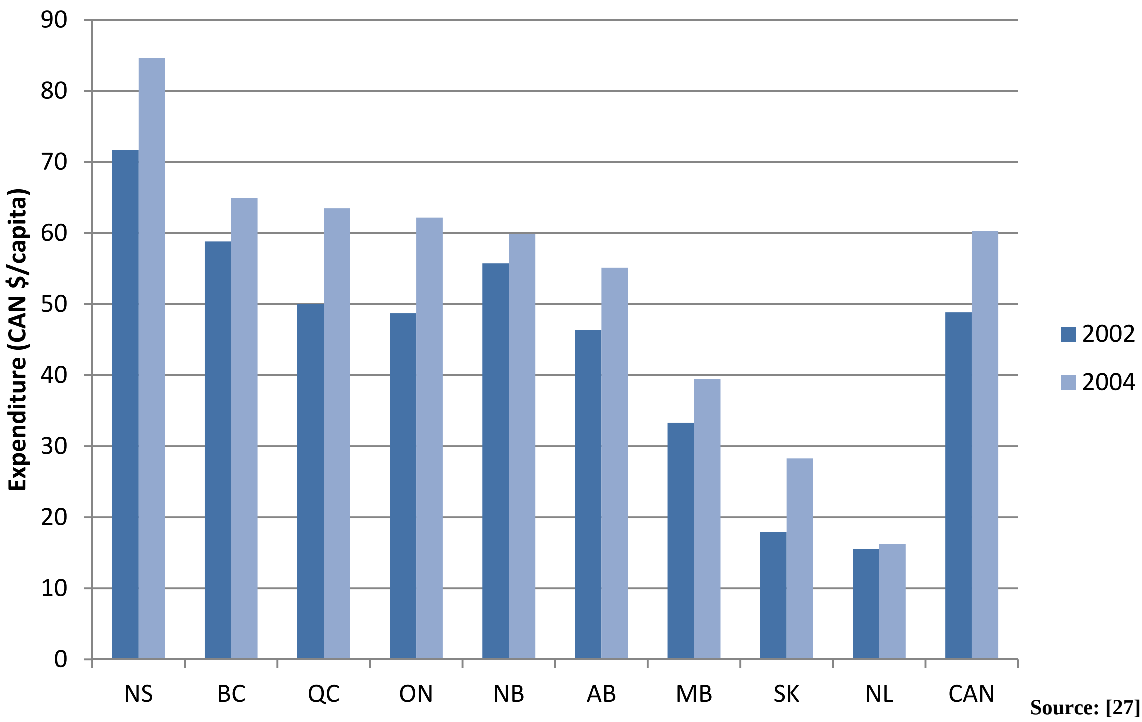
[ix] PEI and Yukon, Nunavut & Northwest Territories were removed for confidentiality

Table 3-2: W&RP generated and diverted by province and territory

	MW&RP (2004)			Change from 2002	
	Generated		Diverted	Generated	Diverted
Province/Territory	tons	kg/per	%	%	%
Newfoundland and Labrador	435,356	841	8.1	7.0	16.2
Prince Edward Island	x	x	34.8	x	45.5
Nova Scotia	620,283	662	35.5	6.7	14.7
New Brunswick	585,977	779	24.5	7.7	10.0
Quebec3	8,290,060	1098	25.7	9.2	22.2
Ontario	12,959,107	1043	22.5	8.8	28.2
Manitoba	1,162,667	993	20.2	4.5	8.7
Saskatchewan	966,274	972	13.7	6.0	14.2
Alberta	3,833,219	1204	19.6	7.0	9.5
British Columbia	4,093,028	974	30.6	4.8	2.7
Yukon, NWT and Nunavut	x	x	11.6	x	31.6
Canada	**33,155,662**	**1037**	**23.7**	**7.9**	**18.4**

Source: [27]

On the topic of finances in this sector, Figure 3-7 shows the expenditures on behalf of local governments per capita. The Canadian average is about 60$ per person in 2004. It can be seen that in all cases that this trend is rising. Another interesting correlation is that between expenditures and diversion rate, see Table 3-2. In most cases the provinces above the national spending average are also above the diversion average. New Brunswick (NB) and Ontario (ON) are the exception, but the relationship is still close.



Source: [27]

Figure 3-7: Expenditure on MW&RP services per capita – Local Government (2004)

Figure 3-8 goes even further and includes expenditures from local government and the private business sector. These figures do not consider the revenue generated for either.

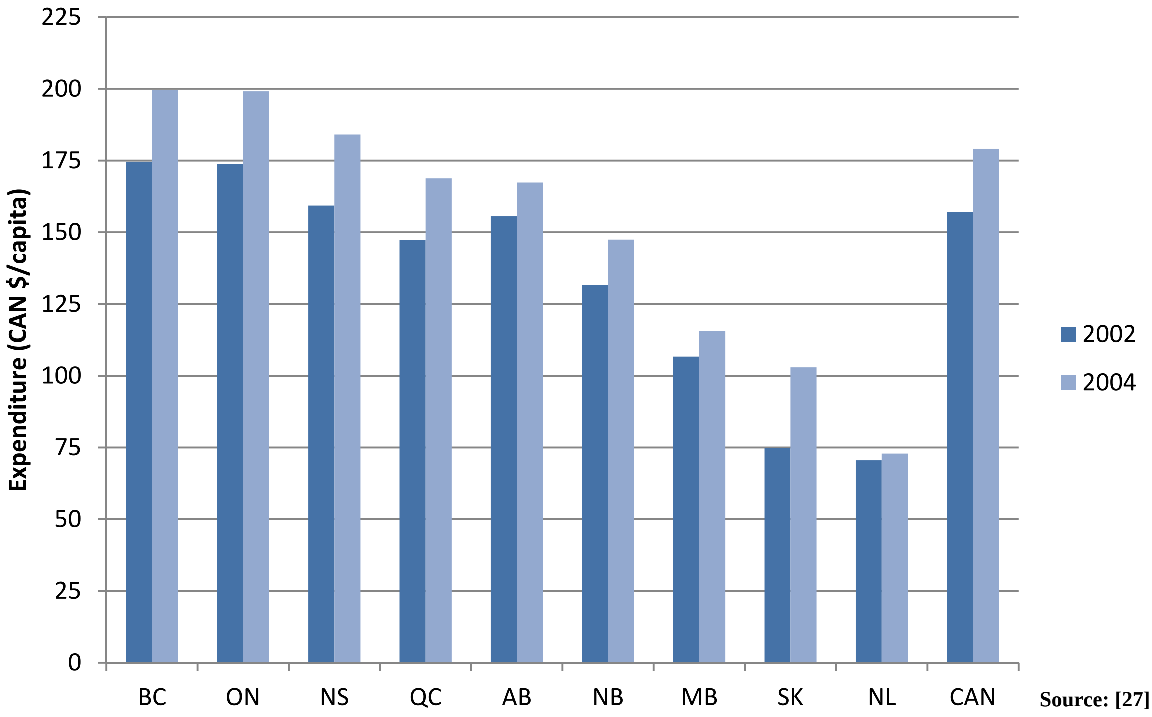


Figure 3-8: Expenditure on MW&RP services per capita – Local Government plus Business Sector (2004)

Among provinces and territories there are drastically different approaches in the waste-related management sector. The following text will attempt to identify why from a policy perspective.

3.3.2.1 Atlantic Canada

Atlantic Canada is a grouping of Eastern coastal provinces, often identified as one group since they are small (relative to the other Canadian provinces and territories) and have similar climates and geography.

3.3.2.1.1 Newfoundland and Labrador

Newfoundland and Labrador has realized that the existing WRM infrastructure is outdated and poorly operated. Numerous provincial and federal reports have highlighted these issues. For example, Newfoundland and Labrador had over 9 times more landfills than the other three Atlantic provinces combined (201 vs. 25) in 2005 [106]. In addition the Government's WRM Advisory Committee reported in October 2001 that incinerators in the Province are responsible for over one-third of the total volume of dioxins and furans released into the atmosphere by municipal incinerators in Canada [107].

The provinces' most recent initiative is its 2002 WRM Strategy [108] which outlines the following goals:

- divert 50% of the materials currently going to disposal by 2010
- reduce the number of waste disposal sites by 80%
- eliminate open burning at disposal sites by 2005 and phase out the use of incinerators by 2008
- phase out use of unlined landfill sites by 2010
- full province-wide modern WRM by 2010

Unfortunately, the province is likely to fall short of its goals. The Auditor General of Newfoundland and Labrador reports in 2005 [106] that it does not foresee the province achieving its goals due to:

- lack of guidance (the province has not set-out plans, targets or benchmarks to achieve these goals)
- misplaced priorities (not recycling paper and organic which represent 67% of the total waste, for example)
- Lack of funding

Overall, the province has recognized that it has a long way to go with regard to its WRM strategy, but is seemingly missing the right leadership and guidelines to do so. In addition there is no mention of using waste as an energy source and engineered landfill sites still top the list of solutions.

3.3.2.1.2 Nova Scotia

The province states that it ranks amongst the best governments in the world regarding WRM. On the provincial Environment and Labour website it claims "Nova Scotia is too good to waste." [109]. Figure 3-4 supports that claim by showing that it leads the country in waste diversion, and a news release from the department in September 2000 [110] sates that is has achieved its 50% waste diversion target. Unfortunately, supporting documentation of this achievement cannot be found. Furthermore, it is unclear what the diversion rate in recent years is.

At the outset, the government of Nova Scotia set out in 1995 its Solid Waste-Resource Management Strategy stating waste diversion targets and measures, improvement and reduction of landfills along with more stringent guidelines for incinerators. It seems as though there has been a degree of success with regard to waste diversion. For example, 90% of residents have curb-side organic waste collection and an electronic recovery program was implemented in 2007. Also, by 2005 there were 7 landfills in the province, versus 40 in 1995.

The Strategy also identified that all incinerators would be required to produce energy from waste and not inhibit diversion strategies. It is unclear what the state of their facilities are and hence we are led to believe that most waste incinerators are used in the industrial sectors and energy is most likely recovered from them, since it is the current trend.

The province seems to be moving in the right direction, but the 1995 WRM strategy is outdated and requires revision. No further Provincial targets have been set and the existing plan does not address innovations in waste-to-energy technologies.

3.3.2.1.3 Prince Edward Island

The province of Prince Edward Island is in fact a national leader in terms of WRM. It is the only province in Canada to have full source separation material pick-up to every home and business. It even states that in 2006 it achieved a 64% diversion rate, which ranks among the best in Canada [111]. Figure 3-4 supports this claim.

The Environmental Act 1988 is the main regulation behind WRM in the province. The province however, commissioned the crown owned Island WRM Corporation (IWMC) [111] to manage and operate this service for the residential and commercial sectors. From its inception in the early 1990's it has implemented some solid strategies through its Waste Watch Program. Landfills and incinerators are subjected to more stringent regulations, the 3 stream source separation of waste at all households has enabled the high diversion rates experienced and hazardous WRM programs are some of the many successful initiatives.

It should be noted that PEI is a small province of 138,000 (2007) residents over 5,680 km^2 of land. In essence it is much easier with a small land mass and population to implement such programs. It has only 2 landfill sites and one incinerator

However, its incineration plant is located in the provincial capital Charlottetown. The heat from the process is used in the adjacent hospital, government and private buildings. This proves that waste-to-energy facilities can be used, even close to urban centres, as a useful energy source without great environmental and social impacts. For this, it should be recognized as a role model for other Canadian jurisdictions.

3.3.2.1.4 New Brunswick

The province of New Brunswick was relatively forward thinking when in 1987 it adopted its New Brunswick's Solid WRM Plan. This plan identified the need to eliminate the uncontrolled waste disposal methods applied at the time throughout the province. The idea was to separate the province into 12 regions, each with their own Solid WRM Commissions. The responsibility was given to them so they could develop their own strategies, to conform to the Clean Environment Act. As a result several landfills were eliminated, the remaining ones were cleaned up and recycling was initiated in order to achieve the 50% diversion target by 2000, set out by the CCME.

However, other than the information shown in Figure 3-4, it is not clear what the province's current waste diversion rate is. And furthermore, no new targets have been set since the 1987 plan.

In 2001 the Department of Environment and Local Government published their Waste Reduction & Diversion - An Action Plan [112], which describes a 10 point plan to improve WRM in the province. Some of the points discuss setting province wide standards for recycling, leading by example, enforcing the regional approach, getting involved at a national level and putting a ban on landfills. If these issues have been addressed at a provincial level it is not clear from the available information.

In fact, the only report on the topic seems to be the recent Climate Change Action Plan 2007-2012 [113]. Improving diversion (including recycling and compost) was at the top of the list, saying that there is still work to do in these areas. The topic of landfill gas capturing to produce energy was also discussed. It turns out that 1 out of 6 landfills in the province currently captures and flares the off gas. Waste-to-energy efforts do not seem to be a top priority.

3.3.2.2 Central Canada

Central Canada comprised of Ontario and Quebec is by far the most populated area of the country. The majority of the population is located to the south, near the American border. Consequently it is a dense region with a lot of potential for integrated waste-related management solutions.

3.3.2.2.1 Quebec

The Province of Quebec has set out its guidelines through the Environment Quality Act and the Québec Residual Materials Management Policy 1998-2008 [114]. In this document, the Quebec government lays out its plan to divert waste from the landfills and states minimum standards for waste disposal facilities.

The main objectives are;

- Divert 65% of all waste from landfills. This will be achieved by encouraging the manufacturers to follow their products during their entire life-cycle, and being accountable for the waste they produce. The responsibility of the citizen is to be informed about their role and use of the city recycling and composting services available to them. Encourage all parties involved to participate in the decision making of their WRM plans, at a municipal level. To achieve the 65% diversion goal, the policy states the following diversion goals must be met;
    - Municipalities:
        - 60% of glass, plastics, metals, fibres, bulky waste and putrescible material
        - 75% of oils, paints, and pesticides (household hazardous materials)
        - 50% of textiles; 80 percent of non-refillable beer and soft drink containers
    - Industrial, commercial and institutional establishments:
        - 85 percent of tires
        - 95 percent of metals and glass
        - 70 percent of plastics and fibres, including wood material
        - 60 percent of putrescible material
    - Construction, renovation and demolition sector:
        - 60 percent of all recoverable resources
- Close most of the “trench landfills”. These are unmonitored pits in the sand or soil where waste is either buried or often burned. Only remote areas will be exempt.
- Instate new minimum requirements for landfills. The leachate must be collected and treated before being released into the environment. The biogas must also be collected and treated.

In terms of WRPtE facilities however, the Law describes minimum environmental standards for waste disposal which are represented by engineered landfill sites. Incinerations, digestion, gasification and other technologies are discussed briefly in terms of pollution, but no standards are set for energy production from W&RP. Even in the engineered landfill sites, the biogas only needs to be captured. After that it can be flared, burned to heat some of the facilities' processes or to produce electricity, but none of this is required.

3.3.2.2.2 Ontario

Ontario generates about 13 million tons per year of MW&RP, by far the most in the country, as seen in Figure 3-5. This accounts for 39% of the MW&RP generated in the country, albeit it is also home to 38% of the population of Canada. For this reason, Ontario is at par with the national average with respect to generation per capita, about 1043 kg/yr (Figure 3-6). In the same vein, they are also responsible for raising the national MW&RP generation average.

The Environmental Protection Act 1990 [115] is the starting point for all initiatives relating to waste-related products. Even back in the 1980's, the province mandated municipalities to develop waste-related diversion strategies. Since then, the largest efforts have been to increase recycling for the residential and IC&I sectors. As of the early 1990's Ontario made regulations to enforce minimum recycling and composting efforts for all jurisdictions [116]. However, Ontario only diverts 22.5% of the WRP from disposal [27].

The Waste Diversion Act, 2002 [117] helped create Waste Diversion Ontario (WDO) [118]. This organization is responsible to develop, implement and operate programs in order to achieve the province's 60% waste diversion target by 2008. The group is comprised of municipal, industry and non-governmental representatives. In 2004, "Ontario's 60% Waste Diversion Goal: A Discussion Paper" [116] was released for public and stakeholders input. It will be interesting to see the 2008 waste statistics when they become available.

On the disposal topic, the Ontario government released a statement on March 23rd, 2007 [119] saying that it will speed up the Environmental Assessment process of waste-related management facilities under the new WRM Project Regulation. In short it states that;

- Small recycling facilities will not need to undergo an Environmental Assessment
- Rural landfills or expansions between 40,000 & 100,000 cubic meters would go through a screening process
- Proponents of new waste technology do not need an Environmental Assessment as long as they meet the provinces air emission standards

On one side, this speeds up the approval process, but also makes it easy for landfill promoters to keep doing what they are doing, not to mention that it will slow down the acceptance process for newer W&RP conversion technologies. The only thing is that Ontario Regulation 232/98 requires that any landfill that has a total capacity over 3.0 million cubic meters must collect the landfill gas, smaller facilities are exempt [120].

One interesting initiative that has been quite successful in the province has been run by The Beer Store. The Beer Store is the sole distributor of beer in the province, while another body regulates and distributes other alcohols. The Beer Store has been using a user-pay system for recovering bottles for 80 years now. The user pays a deposit at purchase of the beer and receives it back upon returning the empty bottles. Not only do they take beer bottles, but everything they sell including bottle caps and packaging. They recover about 91% of all bottles and cans sold and they take plastic back as well [121]. The glass bottles are washed and re-used 12 to 15 times before being recycled into a new bottle [121]. All other materials are recycled. This is a great example of Extended-Producer-Responsibility.

3.3.2.3 The Prairies

The Prairies, (Manitoba, Saskatchewan and Alberta) are located in the centre of Canada and are mainly comprised of flat land and lakes. They cover a large land area and are sparsely populated (3 people/km^2). For this reason, waste collection and management is a challenge. In addition, Alberta is home of the famous tar sands, a waste generation and environmental pollution issue on its own.

3.3.2.3.1 Manitoba

In 1989 the Minister of Environment committed to achieving a 50% waste diversion rate by 2000. They passed the Waste Reduction and Prevention Act in 1990 to implement the required measures to achieve this. Subsequently, various initiatives were implemented such as composting, household recycling, used tire recycling and used oil collection. These actions are still in effect today, however the province had only achieved a 22% diversion in 2002, as published in their 2005 Provincial Sustainability Report [122]. The same report highlights that the province ranks poorly in terms of waste generation and diversion compared to the other provinces.

Furthermore, the guidance on WRM in the province seems scattered at best. The Ministry of Conservation has been reporting on the WRM activities in their State of the Environment reports every 2 years since 1991. However, the latest report dates from 1997. In their 1993 report, it is stated “The composition of our municipal solid waste is not known…” [123]. It is difficult to set targets and benchmarks if this information is missing, and hence this statement indicates the status of their strategies at the time. It might help explain why they have fallen short of their targets.

Since the 1990 Act, the Sustainable Development Act 1998 was developed, but no new targets have been set or clear strategies implemented. However, another Department sates on its web site that the province is investigating the feasibility of waste-to-energy technologies, namely fluidized bed gasification for the disposal of hazardous waste to produce energy and new technologies are being developed for high purity molecular distillation [124].

3.3.2.3.2 Saskatchewan

Despite its dispersed population, since 1988 Saskatchewan has been able to promote waste diversion in its WRM infrastructure. This is in large part due to the province’s acknowledgement of the problems associated with these practices back in the 1970’s. In 1984 the Municipal Refuse Management Regulations (MRMR) came into force, attempting to govern landfills from an environmental perspective. Despite this, there were still 654 active landfill sites in 1994, many of which still burned unsorted garbage [125].

The province is struggling to get a handle on their waste situation, but the dispersed population still requires small communities to fend for themselves. An example of this is in the town of Nipawin in central Saskatchewan, which has recently abandoned its paper and cardboard recycling program due to lack of infrastructure and funding [33]. The city can’t help them and they are losing money.

However most of the regional WRM bodies have banded together under the Association of Regional WRM Authorities of Saskatchewan to act as a unified voice to the government and industry [126]. This has allowed smaller communities to work together in finding workable solutions to their waste problems.

The latest Environmental and Protection Act, 2002 has helped the MRMR to further improve and regulate the way waste and hazardous materials should transported and disposed. The Clean Air Act further regulates open burning and incineration to ensure minimum environmental and human precautions. However, the province has far to go and is still amongst the nation’s largest polluters per capita and far behind when it comes to waste diversion and waste-to-energy initiatives.

3.3.2.3.3 Alberta

Alberta in 1971 was the first in Canada to create an Environmental Department which oversaw the WRM practices. However, over the past 20 years the province has seen an economic and population boom. Consequently the existing infrastructure is at its limits.

Currently, Albertans produce more waste than any other province per capita and their diversion rate is amongst the worst. The province has recognized this and is attempting to change the way waste is perceived in their Too Good to Waste strategy [127]. The current trend is that waste diversion and environmentally sound disposal are only considered when traditional landfills become too expensive.

With an abundance of private landfills, the disposal market has become competitive and hence reduced tipping fees. Another problem is that the waste disposal infrastructure is subsidized. The diversion infrastructure is also subsidized, but it receives less than 15% of what the disposal system receives [127]. Clearly this promotes bad habits.

On the up side, the three largest waste generators in the province also show the highest recovery rates. The agriculture, oil & gas and forestry sectors are responsible for 49%, 23% and 14% of the total waste generated in the province, respectively. The recovery rate for the agriculture, oil & gas and forestry sectors are 92%, 38% and 65%, respectively. The residential and commercial wastes show recovery rates of a little more than 20%, significant improvements are required here [9]. The oil & gas sector could also be improved since it is growing at an alarming rate.

Under the recent Waste Not campaign, the government has set out to decrease the waste sent to landfills to 500 kg/person by 2010 and plans to achieve this by increasing pollution prevention, improving the sustainable WRM infrastructure, better public awareness and ensuring that waste related activities protect human health and the environment.

3.3.2.4 Western Canada

Western Canada is defined as British Columbia (and sometimes part of Alberta).

3.3.2.4.1 British Columbia

British Columbia, on the Pacific coast, ranks in the top three for most waste diversion and for least waste generated in Canada. The biggest factor that seems to explain this is the province’s foresight in WRM planning. It is evident by the amount and quality of information available on the topic that the government has taken this responsibility very seriously.

The WRM Act (now the Environmental Management Act) was amended in 1989, and recognised the value of a regional structure. The regional districts were required to develop and submit their plans by the end of 1995, for approval by the Ministry of Environment. The strategies were to include initiatives to achieve the 50% diversion rate by 2000 and this by highlighting the hierarchy of the 3 R's concept. Furthermore, in 1993 the province set out the Landfill Criteria for MW&RP [128]. The regulations required the regions to audit their existing landfills and identify non-conforming sites, describe in detail the planned new ones and explain how they were going to conform to environmental standards (including corrective measures for existing, non-conforming sites) in their 1995 Regional Solid WRM Plans.

Since then the provincial government has been working arduously at keeping track of progress, lots of information is being collected and compiled every year in the Municipal Waste Tracking Reports [129]. This, more than anything else, helps leaders make decisions on the treatment of waste-related products in the province and consequently contributes to the success of their waste diversion achievements.

In terms of waste-to-energy facilities, an incinerator which produces steam for electricity and other processes is located near the major urban center of Vancouver and accepts 24% of the region's waste [130]. The Environmental Management Act has enabled such facilities to be built and monitored, and more are planned the available land becomes scarce.

3.3.2.5 Northern Canada

Northern Canada is comprised of three territories; Yukon Territory, Northwest Territories and Nunavut. It is by far the least populated and largest area in the Country. It covers 40% of the total land but is occupied by 0.3% of the Canadian people for a population density of 0.03 people per km^2. As a result, this small, dispersed, isolated and vast land area of Canada does not rank well on the waste diversion strategies.

On the other hand, in this part of the country the environment is of utmost importance, since many people still live off the land. So they have been able to establish some important guidelines for WRM, landfill requirements, open burning restrictions and GHG emission reduction plans, amongst others. Follow these references for more information [131], [132], [133].

3.3.3 Municipal/Regional

Across Canada it is bestowed upon the municipalities or regions to develop their own WRM plans. Considering the number of municipalities they will not be discussed individually. However, it is at this level were practical approaches to waster-related management are developed and implemented based on targets set by the provinces and country.

3.4 Canadian Waste-Related-Products-to-Energy Policy

On a national scale, there are no targets or requirements to produce energy from W&RP. In a country like Canada with a wealth of energy sources and large land mass there has been no pressing reason to implement WRPtE facilities. A study by the C.D. Howe Institute, concluded that Canada landfills 79% of its W&RP, compared to an average 58% for the other OECD 2004 countries [41].

Canada is lagging behind other countries such as the US and the Europeans with regard to WRPtE: “Only three per cent of Canada's solid waste is processed to generate electricity, compared to thirteen per cent in the US” [134]. This amounts to about 0.8 million tons in 2002 in Canada. There exist only a few operational WRPtE facilities in Canada;

- Brampton facility, Ontario operated by Algonquin Power Energy From Waste Inc has a generating capacity of 15 MW
- Burnaby, just outside Vancouver, French-owned Veolia ES Waste-to-Energy Inc
- Quebec City, Quebec
- Charlottetown, New Brunswick
- Ottawa, Ontario

In general, these facilities have been localised near the generation of W&RP to alleviate landfills and transportation costs; all in an effort to keep treatment and disposal operations near the source. Yet all these have been implemented on a need basis, not part of a unified goal. Certain provincial legislations across the country are entertaining the idea of incineration, gasification or digestion, but so far no standards for producing energy have been set (provincial or national).

There has been some progress on landfill gas collection. In 2001 it is estimated that 342 ktons were captured across the country mitigating an estimated 7.2 megatons of CO_{2eq} [10]. However, these numbers have been put into question in the last chapter and will be again in the next one. It is uncertain if the captured gas was converted into energy or simply flared.

In the 2002 Climate Change Plan for Canada, the federal government had set out strategies and targets to meet its Kyoto commitment. In this, a minimum 10% of new electricity generation capacity is to come from emerging renewable energy sources, such as WRPtE by 2012. Unfortunately, the current government has revoked this plan (to the point where the report is no longer available online) without putting an alternative in its place. The government's latest Sustainable Development Strategy 2007-2009 [135] offers no real measures for improving the situation.

The IEA has noted that in Canada "Provinces have more jurisdiction over energy than the sub-national governments of other federal countries in the IEA." [136]. This does to some extent explain the lack of federal WRPtE strategies, but cannot be used as an excuse. If a country like Canada is not able to enforce a policy, then we are doomed since climate change requires global cooperation.

In conclusion, there are no Canadian waste-related products to energy policies. It is up to the provinces to formulate their plans, targets and regulations. As an example, the province of Ontario's approach is presented next in greater detail.

3.4.1 The Ontario example

As stated previously, most jurisdictions in Canada have not fully investigated the WRPtE potential. Ontario is no different. However, the Ontario government has recently passed legislation to help WRPtE facilities circumvent full Environmental Assessments and hopefully speed up their application. They do still need to abide by the province's air emission regulations, but, the new W&RP-to-energy facilities in Ontario will not need to go through an Environmental Assessment if they "have predictable environmental effects that can be readily mitigated" [119] or if there is little public opposition to the project.

It is too early to know what effects this will have on the promotion of WRPtE facilities, but it is safe to assume that tried, tested technologies such as landfills may escape full Environmental Assessments, whereas new technologies may be faced with much longer application processes further inhibiting the integration of waste-related products as an energy source in the province.

Ontario has currently one waste-to-energy facility in full operation [137], located in Brampton [138]. It can produce 15 MW of electrical energy by incinerating non-recyclables such as MW&RP. The facility is privately owned with power sold to the provincial utilities.

The reoccurring problem with WRM in Canada is the lack of cooperation between all levels of government. In the city of Ottawa however, the government of Ontario has invested $4 million in cooperation with the city and Plasco Energy Inc. (a WRPtE technology innovator) in a pilot plasma gasification plant [86]. Located beside the city's aging landfill, they have completed the final stages of commissioning and are accepting MW&RP for testing. The proprietary technology was developed in Ottawa (with Spanish cooperation) and is the first of its kind in Canada. It far exceeds the environmental requirements set out by the province. If all goes well it may be the beginning of some important policy changes, which might cascade across the country. This project is a great example of how government, municipalities and industry can come together, promote Canadian technologies and improve the way we deal with W&RP.

3.5 Canada vs. the World

Up to this point it has been shown that local Canadian jurisdictions have developed disparate methods to deal with their W&RP. Although a seemingly scattered approach, is it working? The best way would be to compare some of the key indicators with other nations. The following section discusses this topic.

3.5.1 Waste and Recoverable Product Generation and Diversion

As discussed in the first chapter figures are contradictory and often hard to confirm, even within Canadian data. Results in municipal, provincial and national reports can differ by large amounts. Until now, this has not been much of a problem since conclusions could still be drawn. For comparison on the world stage however, it becomes even more difficult to validate data from various sources. For this reason, some of the data may conflict with previously presented figures. However, for relative comparison the information is still valid since it is from the same source.

Figure 3-9 shows the MW&RP generated on a per capita basis for certain countries. Among the worst producers are Canada and the United States. These figures represent the W&RP that enters the waste stream overseen by the municipal authorities or their affiliates, which includes household, institutional and commercial wastes.

Figure 3-9 does not represent the recycling and diversion efforts of the countries; it does indicate however the level of W&RP generated and subsequently is an indicator of the wastefulness of a nation. In the long run this is all that matters. Waste generation globally is on the rise, and hence recycling is not the solution, reduction is. Consequently, it is clear that Canada does not rank well with respect to other countries and is not heading in the right direction.

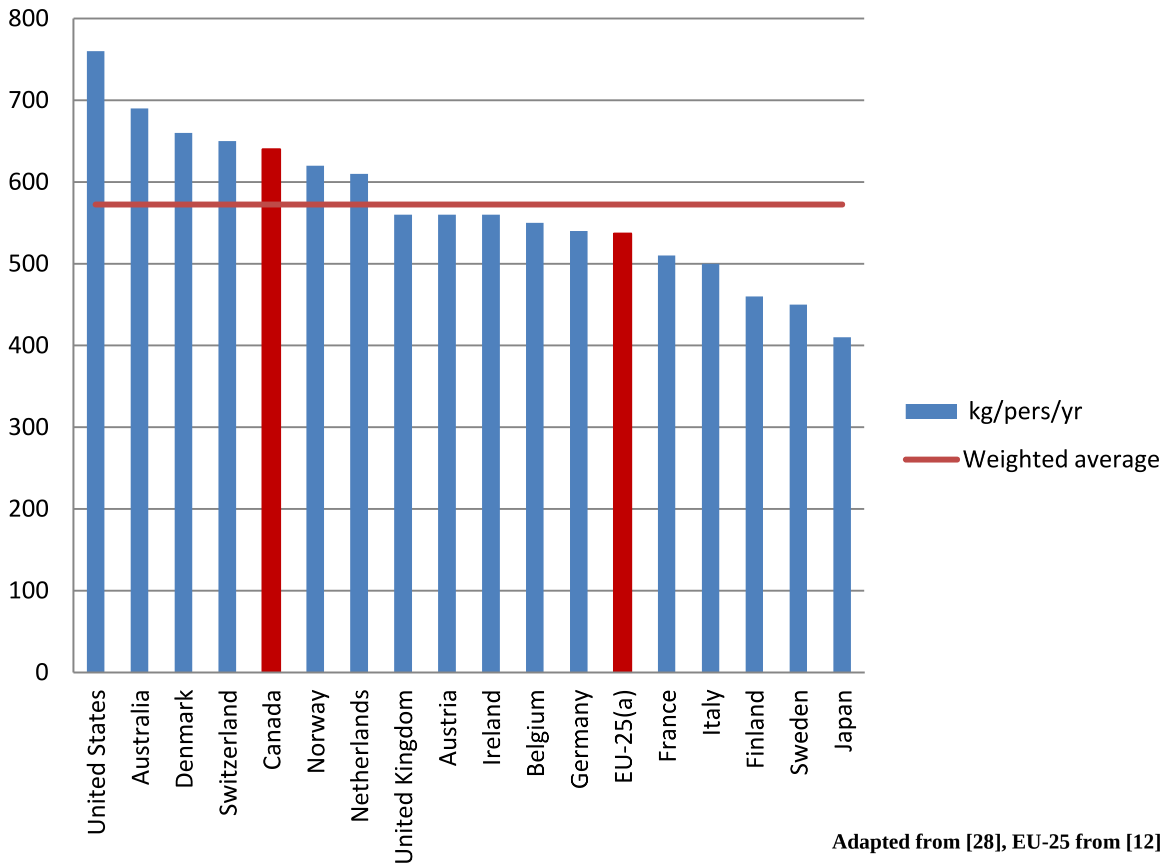
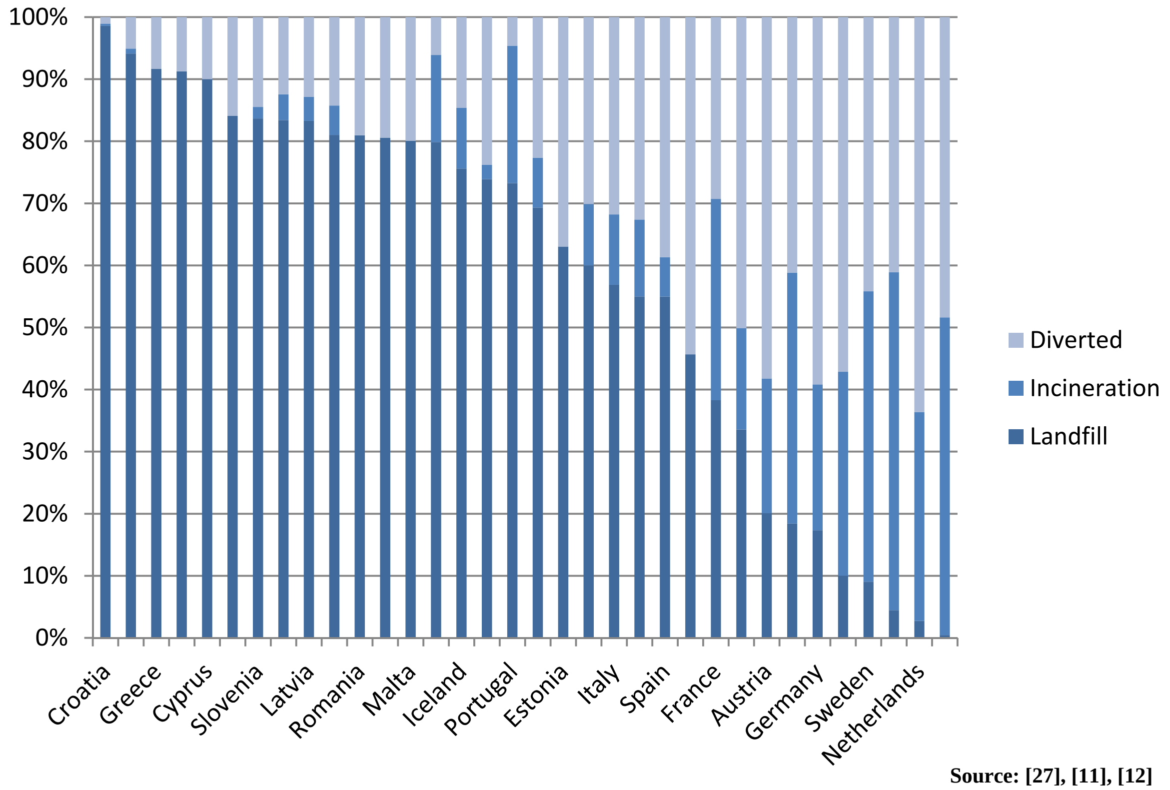


Figure 3-9: Municipal Solid Waste Generated per capita per year

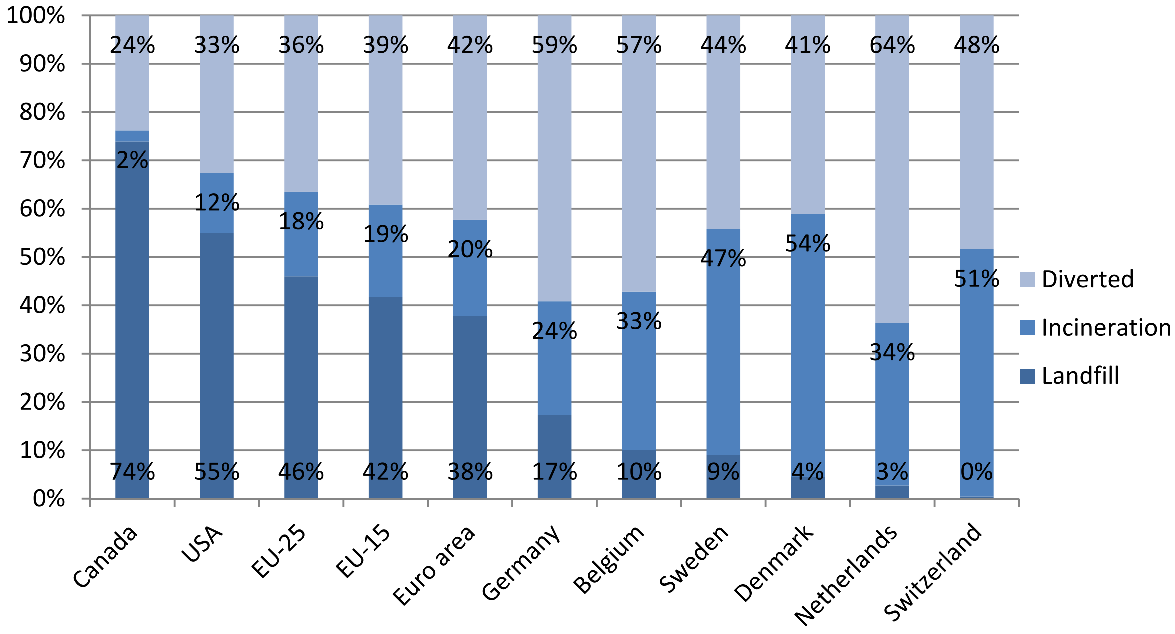
Japan is at the other end of the range. They generate almost 40% less W&RP than Canadians and almost 50% less than Americans.

On the topic of diversion and final disposal, Figure 3-10 shows the percentage distribution of MW&RP diverted, incinerated and sent to landfill for countries in Europe. It can be seen that at one end of the spectrum Croatia does little diversion and almost no incineration, whereas the Netherlands and Switzerland have almost negligible waste-related products sent to landfill and display some important diversion efforts. Canada is in the middle with regards to MW&RP sent to landfill, but also shows very little incineration. One important thing to note is that most countries with the highest diversion rates also have high incineration proportions. This tends to support the premise that incineration and diversion can co-exists and complement one another.



Source: [27], [11], [12]

Figure 3-10: Distribution of waste-related activities in various countries



Sources: [27], [11], [12]

Figure 3-11: Distribution of waste-related activities in selected countries

Figure 3-11 takes a closer look at the numbers shown in Figure 3-10 and shows that countries like Sweden, Denmark, Netherlands and Switzerland landfill only a small portion of their MW&RP. Switzerland in fact landfills less than 0.5% of its municipal waste & recoverable products, diverting almost half and incinerating the rest. The Netherlands divert over 60% of the W&RP and landfill less than 3% of the remainder. It is apparent that Canada's efforts leave a lot to be desired.

3.5.2 Energy Recycling

The previous figures represent energy recycling (WRPtE) on a relative basis. As an absolute comparison, Canada doesn't even rank on the world stage. Table 3-3 shows that amount of WRPtE being used around the world. Europe, Japan and the USA stand out as the ones investing much more than other nations.

Table 3-3: State of WRPtE around the world

Nation	WRPtE (million tons)
EU 25	48.8
Japan	40.0
USA	26.3
Taiwan	7.0
Singapore	4.0
China	3.0
Switzerland & Norway	3.8
South Korea	1.0
All Others	9.0
Total	**143**

Source: [139]

Waste-related products to energy technologies are also more accepted in other countries than here in Canada. For example the EU's 2005 Biomass Action Plan perceives waste as an "underused energy resources" [140]. It clarifies that it needs to be implemented within proper WRM strategies that reduce the environmental impacts of using it as a fuel. The report goes on to say that achieving the EU's renewable energy targets without biomass "looks impossible to achieve" [140].

Some of the reasons for Japan's success (which are similar to those of Europe) include environmental consciousness, expensive refuse disposal fees, and government subsidies for WRPtE and requirements that W&RP must be treated close to the source [139]. Europe and Japan have come to terms with the reality of waste-related management in today's world, where WRPtE or energy recycling become an integral part of the process.

3.5.3 Summary

It is clear that the nations with the highest WRPtE rates also show the best W&RP diversion, the least landfill disposal and relatively less W&RP generated per capita. Canada does not rank well. It is amongst the worst in all categories, compared to the other developed nations.

It can easily be concluded that Canada's current waste-related management priorities need to be revised.

3.6 Conclusion

In summary, the quantity of waste-related products generated is an indicator of the inefficiency of a society [41]. This can be considered true for Canada as seen in previous figures. It has been presented that the main problem is the current lack of cooperation between the federal and provincial/territorial governments [41]. In theory the structure is workable, but in reality there seems to be a disconnect between different levels of governments or a lack of vision and leadership with regard to the environment.

This can easily be demonstrated by Canada's commitment (or lack thereof) to the Kyoto protocol. The country ratified the agreement with the goal of reducing GHG's by 5.2% from 1990 levels by 2012. However, 2005 statistics show Canada is 25.3% above the 1990 level, or 32.7% from its Kyoto target [141]. The main reason for this is that the Government of Canada Action Plan [142] and the Moving Forward on Kyoto [143] plans have been scrapped and nothing has replaced them. The cynics agree that as a nation we were not going to meet our targets and these plans had no substance. On the other hand, supporters are furious since no clear goals or plans are being developed to improve the state of affairs.

As attempted through the Kyoto agreement, the federal government is responsible for setting clear and concise GHG targets. The provinces/territories on the other hand control the energy policies. For this reason agreements are hard to reach. Intergovernmental cooperation is required. The W&RP issue is no different.

This is not however the only problem. The consumer is also at fault, due to continued wasteful habits. The solution is individual accountability, but the individual can only go so far without clear direction.

The direction must come from the top. It is the responsibility of the Canadian Government to lead the provincial governments down the path to sustainability. Waste-related management is an integral part of this. The previous chapter explained that provinces are setting their own diversion targets, simply due to economic and social pressures. But the extent of their abilities to motivate change is limited to their jurisdictions and they rely on adhoc interprovincial cooperation to promote any kind of unified goals.

Europe's nations and Japan have successfully implemented waste-related management strategies that, more or less, encompass all the facets of the SIWRM hierarchy. They produce less, divert more, energy recycle as much as possible and landfill only what is required. This is not to say that their methods are perfect, it merely shows that Canadians can do better.

Within the current government structures there is potential for Canada to promote change and innovation and provide leadership for unified strategies. The idea that regions or municipalities are responsible for their waste-related management plan is effective in tailoring to local needs. Provinces and territories are best positioned to detail and enforce goals and strategies. Nationally, some direction is required.

CHAPTER 4: GREENHOUSE GAS EMISSIONS FROM WASTE-RELATED MANAGEMENT

4.1 Introduction

One of the most important factors when discussing the concepts of sustainability is Greenhouse Gas (GHG) emissions and this also applies to waste-related management. Waste-related activities are large contributors to GHG emissions and many policy makers are now considering this in their planning. It has been suggested that the emission cuts in this field could be of the same order of magnitude as improvements in energy efficiency and electricity generation [144]. In Canada, landfill is the most popular method of disposal and in 2004 it is estimated that 26 Mt of CO_{2eq} (3.7% of the national total) were emitted from the disposal of solid waste-related products on land [145].

There are many elements and variables to consider when estimating GHG emissions. This chapter will attempt to consolidate and qualify all of these, in an effort to develop a model to estimate GHG emissions for various waste-related management activities. The methodology is based on one described in a paper published by the European Commission – EU: Waste Management and Climate Change Options (2001) report [43]. Results obtained from previous chapters and Canadian information are used in the model to evaluate the GHG emissions.

Seven scenarios are then modelled for the Canadian situation based on unsorted MW&RP as well as its individual materials:

1. Base case – Status Quo
2. Maximum Landfill
3. Maximum diversion – Composting and Recycling
4. Maximum WRPtE – AD and incineration
5. Optimised diversion and WRPtE
6. Improved Base Case 1 – 2x Diversion, 2x WRPtE
7. Improved Base Case 2 – +20% Diversion & 50% WRPtE

The goal of this chapter is to develop a reasonable GHG emission model for various waste-related management activities and determine which solutions are better from an emissions perspective and then use the Canadian data to analyse and compare the seven scenarios.

4.2 Methodology

The calculation method used to obtain the GHG emissions relating to waste-related management are based on the EU: Waste Management and Climate Change Options (2001) report [43]. The purpose of this method is to quantify the effect of different waste-related practices on climate change. The practices assessed in this paper are:

- Landfill of MW&RP, with various degrees of landfill gas recovery
- Incineration of MW&RP, mass-burn and gasification technologies are considered with no energy recovery, heat only, electricity only or combined heat and power
- Composting of putrescible, either at home or at centralized facilities.
- Anaerobic digestion of putrescible, in a controlled environment to produce heat, electricity or both
- Recycling of metal, paper, plastics, textiles and glass to make secondary materials

For each of these waste-related management practices the GHG effect of each product is calculated individually per ton of material (i.e. if the material is separated at source). This process is also applied for unsorted MW&RP, based on average Canadian data.

For each of the processes, emissions and sinks are summed to profile the GHG's over the whole cycle. Short cycle carbon (that which is assumed to be realised during degradation and consumed during growth in equal amounts) is tabulated only for comparison purposes, but is not included in the overall emissions of a process since it is considered carbon neutral.

The positive emission sources considered are:

- Methane emissions from landfill, due to the decomposition of organic material
- Emission of fossil CO_2 during the combustion of plastics and textiles
- Emission of N_2O during incineration
- Indirect emissions caused by the fuel consumed to collect, transport and process the materials

The negative emission sinks considered are:

- Emissions avoided by displacing another process, for example;
    - Incineration with energy recovery reduces the need for energy from other, potentially more polluting sources
    - Recycling avoids the energy consumed to extract and process raw materials

    - Compost avoids emissions associated with other fertilizers
- Non-fossil carbon that is retained (sequestered) in the earth's surface for longer than the 100 year time horizon. This includes:
    - The carbon from slowly degrading putrescible material, which remains in landfill
    - Carbon that remains in compost

Other environmental effects are not quantified in this analysis, but comments are made based on previous analysis in this paper.

To generate different scenarios, Microsoft Excel is used to develop the calculation and modify the inputs for the various scenarios described above.

4.2.1 Validation of the method used

In order to validate the above method, other Canadian reports on the global warming effects of waste-related management are used for comparison. One such paper is the National Inventory Report: Greenhouse Gases Sources and Sinks in Canada (2005) [145]. In that paper the methane produced from landfills in 2004 was estimated to be 1,434,652 tons by using the Scholl Canyon Model Representation of Landfill Degradation. That model is simple to use and considers the time delay between disposal and methane production. However, the method used in this paper was further simplified by assuming that generation of methane is independent of time since we are observing things over a 100year horizon. The impact of such an assumption is minimal at less than 1% difference, as shown in Table 4-2 below. Therefore one ton of material will produce 'x' amount of methane, which can be expressed as a single value.

One of the biggest potentials for error in determining the methane produced from landfills is the quantity of Degradable Organic Carbon (DOC). This is calculated by considering the Total Carbon (TC) in a material and the amount (from 0% to 100%) of this carbon that can escape from the material during decomposition. In most organic materials, the portions of carbon that will degrade are 100% (or near enough to). However, the carbon content of each material (especially in municipal waste & recoverable products) can vary greatly depending on geography, GDP, social and political situations, etc. Since these figures are not readily available for Canadian MW&RP, they are adapted from the previous Table 2-3 using American data for the purpose of this model. The difference between the Canadian DOC figures (calculated using IPCC/OECD/IEA, 1997) and those used in this report are shown in Table 4-1. Although the individual figures vary, the weighted averages using the Canadian composition of MW&RP are very close.

Table 4-1: Degradable Organic Carbon in MW&RP Comparison

	Degradable Organic Carbon (DOC, %)	
Material	**Based on Canadian Report [145]**	**Based on EU Report [43] and other Sources**
Paper	40%	35%
Wood	30%	
Garden and Park Waste	17%	23%
Food Waste (putrescible)	15%	18%
Average Putrescible	**16%**	**21%**
Textiles	40%	19%
Miscellaneous combustibles	22%	28%
Fines	N/A	9%
Other (Miscellaneous non-combustibles, Plastic, Glass Metals)	N/A	0%
MW&RP - Unsorted	**21%**	**20%**

To validate the EU model used, the DOC values from Table 4-1 are inserted into the model for landfills developed in this paper. Table 4-2 compares these results to the methane generation value of the Canadian Report. By using the Canadian DOC data in the EU model, the error is less than 1% compared to the report data. Furthermore, using the DOC values obtained from other sources, the generated CH_4 has decreased by about 0.6%. Considering the small deviations in methane production, it is assumed that the EU method used in the model is acceptable for the purposes of this study.

Table 4-2: CH4 generated from landfills in Canada comparing methods of calculation

		CH4 Generated		
Source of information	**DOC %**	**kg/ton of raw MW&RP**	**Tons based on 2004**	**Difference %**
Canadian GHG Report (2005) [145]	N/A	N/A	1,434,652	0.00%
EU Model [43] with Canadian GHG Report DOC %	20.9%	59.0	1,448,183	0.94%
EU Model [43] with adjusted DOC %	19.9%	58.1	1,426,482	0.57%

Another Canadian report is also available for comparison purposes; Determination of the Impact of WRM Activities on Greenhouse Gas Emissions (2005) [144]. This paper has a similar approach to the methods used in the EU model, with different considerations for each process. Therefore, parallels will be drawn with this report throughout this paper.

4.2.2 Common information

Throughout the following process certain information, such as the composition of waste, is used consistently. The following tables are referenced throughout the rest of the paper.

As discussed previously, the composition and carbon content of MW&RP varies greatly. For this study, the average Canadian composition obtained in Figure 1-4 is used. The carbon content is more difficult to define with available Canadian information. Therefore the data described in Table 2-3, based on American information, is used throughout. This is an acceptable assumption considering the commonalities between our societies and is validated in Table 4-2 of the previous section. This information is summarised in Table 4-3. It should be noted that all values are assumed on a wet basis.

Heating values are determined by using the following equations:

$$HHV_{wet} = 33.9C + 144H + 13.9O + 10.5S$$

$$LHV_{wet} = HHV_{wet} - 2.44 \times (w + 9H)$$

Where C, H, O and S are carbon, hydrogen, oxygen, and sulphur respectively, expressed as a percentage of the total mass on a wet basis. The moisture content 'w' is also expressed as a percentage of the total mass on a wet basis. All values are taken from Table 2-3.

Table 4-3: Composition of MW&RP in Canada and heating value

Material	**Share (%) Base**	**Adj [d]**	**Diversion/Disposal Method**	**Carbon[e] (%)**	**Heating Value (MJ/kg) Gross**	**Net**
Paper & Cardboard	29.0	27.9	Reuse, recycling or thermal conversion	34.7	14.1	12.5
Yard Trimmings	7.6	7.3	Thermal conversion	23.3	9.7	8.0
Organics	28.2	27.1	Biochemical WRPtE or Composting	17.9	8.0	5.9
Plastics	9.2	8.9	Reuse, recycling or thermal conversion	56.4	29.3	27.2
Glass	3.4	3.2	Reuse, recycling	N/A	N/A	N/A
Metals [a]	4.6	4.4	Reuse, recycling	N/A	N/A	N/A
Textiles	2.4	2.3	Reuse, recycling or thermal conversion	37.2	16.1	14.4
Other [b]	15.7	15.1	Reuse, recycling or thermal conversion	24	10.0	8.4
Not Considered[c]	0.0	3.7				
MW&RP-Unsorted	100.0	100.0		**27**	**11.7**	**10.1**
		33.2	**million tons, 2004**			

a Metals are comprised of 4% ferrous and 1% non-ferrous metals. Information based on [58].
b Other is assumed to be 7% misc. combustibles, 2% misc. non-combustibles and 6% fines (dust). Information based on [58].
c Not considered are; White goods, Electronics, Tires, Construction & Demolition Waste.
d The adjusted percentage is used to calculate the GHG's for the scenarios. In the Canadian data for recycling there are various small categories which cannot be attributed to exact materials, therefore a small share of each material is assumed to be part of the not considered category. Both percentages are used throughout the analysis.
e Carbon content and Heating values taken from Table 2-3.

Another important factor is energy offset by using waste-related products to energy technologies. The benefits of such offsets are generally seen when avoiding energy production from dirty sources such as coal and diesel fuel, since they generate more emissions per kWh of electricity produced. In Canada, a large share (almost 60%) of the electricity comes from hydro power. Hydro being a relatively clean energy source, makes the average CO_2eq/kWh generated fairly low (250 CO_2eq/kWh) compared to other countries such as the EU at 450 CO_2eq/kWh, for example. So in Canada, any energy offset from WRPtE has a smaller effect than in other countries with higher average emissions. Most of the hydro power is concentrated in the provinces of Quebec and British Columbia and consequently energy offsets in various regions of the country would have varying benefits. However, since this is a macro approach to the Canadian waste-related GHG's, the Canadian average is used throughout these calculations. Table 4-4 shows the distribution of electricity generation in Canada.

Table 4-4: Electricity production share - GHG emissions by source

		Emissions (g CO2/kWh)	
Energy Source	**Share [146]**	**Per [147]**	**Weighted**
Hydro	58%	11	6.4
Coal	19%	975	185.3
Nuclear	12%	24	2.9
Natural Gas	6%	608	36.5
Fuel Oil	3%	742	22.3
Wind and other	2%	32	0.6
Total Canada	**100%**		**253.9**
Total EU [43]			**450.0**

4.2.3 Transportation/Mobilisation

In general the collection, transportation and mobilisation aspects of MW&RP are very difficult to estimate with a country as large as Canada. As a starting point, the EU table for transportation is used and some of the values are taken for this analysis. Whenever possible, the data is extrapolated or adjusted for the Canadian example.

Table 4-5: Vehicle type assumptions

Vehicle Type	Payload (ton)	Average Emission (kg CO2/km)
Car	0.05	0.21
Small truck (ST)	5	0.45
Large Truck (LT)	20	0.84
Refuse Collection Vehicle (RCV)	6.67	0.71

Source: [148]

The emissions generated from the transportation and mobilisation of MW&RP for various processes are summarised in Table 4-6. The emissions per kilometre are based on the estimates taken from Table 4-5.

4.2.3.1 Landfill:

In Canada landfills are generally located relatively close to the source, considering the vast amount of land and low population density. In the case of major cities it is assumed that the average distance is 60km from generator to disposal. However, as seen in Table 3-1 only about 50% of the population lives in major cities. The rest of the population is greatly dispersed. At one time, smaller villages would have each had a small open pit for MW&RP landfills and hence small travel distances. However, newer legislation is generally banning these uncontrolled facilities and increasingly MW&RP in rural Canada must travel greater distances before it reaches a more controlled facility. In rural Canada it is currently assumed that MW&RP travels about 100km for 50% of the Canadian population. Therefore on average MW&RP travels about 80km's from source to landfill.

In most Canadian cities MW&RP are delivered to landfill by the same truck that picks them up, sometimes called Refuse Collection Vehicles (RCV). However, in some of the larger cities such as Toronto some of the waste is sent to a transfer stations where it is put into a larger truck and shipped greater distances to other landfill sites. For the Toronto case about 4% (or one million tons per year) of our Canadian MW&RP is sent 60km's to a transfer station, then another 360km's to the United States in larger trucks. Since national figures are not available for these types of activities, it is assumed that about 6% of Canadian MW&RP undergoes a similar process. This is based on reasonable quantities for the largest cities in Canada.

Overall, the emissions related to the transport of MW&RP in Canada are estimated to be 9.3 kg CO_{2eq} per ton of material. Comparing this value to that obtained in the Canadian report [144] of 0.01 ton CO_{2eq} per ton of material, the numbers agree quite well.

4.2.3.2 WRPtE

Transportation from the source to a WRPtE facility is as difficult to define as for the distance to landfill, especially since Canada has few of these facilities. However, experience has shown that WRPtE sites need to be located close to major sources (i.e. major cities) in order to be financially feasible. Therefore for the purpose of this analysis, it is assumed that all major cities have a WRPtE close to or near the city, and in some cases (i.e. Ottawa, Ontario) the facilities are beside the landfill. Using the landfill transportation logic, it can be assumed that 50% of the MW&RP would travel 60km at all major cities. For the rural MW&RP facilities this may not be feasible therefore it would need to travel to larger cities via transfer stations. It is assumed that 50% of the MW&RP would travel 100km to a RTS then another 100km to the WRPtE facility.

Ash and other hazardous contaminants are produced as by-products of WRPtE, the quantity of which depends greatly on the characteristics of the feedstock and the technology used. As discussed previously, anywhere between 10% and 25% of solids can be collected, based on the initial mass. As an average, it is assumed that 15% ash is collected, of which 50% is usable for the market and the balance goes to landfill. Another 4% is considered to be hazardous and must be disposed of accordingly. Since most WRPtE sites are nearby to landfills, which in most cases also are hazardous sites, the transportation of these materials is assumed to be 5km.

During the thermal processing of MW&RP, metals are also left behind as solids. The ferrous metals are typically removed and sent for recycling. In general 98% of the ferrous metal can feasibly be recovered, however not all facilities do this [144]. Therefore it is assumed that 90% of the ferrous metal in MW&RP is recovered and sent for recycling. For the metal recycling, the distance is much greater as discussed later, and is assumed to be 400km's.

4.2.3.3 Composting and Anaerobic Digestion

Composting is fairly common in Canada, depending on whether a person has a garden and the seasonal conditions. Rural residents are more likely to compost than city folk. However, no figures are available relating to the quantity of on-site composting done. Considering the 50% rural, 50% urban population scenario, and knowing that not all people compost, it is assumed that 1/3 compost at home. Therefore, there are no emissions associated to transportation in this case. The remaining 2/3 organics are assumed to be collected either for composting or anaerobic digestion at central facilities. Since the least likely to compost are urban dwellers, it is assumed that the central facilities are at an average of 60km from the source.

4.2.3.4 Recycling

Data for transportation distances of recycled material is not readily available. In general, curb-side collection of unsorted recyclables is common in Canada and so the average of 80kms defined in the landfill section will be used. Furthermore, the recycling plants are few and far between and so an average of 400kms is assumed from collection point to re-processing plant.

Table 4-6: Mobilisation Emissions for W&RP

Treatment	Stage	Type	From	To	Payload Type	Vehicle Type	Average Payload (t)	ton payload per ton waste	km	Kg CO2 / km	Kg CO2 / ton	% by route	Weighted Emission Factor kgCO2/t
Landfill													
	Collection	Direct	Household	Landfill	MSW	RCV	6.67	1	80	0.71	8.52	94%	8.00
		Via RTS	Household	RTS	MSW	RCV	6.67	1	60	0.71	6.39	6%	0.38
		Via RTS	RTS	Landfill	MSW	LT	20	1	360	0.84	15.12	6%	0.91
Total													***9.30***
WRPtE													
	Collection	Direct	Household	WRPtE	MSW	RCV	6.67	1	60	0.71	6.39	50%	3.19
		Via RTS	Household	RTS	MSW	RCV	6.67	1	100	0.71	10.64	50%	5.32
		Via RTS	RTS	Landfill	MSW	ST	5	1	100	0.45	9.00	50%	4.50
	Fly Ash and Flue Gas cleaning		WRPtE	Hazardous Landfill	Ash and FG residue	ST	5	0.04	5	0.45	0.02	100%	0.02
	Ash to market		WRPtE	Market	Ash	ST	5	0.15	40	0.45	0.54	50%	0.27
	Unusable Ash		WRPtE	Landfill	Ash	ST	5	0.15	5	0.45	0.07	50%	0.03
	Metals to reprocessor		WRPtE	Metals reprocessor	Metal scraps	LT	20	0.05	400	0.84	0.84	100%	0.84
Total													***14.18***
Composting/AD													
	Collection	Kerbside	Household	Composter/ AD plant	Putrescibles	ST	5	1	60	0.45	5.40	67%	3.62
		Home Compost	Household	Compost heap	Putrescibles	N/A		1	0	0.00	0.00	33%	0.00
	Residue to landfill		Composter/ AD plant	Landfill	Residue	ST	5	0.1	5	0.45	0.05	100%	0.05
	Compost to Market		Composter/ AD plant	Market	Compost	ST	5	0.4	60	0.45	2.16	100%	2.16
	Unmarketable compost to landfill		Composter/ AD plant	Landfill	Compost	ST	5	0.4	60	0.45	2.16	0%	0.00
Total													***5.82***

Table 4-6: Mobilisation Emissions for W&RP (cont'd)

Treatment	Stage	Type	From	To	Payload Type	Vehicle Type	Average Payload (t)	ton payload per ton waste	km	Kg CO2 / km	Kg CO2 / ton	% by route	Weighted Emission Factor kgCO2/t
Recycling													
	Collection	Kerbside	Household	MRF	Mixed recyclables	ST	5	1	80	0.45	7.20	100%	7.20
	Residue to landfill		MRF	Landfill	Residue	ST	5	0.45	0.02	100%	0.02	5	0.45
	MRF to reprocessor	Paper	MRF	Paper reprocessor	Paper	LT	20	0.95	400	0.84	15.96	100%	15.96
		Glass	MRF	Glass reprocessor	Glass cullet	LT	20	0.95	400	0.84	15.96	100%	15.96
		Ferrous metal	MRF	Ferrous metal reprocessor	Ferrous scrap	LT	20	0.95	400	0.84	15.96	100%	15.96
		Aluminum	MRF	Aluminum reprocessor	Aluminum scrap	LT	20	0.95	400	0.84	15.96	100%	15.96
		Plastic	MRF	Plastic reprocessor	Plastic feedstock	LT	20	0.95	400	0.84	15.96	100%	15.96
	Collection point to reprocessor	Textiles	Collection point	Textile reprocessor	Textiles	LT	20	0.95	400	0.84	15.96	100%	15.96
	HHW site etc to reprocessor	WEEE	HHW site etc	WEEE reprocessor	WEEE	LT	20	1	400	0.84	16.80	100%	16.80
Total		***Paper***											***23.18***
		Glass											***23.18***
		Ferrous metal											***23.18***
		Aluminium											***23.18***
		Plastic											***23.18***
		Textiles											***23.18***

4.2.4 Landfill

Determining the effect that landfills have on greenhouse gases is subject to much debate and uncertainty. There are numerous factors that affect the degradation of putrescible. In landfills these effects are event greater. For example annual rain fall, compaction, depth of pit, ratio of organics, etc., can all affect the degradation rate. Furthermore, some studies [144 and 43] even suggest that some biogenic carbon will not degrade within the 100 year time horizon, which can then be considered as sequestered carbon, ultimately acting as a carbon sink. However, the level of sequestration is highly uncertain and can only be estimated at best.

As discussed in the validation section of the methodology, the DOC (degradable organic carbon) within the waste-related material determines the quantity of carbon that could potentially degrade under normal conditions. Then by assuming that a certain portion of the DOC will actually be degraded the DDOC (Dissimilated DOC) can be determined. The DDOC can be defined as the actual carbon degradation potential based on the original total carbon content. The balance of carbon which does not degrade can then be considered as sequestered.

Table 4-8 & Table 4-9 demonstrate the values assumed and the calculation used to determine the emissions and sinks for landfills. This example is the Base Case, as defined in Table 4-7. In an effort to establish sensitivity to the DDOC, the average value is taken for the scenarios, except on the base case. For the base case, high and low DDOC values are compared for discussion purposes only, as can be seen in Table 4-10.

Three principal scenarios are compared in this analysis;

- Base Case: using known Canadian data for landfill gas collection. In 2004, the estimated landfill gas collection rate was estimated to be 22% based on collected data from landfill operators [145]. Of the captured gas, only about 50% was used for energy recovery
- Best Case: assuming that 80% of the emitted landfill gas is collected and that 90% of that gas is used for energy production
- Restoration layer: is a futuristic approach to landfills, where a restoration layer is placed on top of the landfill. This allows escaping CH_4 to oxidize by being in contact with methanogens located in the restoration layer. In this case, it is assumed 90% of the uncollected methane is oxidized

Table 4-7: Scenario information

Energy Source	Base Case	Best Case	Restoration Layer	Unit	Source
Fraction of landfill carbon decaying to methane	50	50	50	%	[43]
CH_4 collected in Canadian landfills (2004)	22	80	80	%	[145]
Percentage of uncollected methane oxidised	10	10	90	%	[43]
Percentage of collected LFG vented without combustion	0.15	0.15	0.15	%	[145]
Percentage of collected LFG utilised for energy	51	90	90	%	[145]
Percentage of collected LFG flared	49	10	10	%	[145]
LFG electricity generation efficiency	30	30	30	%	[43]
Heating value of methane	15.4	15.4	15.4	kWh/kg	
Canadian average avoided emissions	0.25	0.25	0.25	kg eCO_2/kWh	

For all cases, it is assumed that 50% of the DDOC is converted into methane and the other 50% into CO_2. Table 2-18 shows that the electrical conversion efficiency for AD ranges from 10% to 16% of the initial feedstock with a CO_2 / CH_4 mix. Therefore, if only methane is being collected than the LFG electricity generation efficiency can be doubled to 30% for 100% methane.

The calculations and results for all three (3) scenarios are shown in Table 4-10. The short cycle CO_2 is ignored from the total flux. All other figures are calculated from the other tables and summed to show the total GHG flux in eCO_2/ton of material. Unsorted MW&RP is also shown and is weighted based on the average composition of Canadian data. Energy Use is included as 1 kg CO_{2eq} per ton for the machinery used at landfills. The avoided energy is the displaced energy based on the average Canadian energy mix.

The sensitivity analysis for the DDOC range is also shown in Table 4-10. It is clear that the DDOC has a large effect on the net GHG flux. This is mainly due to the amount of methane generated and released into the atmosphere. The average will be used henceforth, but it demonstrates the effect these assumptions can have on the projected emissions of organics in landfills.

Figure 4-1, Figure 4-2 and Figure 4-3 show the GHG fluxes for all three cases. Figure 4-4 compares all 3 scenarios.

It is clear that landfills, as they are currently operated, have a positive greenhouse gas effect. On the other hand if improvements and best practices are applied, landfills can in fact become GHG sinks. However, as seen in the previous chapters, it is estimated that only 19% of methane generated in landfills can be captured, Table 2-17. Therefore a methane capture of 80% may in fact be a little aggressive and potentially impossible (or unfeasible).

Table 4-8: Base Case – Estimates of short-cycle carbon dioxide and methane generated from landfilled waste

Component	total carbon content (TC) of waste component (a)	proportion of TC which is degradable (b)	degradable organic carbon (DOC) as % of waste component (c)	composition of CAN average MW&RP (d)	contribution of each component to DOC of a tonne of MSW (e)	% of DOC which is dissimilated (sensitivity range) (f)	dissimilated organic carbon (DDOC) (g)	methane generated kg CH4/t (h)	CO2 generated kg CO2/t (i)	carbon sequestered kg CO2/t (j)
Paper & Cardboard	35%	100%	35%	29%	10.1%	35% [b]	12.1%	81	223	827
Yard	23%	100%	23%	8%	1.8%	50%	11.6%	78	213	427
Organics	18%	100%	18%	28%	5.0%	63% [b]	11.2%	75	205	247
Textiles	37%	50%	19%	2%	0.4%	30%	5.6%	37	102	478
Miscellaneous combustibles	37%	75%	28%	7%	2.0%	35%	9.7%	65	178	661
Fines	14%	65%	9%	6%	0.5%	60%	5.5%	36	100	133
Other [a]	0%	0%	0%	20%	0.0%	0%	0.0%	0	0	0
MW&RP unsorted	**27%**		**20%**				**8.7%**	**58**	**160**	**409**

[a] Others is comprised of (Miscellaneous non-combustibles, Plastic, Glass Metals)
[b] Range for DOC of paper & cardboard assumed to be (20%-50%) and for organics (50%-80%), therefore average taken in both cases.

Values in **Table 4-8** are tabulated as follows:

Column	Reference / Calculation	Additional Comments
(a)	Taken from Table 4-3	
(b)	Accepted values from EU report (2001) [43]	
(c)	= (**a**) x (**b**)	
(d)	Base share of Canadian MW&RP from Table 4-3	
(e)	= (**c**) x (**d**)	
(f)	Accepted values from EU report (2001) [43]	
(g)	= (**c**) x (**f**)	
(h)	$= (\mathbf{g})\% \text{ of } \frac{\text{DDOC}}{\text{ton of waste}} \times 50\% \text{ of DDOC to } CH_4 \times 16 \frac{g}{mol} \text{ of } CH_4 \div 12 \frac{g}{mol} \text{ of Carbon} = \frac{\mathbf{kg\ CH_4}}{\mathbf{ton\ of\ material}}$	50% of DDOC to CH_4 from Table 4-7
(i)	$= (\mathbf{g})\% \text{ of } \frac{\text{DDOC}}{\text{ton of waste}} \times 50\% \text{ of DDOC to } CO_2 \times 44 \frac{g}{mol} \text{ of } CO_2 \div 12 \frac{g}{mol} \text{ of Carbon} = \frac{\mathbf{kg\ CO_2}}{\mathbf{ton\ of\ material}}$	50% of DDOC to CO_2 from Table 4-7
(j)	$= \left\{(\mathbf{c})\% \text{ of } \frac{\text{DOC}}{\text{ton of waste}} - (\mathbf{g})\% \text{ of } \frac{\text{DDOC}}{\text{ton of waste}}\right\} \times 44 \frac{g}{mol} \text{ of } CO_2 \div 12 \frac{g}{mol} \text{ of Carbon} = \frac{\mathbf{kg\ CO_2}}{\mathbf{ton\ of\ material}}$	The balance of Carbon that is not converted to gas is considered to be sequestered.

Table 4-9: Base Case – Estimates of CO2 and methane released from landfill waste and electricity generated from landfill gas

Component	CH4 generated kg/t waste material	CO2 generated kg/t waste material	CH4 collected kg/t waste material	CH4 oxidised kg/t waste material	CH4 released kg/t waste material	CH4 used for energy kg/t waste material	Product of combustion CO2 released kg/t waste material	Short term CO2 released kg/t waste material	Electricity generated kWh/t waste material	Avoided emissions kg CO2/t waste material
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)
Paper	81	223	18	6	57	9	49	289	42	11
Yard	78	213	17	6	55	9	47	277	40	10
Organics	75	205	16	6	52	8	45	267	38	10
Textiles	37	102	8	3	26	4	22	133	19	5
Miscellaneous Combustibles	65	178	14	5	45	7	39	231	33	8
Fines	36	100	8	3	26	4	22	130	19	5
MW&RP Unsorted	**58**	**160**	**13**	**5**	**41**	**6**	**35**	**207**	**30**	**8**

Values in **Table 4-9** are tabulated as follows:

Column	Reference / Calculation	Additional Comments
(a)	Taken from Table 4-8 column (**h**)	
(b)	Taken from Table 4-8 column (**i**)	
(c)	= (**a**) x CH_4 collected in Canadian landfills (2004)	Value from Table 4-7
(d)	= {(**a**) – (**c**)} x Percentage of uncollected methane oxidised	Value from Table 4-7
(e)	= (**a**) – (**c**) – (**d**) + (**c**) x Percentage of collected LFG vented without combustion	Value from Table 4-7
(f)	= (**c**) x Percentage of collected LFG utilised for energy	Value from Table 4-7
(g)	$= \{(\mathbf{f}) + (\mathbf{c}) \times \text{Percentage of collected LFG flared}\} \times 44\frac{\text{g}}{\text{mol}} \text{ of } CO_2 \div 16\frac{\text{g}}{\text{mol}} \text{ of } CH_4 = \frac{\mathbf{kg\ CO_2}}{\mathbf{ton\ of\ material}}$	Value from Table 4-7
(h)	$= (\mathbf{b}) + (\mathbf{d}) \times 44\frac{\text{g}}{\text{mol}} \text{ of } CO_2 \div 16\frac{\text{g}}{\text{mol}} \text{ of } CH_4 + (\mathbf{g}) = \frac{\mathbf{kg\ CO_2}}{\mathbf{ton\ of\ material}}$	
(i)	$= (\mathbf{f}) \times \text{ LFG electricity generation efficiency } \times \text{Heating value of methane } \frac{\text{kWh}}{\text{kg}} = \frac{\mathbf{kWh}}{\mathbf{ton\ of\ material}}$	Values from Table 4-7
(j)	$= (\mathbf{i}) \times \text{ Canadian average avoided emissions } \frac{\text{kg } eCO_2}{\text{kWh}} = \frac{\mathbf{kg\ eCO_2}}{\mathbf{ton\ of\ material}}$	Value from Table 4-7

Table 4-10: Landfill Net GHG Emissions with Sensitivity Analysis (kg CO2eq/t material treated)

Waste-related management option	Waste component	Short cycle CO2	Fossil CO2				Short cycle C sequestered	Sum of fossil C and sequestered C	CH4 emission (CO_{2eq})	N2O emission (CO_{2eq})	
Landfill		**GWP=0**	**Process**	**Energy use**	**Avoided energy and materials**	**Transport / mobilisation**	**GWP = -1**		**GWP=21**	**GWP=310**	**Total GHG flux**
		(a)	**(b)**	**(c)**	**(d)**	**(e)**	**(f)**	**(g)**	**(h)**	**(i)**	**(j)**
Landfill gas collected and used for electricity generation. Base case assumptions.	Paper & Cardboard	289	0	1	-10.6	9.3	-827	-827	1,194	0	367
	Yard Trimmings	277	0	1	-10.2	9.3	-427	-427	1,145	0	718
	Organics	267	0	1	-9.8	9.3	-247	-246	1,102	0	856
	Plastic	0	0	1	0.0	9.3	0	10	0	0	10
	Glass	0	0	1	0.0	9.3	0	10	0	0	10
	Metal	0	0	1	0.0	9.3	0	10	0	0	10
	Textiles	133	0	1	-4.9	9.3	-478	-472	549	0	77
	Other [a]	157	0	1	-5.7	9.3	-357	-352	647	0	295
	MW&RP	**207**	**0**	**1**	**-7.6**	**9.3**	**-409**	**-406**	**858**	**0**	**452**
Sensitivity Analysis											
Low DDOC	MW&RP	157	0	1	-5.7	9.3	-487	-483	647	0	165
High DDOC	MW&RP	264	0	1	-9.7	9.3	-321	-320	1,093	0	773
Best Practice gas Collection	MW&RP	291	0	1	-49.2	9.3	-409	-448	221	0	-226
Restoration Layer	MW&RP	316	0	1	-49.2	9.3	-409	-448	26	0	-422

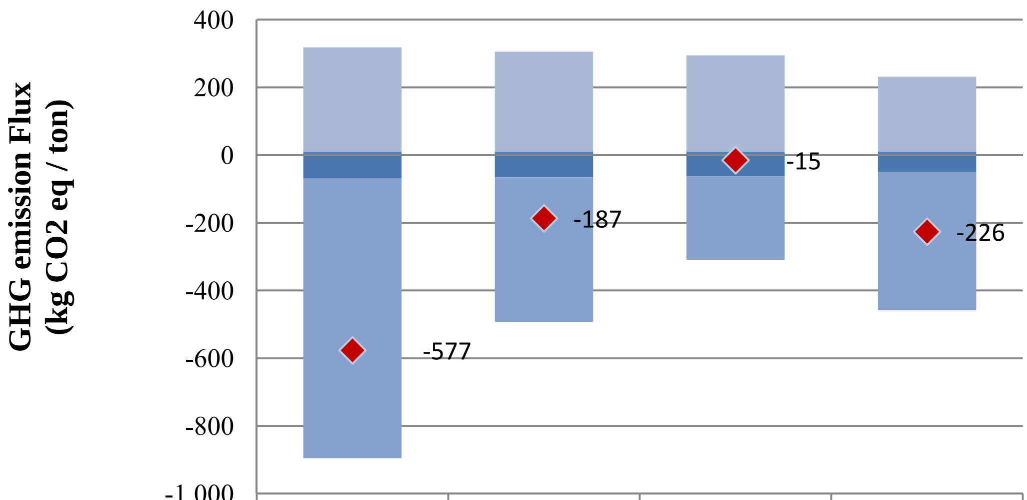
[a] Other is the weighted average of miscellaneous combustibles and non-combustibles and fines.

Values in **Table 4-10** are tabulated as follows:

Column	Reference / Calculation	Column	Reference / Calculation
(a)	Taken from Table 4-9 column (**h**)	(f)	Taken from Table 4-7 column (**j**)
(b)	Accepted values from EU report (2001) [43]	(g)	= Sum of columns (**b**) through (**f**)
(c)	Accepted values from EU report (2001) [43]	(h)	= CH_4 released kg/t waste material (from Table 4-9 column (**e**)) x 21 eCO_2 GWP of CH_4
(d)	Taken from Table 4-9 column (**j**)	(i)	= N_2O released kg/t waste material x 310 eCO_2 Global Warming Potential of N_2O
(e)	Taken from Table 4-6	(j)	= Sum of columns (**g**) through (**i**)

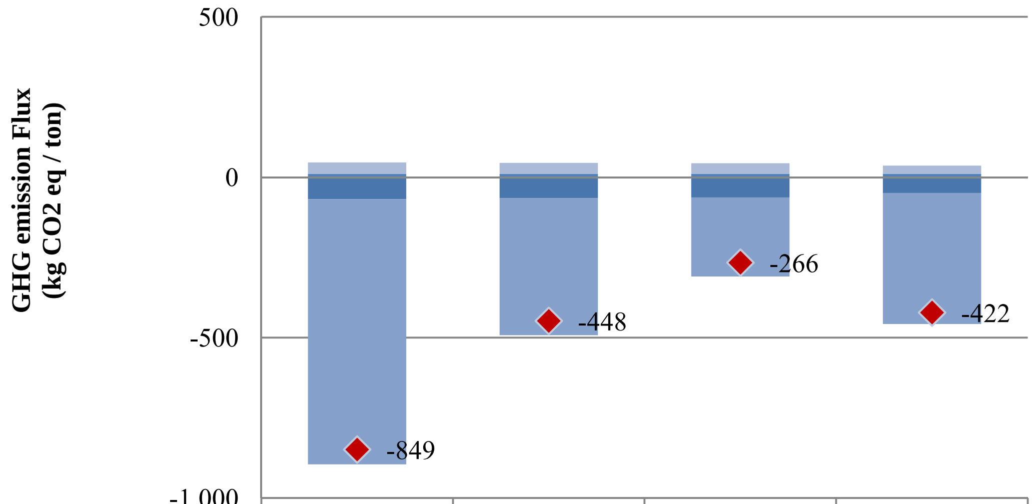
	Paper & Cardboard	Yard Trimmings	Organics	MW&RP
CH4 emission	1.194	1.145	1.102	858
Short cycle C sequestered	-827	-427	-247	-409
Transport/mobilisation	9,3	9,3	9,3	9,3
Avoided energy and materials	-10,6	-10,2	-9,8	-7,6
Energy use	1	1	1	1
Process	0	0	0	0
Net Flux	367	718	856	452

Figure 4-1: Base Case - Current Canadian Emissions from Landfill



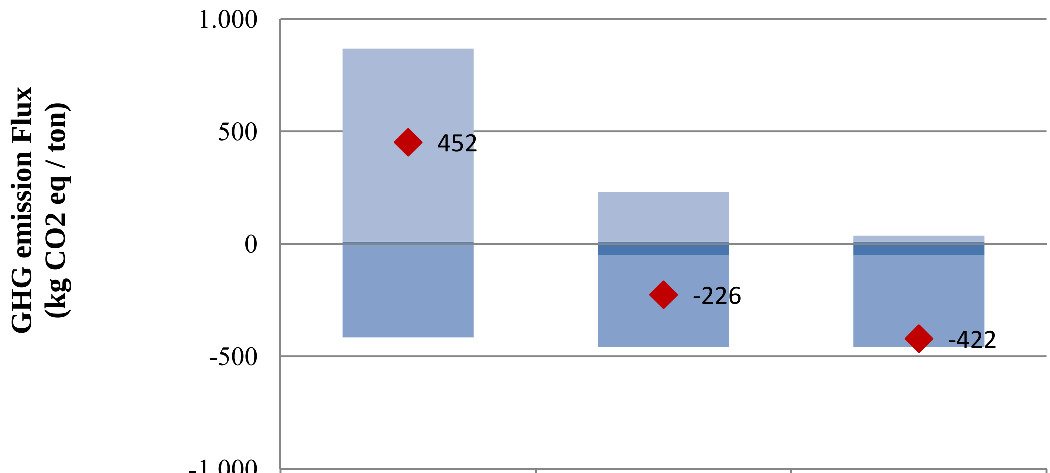
	Paper	Wood	Putrescible	MW&RP
CH4 emission	308	295	284	221
Short cycle C sequestered	-827	-427	-247	-409
Transport/mobilisation	9,3	9,3	9,3	9,3
Avoided energy and materials	-68,4	-65,6	-63,2	-49,2
Energy use	1	1	1	1
Process	0	0	0	0
Net Flux	-577	-187	-15	-226

Figure 4-2: Best Case - All Landfill Sites Capture Methane



	Paper	Wood	Putrescible	MW&RP
CH4 emission	36	35	33	26
Short cycle C sequestered	-827	-427	-247	-409
Transport/mobilisation	9,3	9,3	9,3	9,3
Avoided energy and materials	-68,4	-65,6	-63,2	-49,2
Energy use	1	1	1	1
Process	0	0	0	0
Net Flux	-849	-448	-266	-422

Figure 4-3: Restoration Layer is applied to all Landfills



	Base Case	Best Case	Restoration Layer
CH4 emission	858	221	26
Short cycle C sequestered	-409	-409	-409
Transport/mobilisation	9	9	9
Avoided energy and materials	-8	-49	-49
Energy use	1	1	1
Process	0	0	0
Net Flux	452	-226	-422

Figure 4-4: Comparison of Emissions for three (3) Landfill Scenarios

4.2.5 Incineration

There exist many technologies for the thermal conversion of MW&RP, each have their pros and cons. But most importantly certain processes are better suited for certain types of feedstock. This is more important for material with high moisture content, such as organics and yard trimmings which should undergo biochemical processing (e.g. AD).

When assessing the incineration of MW&RP (or any biomass for that matter) it is important to be aware of the composition. As discussed earlier, hazardous products can be present in the feedstock and some can be created as a result of the process. For the purpose of comparing the global warming effect of incineration, it is assumed that the MW&RP is sorted prior to combustion to remove the hazardous components. This is true in practice since not all materials present in MW&RP should be incinerated. Most facilities will do so to stabilise the energy content of the fuel by removing non-combustibles (for recycling if possible) and high moisture organics.

It was also shown previously that newer technologies can minimize most harmful emissions created during the process. Coupled with appropriate flue cleaning technologies, the overall emissions can be well below environmental limits. Consequently, the only emissions considered in this analysis are that of fossil CO_2 and N_2O.

Table 4-11 shows the raw data used to calculate the emissions from incineration. Values for N_2O are sparse and depend on the technology used. The value of 0.05 kg/t is taken from the EU report [43]. The estimates for the % fossil carbon of ‘textiles’ and ‘others’ was also taken from the same report.

As discussed in the transportation section, a portion of the input MW&RP is collected as ferrous metal which can be sent to recycling. In this case, the avoided energy and material considered is taken from the recycling estimates further on. This is factored into the weighted MW&RP only for comparison purposes. Table 4-12 summarizes the calculation for the incineration, without energy recovery.

The main purpose of MW&RP incineration is not only to reduce the volume, but also create some useful energy. This makes the whole process more attractive and financially feasible. The net heating value (wet) of each product is taken from Table 4-3 and used to assess the avoided energy emissions. A comparison for various processes and efficiencies is shown in Table 4-13 with the net GHG flux. Two technologies (mass burn and gasification) are compared with electricity only or CHP operation. The efficiencies noted are taken from Table 2-18.

Table 4-11: Incineration of MW&RP – emissions

Component	Composition of Waste (a)	% Carbon content (b)	% Fossil Carbon (c)	Fossil CO_2 kg/t (d)	N_2O kg/t (e)	% Short Cycle CO_2 (f)	Short Cycle CO_2 kg/t (g)
Paper/Card	29%	35%	0%	0	0.05	100%	1272
Yard	8%	23%	0%	0	0.05	100%	854
Organics	28%	18%	0%	0	0.05	100%	657
Plastic	9%	56%	100%	2069	0.05	0%	0
Glass	3%	0%	0%	0	0.05	0%	0
Metals	5%	0%	0%	0	0.05	0%	0
Textiles	2%	37%	50%	683	0.05	50%	683
Other	16%	24%	29%	255	0.05	61%	537
MW&RP	**100%**	**27%**		**248**	**0.05**		**719**

Values in **Table 4-11** are tabulated as follows:

Column	Reference / Calculation
(a)	Base share of Canadian MW&RP from Table 4-3
(b)	Carbon content from Table 4-3
(c)	Accepted values from EU report (2001) [43]
(d)	$= (\mathbf{b}) \times (\mathbf{c}) \times 44\frac{\text{g}}{\text{mol}}\text{of CO}_2 \div 12\frac{\text{g}}{\text{mol}}\text{of Carbon} \times \frac{1000\text{kg}}{\text{ton}} = \frac{\textbf{kg of Fossil CO}_2}{\textbf{ton of material}}$
(e)	Accepted values from EU report (2001) [43]
(f)	$= 1 - (\mathbf{c})$
(g)	$= (\mathbf{b}) \times (\mathbf{f}) \times 44\frac{\text{g}}{\text{mol}}\text{of CO}_2 \div 12\frac{\text{g}}{\text{mol}}\text{of Carbon} \times \frac{1000\text{kg}}{\text{ton}} = \frac{\textbf{kg of Fossil CO}_2}{\textbf{ton of material}}$

Table 4-12: Incineration Net GHG Emissions – No energy recovery (kg CO2eq/t material treated)

Waste-related management option	Component	Short cycle CO_2 (GWP=0) (a)	Fossil CO_2 Process (b)	Fossil CO_2 Energy use (c)	Fossil CO_2 Avoided energy and materials (d)	Fossil CO_2 Transport / mobilisation (e)	Short cycle C sequestered (GWP=-1) (f)	Sum of fossil C and sequestered C (g)	CH4 emission GWP=21 (h)	N2O emission GWP=310 (i)	Total GHG flux (i)
Mass Burn - No Energy Recovery 0% Elec – 0% Heat	Paper/cardboard	1,272	0	0	0.0	14.2	0	14	0	15.5	30
	Yard	854	0	0	0.0	14.2	0	14	0	15.5	30
	Putrescibles	657	0	0	0.0	14.2	0	14	0	15.5	30
	Plastic	0	2,069	0	0.0	14.2	0	2,083	0	15.5	2,099
	Glass	0	0	0	0.0	14.2	0	14	0	15.5	30
	Metals*	0	0	0	-881	14.2	0	-867	0	15.5	-851
	Textiles	683	683	0	0.0	14.2	0	697	0	15.5	712
	Other	537	255	0	0.0	14.2	0	269	0	15.5	285
	MW&RP	**719**	**248**	**0**	**-40.7**	**14.2**	**0**	**221**	**0**	**0**	**221**

* Avoided energy and materials for *metals* includes greenhouse gas emissions avoided by recovering ferrous metal from combustion residues and replaced energy that would have come from other sources. For steel, 1 ton recovered = 1,223 kg of CO_2 avoided. Ferrous metals are 80% of the metals and only 90% of ferrous metals can be recovered. Which means 1,223*90%*80% = 881 kg CO_2/ton of metal.

Values in **Table 4-12** are tabulated as follows:

Column	Reference / Calculation	Additional Comments
(a)	Taken from Table 4-11 column (**g**)	
(b)	Taken from Table 4-11 column (**d**)	
(c)	Accepted values from EU report (2001) [43]	
(d)	$= -1 \times \text{Net Heating Value } \frac{\text{MJ}}{\text{kg}} \times \frac{\text{1hr}}{\text{3600s}} \times \frac{\text{1000 kJ}}{\text{MJ}} \times \frac{\text{1000 kg}}{\text{ton}} \times \text{Average Energy Production Emissions } \frac{\text{kg CO}_2}{\text{kWh}} \times \text{\% Energy Conversion Eff} = \frac{\textbf{kg eCO}_2}{\textbf{ton of material}}$	Net Heating Values from Table 4-3 Average Energy Production Emissions for Canada from Table 4-4 Energy Conversion Eff from Table 2-18
(e)	Taken from Table 4-6	
(f)	= 0 because there is no short cycle carbon sequestered as part of the incineration process	
(g)	= Sum of columns (**b**) through (**f**)	
(h)	= 0 because all carbon is converted to either short cycle or fossil CO_2	
(i)	= N_2O released kg/t waste material x 310 eCO_2 Global Warming Potential of N_2O	N2O release from Table 4-11
(j)	= Sum of columns (**g**) through (**i**)	

Table 4-13: Incineration Net GHG Emissions – Various energy recovery (kg CO2eq/t material treated)

	Incineration (mass Burn)						Gasification			
	0% Elec - 0% Heat		18% Elec - 0% Heat		18% Elec - 50% Heat		30% Elec - 0% Heat		30% Elec - 50% Heat	
Waste-related component	**Avoided energy and materials**	**Total GHG flux**	**Avoided energy and materials**	**Total GHG flux**	**Avoided energy and materials**	**Total GHG flux**	**Avoided energy and materials**	**Total GHG flux**	**Avoided energy and materials**	**Total GHG flux**
Paper/cardboard	0	30	-159	-129	-600	-571	-265	-235	-706	-677
Yard	0	30	-101	-71	-381	-352	-168	-139	-449	-419
Putrescibles	0	30	-75	-46	-285	-256	-126	-96	-336	-306
Plastic	0	2,099	-345	1,754	-1,304	795	-575	1,524	-1,534	565
Glass	0	30	0	30	0	30	0	30	0	30
Metal	-881	-851	-881	-851	-881	-851	-881	-851	-881	-851
Textiles	0	712	-183	529	-691	22	-305	408	-812	-100
Other	0	285	-107	178	-403	-118	-178	107	-474	-189
MW&RP	**-41**	**221**	**-169**	**93**	**-524**	**-262**	**-254**	**8**	**-609**	**-348**

Values in **Table 4-13** are tabulated as follows:

Column	**Reference / Calculation**	**Additional Comments**
Avoided energy and materials	$= -1 \times \text{Net Heating Value}\ \frac{\text{MJ}}{\text{kg}} \times \frac{1\text{hr}}{3600\text{s}} \times \frac{1000\ \text{kJ}}{\text{MJ}} \times \frac{1000\ \text{kg}}{\text{ton}}$ $\times \text{Average Energy Production Emissions}\ \frac{\text{kg CO}_2}{\text{kWh}}$ $\times \%\ \text{Energy Conversion Eff} = \frac{\textbf{kg eCO}_2}{\textbf{ton of waste}}$ The above formula is used for all materials, except for metal as per note in Table 4-12	Net Heating Values from Table 4-3 Average Energy Production Emissions for Canada from Table 4-4 Energy Conversion Eff from Table 2-18
Total GHG flux	All values are calculated using the same method as in Table 4-12, except the values for “Avoided energy and materials” changes depending on the process efficiency.	

4.2.6 Composting

The purpose of composting is to aerate the putrescible material during decomposition so that any carbon can be released and oxidized into CO_2. Since the carbon is considered biogenic or short cycle, the CO_2 emissions can be ignored (net zero). Some carbon may even be sequestered in the compost which would then act as a carbon sink. However, there is immense debate over the quantity and duration of sequestration [144], [43]. Since this analysis spans 100 years, some studies suggest that there is no carbon left in the compost after that period of time. Others suggest that all carbon has been released way before the 100 years is up. On the other hand, this depends on a plethora of environmental factors which cannot all be accurately assessed. Some other reports identify that large amounts of carbon can be sequestered in compost. For example the Canadian study concluded that 0.27 tonnes of CO2eq per tonne of putrescible waste can be sequestered during compost [144]. However, these values are not over the 100 year time frame of this study.

Considering the method used in this paper, the approach elaborated in the European study [43] is applied here. Based on all the analysed research, it was concluded that on average 8.2% of the carbon remaining in the fertilizer after composting will be sequestered. This represents 22 kg CO_2/tonne of putrescible sequestered, which is 10 times less than the Canadian report. The numbers used in this report are calculated based on the average retention of 8.2% in compost within the 100 year time frame. The results of this are shown in Table 4-15. The methodology to calculate the emissions is consistent with the technique applied for landfills.

The solid by-product of composting can be used as a fertilizer. Typically compost contains nitrogen (N), phosphorous (P) and potassium (K) which is essential to plant growth. Although the concentrations of these later in compost is low compared to inorganic fertilizers, there is nevertheless merit to compost used as a fertilizer. Consequently, it can be assumed that compost will displace the need for other inorganic fertilisers. Table 4-14 is a summary of the avoided emissions associated with using compost as a fertiliser.

The emissions associated with three different methods (Open, Closed and Home Composting) are presented in Table 4-16. Open and closed composting is done at centralised facilities where machinery is used to turn and aerate the compost. The difference being that open composting is performed outdoors, exposed to the environment, whereas closed composting is done indoors, in a relatively more controlled environment. The machinery used to till the compost contributes to the emission flux. Based on the EU study, the emissions are estimated to be 13kg CO_{2eq}/ton for open composting and 18kg CO_{2eq}/ton for closed. The emissions for closed composting are slightly higher due to those associated with the building and its services.

Table 4-14: Potential greenhouse gas emissions avoided in fertiliser manufacture if compost displaces mineral fertiliser.

Nutrient element	kg CO2 equiv/kg element	Nutrient content in compost kg/tonne fresh weight	Avoided emission kg CO2 equiv / tonne of compost (1:1 replacement)
N	5.29	6.2	-32.8
P	0.52	2	-1.0
K	0.38	4.5	-1.7
Total			**-35.5**

Source: [43]

In addition to the energy use for open and closed composting, there are transportation emissions from the curb-side collection to the facility and from the facility to the fertiliser usage point. The home composting method avoids all the transportation and energy use emissions since the whole process is done at home.

In all cases, composting is shown to have a negative GHG flux due to the carbon sequestration and the avoided fertiliser use. The most favourable, being of course, home composting since transportation emissions and additional energy use is avoided. These values are quite different from the results obtained in the Canadian report since it assumed a much higher sequestration rate.

Table 4-15: Estimates of carbon dioxide released during composting and over subsequent 100-years after use of compost as soil conditioner.

Waste component	Degradable Organic Carbon (DOC) (a)	CO2 equivalent of DOC (b)	% of DOC lost during composting (c)	Dissimilated Organic Carbon (DDOC) (d)	emission factor kgCO2/t (e)	% DOC mineralising during 100y after compost use (f)	CO2 produced during compost use (g)	emission factor kgCO2/t (h)	CO2 sequestered kgCO2/t (i)=(b)-(h)
Paper	35%	1272	35%	12%	445	21%	759	1204	68
Yard	23%	854	50%	12%	427	11%	392	819	35
Organics	18%	657	75%	13%	493	4%	151	644	13
Putrescibles [a]	**19%**	**699**	**70%**	**13%**	**479**	**6%**	**202**	**681**	**18**

[a] Putrescibles are the average 21% yard and 79% Organics

Values in **Table 4-15** are tabulated as follows:

Column	Reference / Calculation
(a)	Taken from Table 4-8 column (**c**)
(b)	$= (\mathbf{b}) \times 44\frac{g}{mol} \text{ of } CO_2 \div 12\frac{g}{mol} \text{ of Carbon} \times \frac{1000kg}{ton} = \frac{\mathbf{kg\ of\ eCO_2}}{\mathbf{ton\ of\ material}}$
(c)	Accepted values from EU report (2001) [43]
(d)	= (**a**) x (**c**)
(e)	$= (\mathbf{d}) \times 44\frac{g}{mol} \text{ of } CO_2 \div 12\frac{g}{mol} \text{ of Carbon} \times \frac{1000kg}{ton} = \frac{\mathbf{kg\ of\ eCO_2}}{\mathbf{ton\ of\ material}}$
(f)	= {(**a**) - (**d**)} x 91.8% (based on the average retention of 8.2% in compost within the 100 year time frame)
(g)	$= (\mathbf{f}) \times 44\frac{g}{mol} \text{ of } CO_2 \div 12\frac{g}{mol} \text{ of Carbon} \times \frac{1000kg}{ton} = \frac{\mathbf{kg\ of\ eCO_2}}{\mathbf{ton\ of\ material}}$
(h)	= (**g**) + (**e**)
(i)	= (**b**) - (**h**)

Table 4-16: Emission factors for wastes processed through composting (kg CO_2eq/t material treated).

Waste – related mgmt option	Waste-related component	Short cycle CO2 (GWP=0)	Fossil CO2				Short cycle C sequestered GWP = -1	Sum of fossil C and sequestered C	CH4 emission GWP=21	N2O emission GWP=310	Total GHG flux
			Process	Energy use	Avoided energy and materials	Transport / mobilisation					
		(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)
Open composting											
	Paper	1204	0	13	-35.5	5.8	-68	-85	0	0	-85
	Yard	819	0	13	-35.5	5.8	-35	-52	0	0	-52
	Organics	644	0	13	-35.5	5.8	-13	-30	0	0	-30
Closed composting											
	Paper	1204	0	18	-35.5	5.8	-68	-80	0	0	-80
	Yard	819	0	18	-35.5	5.8	-35	-47	0	0	-47
	Organics	644	0	18	-35.5	5.8	-13	-25	0	0	-25
Home composting											
	Paper	1204	0	0	-35.5	0.0	-68	-103	0	0	-103
	Yard	819	0	0	-35.5	0.0	-35	-71	0	0	-71
	Organics	644	0	0	-35.5	0.0	-13	-49	0	0	-49

Values in **Table 4-16** are tabulated as follows:

Column	Reference / Calculation	Column	Reference / Calculation
(a)	Taken from Table 4-15 column (**h**)	(f)	Taken from Table 4-15 column (**i**)
(b)	Accepted values from EU report (2001) [43]	(g)	= Sum of columns (**b**) through (**f**)
(c)	Accepted values from EU report (2001) [43]	(h)	= 0 because it is assumed that all carbon is either oxidized or sequestered
(d)	Taken from Table 4-14	(i)	= 0 because N_2O is not a by-product of composting
(e)	Taken from Table 4-6	(j)	= Sum of columns (**g**) through (**i**)

4.2.7 Anaerobic Digestion

Anaerobic digestion (AD) is the process of organic decomposition in the absence of oxygen. This is what typically occurs in landfills. In this case however, the decomposition is accelerated (by increasing temperature and moisture) and occurs in a closed and controlled environment. This allows the collection of methane for useful energy. The process is also similar to composting, in the sense that a fertiliser type solid is produced as a by-product. Therefore the logic used for landfills and composting applies in estimating the GHG flux of the AD process.

A portion of the biogenic carbon is degraded during the AD process. This quantity is similar to that estimated in composting, except in that 50-75% of the carbon is converted to methane in this case. This methane is then converted into either electricity, heat or both. The avoided emissions from the methane production are summed with the fertiliser emissions saved, as calculated in composting. The results of these calculations are presented in Table 4-17. In addition, AD uses some energy to support the process, so only a portion of the recovered energy is available for export. The rest of the analysis is the same as composting. The results are summed in Table 4-18.

Table 4-17: Table: Avoided emissions from AD

	Parameter	Paper & Cardboard	Yard Trimmings	Organics	Unit
(a)	Methane content of Biogass	60	60	60	%
(b)	Dissimilated organic carbon (from composting)	12.1	11.6	13.4	%
(c)	CH_4 in Biogass (based on composting)	97.1	93.2	107.6	$kgCH_4$/ton
(d)	CO_2 in Biogass (based on composting)	178.1	170.8	197.2	$kgCO_2$/ton
	Energy Calculations				
(e)	Calorific Value of Biogass	1349.0	1293.9	1494.2	kWh/t
(f)	Electricity generated (30% efficiency)	404.7	388.2	448.3	kWh/t
(g)	Electricity for export (67% of elec. generated)	271.1	260.1	300.3	kWh/t
(h)	Average Electricity Emission	0.25	0.25	0.25	kg CO_{2eq}/kWh
(i)	Heat recovered for CHP option (50%)	674.5	646.9	747.1	kWh/t
(j)	Heat exported for CHP option (65% of heat recovered)	438.4	420.5	485.6	kWh/t
(k)	Average Heat emissions	0.28	0.28	0.28	kg CO_{2eq}/kWh
	Avoided emissions				
(l)	From electricity export	68.8	66.0	76.3	kg CO_{2eq}/kWh
(m)	From heat export	122.8	117.7	136.0	kg CO_{2eq}/kWh
(n)	Energy and Materials (Compost)	35.5	35.5	35.5	kg CO_{2eq}/kWh

Values in **Table 4-17** are tabulated as follows:

Row	Reference / Calculation
(a)	Accepted values from EU report (2001) [43]
(b)	Value from Table 4-15 column (**d**)
(c)	$= (\mathbf{a}) \times (\mathbf{b}) \times 16\frac{\text{g}}{\text{mol}}\text{ of }CH_4 \div 12\frac{\text{g}}{\text{mol}}\text{ of Carbon} \times \frac{1000\text{kg}}{\text{ton}} = \frac{\textbf{kg of }\mathbf{CH_4}}{\textbf{ton of material}}$
(d)	$= (1-\mathbf{a}) \times (\mathbf{b}) \times 44\frac{\text{g}}{\text{mol}}\text{ of }CH_4 \div 12\frac{\text{g}}{\text{mol}}\text{ of Carbon} \times \frac{1000\text{kg}}{\text{ton}} = \frac{\textbf{kg of }\mathbf{CO_2}}{\textbf{ton of material}}$
(e)	$= (\mathbf{c})\frac{\text{kg of }CH_4}{\text{ton}} \times 13.89\frac{\text{kWh}}{\text{kg of }CH_4} = \frac{\textbf{kWh}}{\textbf{ton of material}}$
(f)	= (**e**) x 30% (efficiency of electricity production)
(g)	= (**f**) x 67% (electricity for sale to grid after internal process use)
(h)	Value from Table 4-4
(i)	= (**e**) x 50% (efficiency of Combined heat and power production)
(j)	= (**i**) x 65% (efficiency of heat recovery)
(k)	Average emissions from a CHP plan in the EU report (2001) [43] , values for Canada not available
(l)	= (**g**) x (**h**)
(m)	= (**j**) x (**k**)
(n)	Value from Table 4-14

Table 4-18: Emission factors for waste & recoverable products processed through AD (kg CO2eq/t material treated)

Waste – related mgmt option	Component	Short cycle CO2 (GWP=0) (a)	Fossil CO2: Process (b)	Fossil CO2: Energy use (c)	Fossil CO2: Avoided energy and materials (d)	Fossil CO2: Transport / mobilisation (e)	Short cycle C sequestered (GWP=-1) (f)	Sum of fossil C and sequestered C (g)	CH4 emission GWP=21 (h)	N2O emission GWP=310 (i)	Total GHG flux (j)
AD – Electricity Recovered Only											
	Paper	937	0	0	-104.4	5.8	-67.8	-166.4	0	0	-166
	Yard Trimming	563	0	0	-101.6	5.8	-35.0	-130.8	0	0	-131
	Organics	348	0	0	-111.8	5.8	-13.5	-119.5	0	0	-119
AD – Electricity & Heat Recovered											
	Paper	937	0	0	-227.1	5.8	-67.8	-289.1	0	0	-289
	Yard Trimming	563	0	0	-219.3	5.8	-35.0	-248.5	0	0	-249
	Putrescible	348	0	0	-247.8	5.8	-13.5	-255.4	0	0	-255

Values in **Table 4-18** are tabulated as follows:

Column	Reference / Calculation	Column	Reference / Calculation
(a)	= (**d**) from Table 4-17 + (**g**) from Table 4-15 This is a combination of AD and composting CO_2 generated	(f)	Taken from Table 4-15 column (**i**)
(b)	= 0 because process is self sustaining [43]	(g)	= Sum of columns (**b**) through (**f**)
(c)	= 0 because process is self sustaining [43]	(h)	= 0 because it is assumed that all carbon is either oxidized or sequestered
(d)	= (**l**) + (**n**) from Table 4-15 for Elec Only = (**l**) + (**m**) + (**n**) from Table 4-15 for CHP	(i)	= 0 because N_2O is not a by-product of composting
(e)	Taken from Table 4-6	(j)	= Sum of columns (**g**) through (**i**)

4.2.8 Recycling

The purpose of recycling is to minimize the need for new resources and avoid the emissions associated with processing raw materials. The avoided energy and materials is the net emissions saved by recycling materials vs. producing virgin materials. The emissions associated with extracting raw minerals and processing them into raw products such as metals, plastics or glass are considered to be avoided. The resources required to separate and process recyclables into usable metals, plastics or glass are considered to be positive emissions. In both cases the transportation costs are considered, as explained above. The summation of these emissions is presented in Table 4-19.

Table 4-19: Recycling - Avoided Energy and Materials - Summary

Material	Avoided energy and materials (kg CO_{2eq}/ton)	Reference
Paper [a]	336	Canada [144]
HDPE	2,303	Canada [144]
PET	3,653	Canada [144]
Glass	133	Canada [144]
Ferrous metal	1,223	Canada [144]
Aluminum	6,513	Canada [144]
Textiles	3,203	EU [43]

[a] Carbon sequestration ignored from report figures.

The data for offset emissions shown in Table 4-19 are taken from the Canadian Report – Determination of the Impact of Waste Management Activities on Greenhouse Gas Emissions: 2005 Update [144]. In general the avoided material and energy estimates are much more accurate than those of the EU report, since the provincial share of virgin and recycled products is taken into account, including the provincial energy mix. The only estimate taken from the EU report is that of textiles, since the Canadian report does not address this.

Also, the avoided emissions estimated for paper in the Canadian report are found to be quite high and are adjusted for this analysis. The Canadian report estimates the avoided emissions for paper to be on average 2,978 CO_{2eq}/ton. In that report however, it is assumed that 2,665 CO_{2eq}/ton is sequestered. Their rational is that recycling paper avoids the need to cut new trees. Consequently the trees that are not cut are removing CO_2 from the atmosphere, creating a sink. Although this holds some truth in the short term, it is not accurate over the 100 year time frame.

Assuming that not cutting a tree for paper creates a carbon sink is trivial. This statement assumes that this tree is already dedicated to capturing the emissions created by the paper process, which cannot be assumed as accurate. In essence, for this statement to be true, new trees would need to be planted with the resources generated from the paper process to act as a carbon sink. Over the 100 year time frame the trees that are not cut for this GHG balance would die and release the sequestered carbon back into the atmosphere. The trees would therefore be neutral on their own.

Furthermore, in Canada, the forestry industry must plant trees replacing what it cuts. By this process the carbon sink pool remains constant, and in that sense cannot be assumed as a sink. Therefore, for this analysis, the sequestration aspect for paper recycling of the Canadian study is omitted. The avoided energy and materials represents only the harvesting and processing savings.

Based on the avoided energy and materials and the transportation emissions, the GHG flux of recycling is shown in Table 4-20. The process and energy use components have been included in the avoided energy and materials balance. Recycling demonstrates some important savings in greenhouse gas emissions compared to the other MW&RP management practices.

Table 4-20: Emission factors for recycling (kg CO2eq/t material treated)

Waste – related mgmt option	Component	Short cycle CO2 (GWP=0)	Fossil CO2				Short cycle C sequestered (GWP=-1)	Sum of fossil C and sequestered C	CH4 emission GWP=21	N2O emission GWP=310	Total GHG flux
			Process	Energy use	Avoided energy and materials	Transport / mobilisation					
		(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)
	Paper	0	0	0	-336	23.2	0	-313	0	0	-313
	HDPE	0	0	0	-2303	23.2	0	-2280	0	0	-2280
	PET	0	0	0	-3653	23.2	0	-3630	0	0	-3630
	Glass	0	0	0	-133	23.2	0	-110	0	0	-110
	Ferrous metal	0	0	0	-1223	23.2	0	-1200	0	0	-1200
	Aluminum	0	0	0	-6513	23.2	0	-6490	0	0	-6490
	Textiles	0	0	0	-3203	23.2	0	-3180	0	0	-3180

Values in **Table 4-20** are tabulated as follows:

Column	Reference / Calculation	Column	Reference / Calculation
(a)	= 0 because there is no organic carbon	(f)	= 0 because there is no organic carbon
(b)	= 0 because the GHG have been considered in the balance for the values in (**d**)	(g)	= Sum of columns (**b**) through (**f**)
(c)	= 0 because the GHG have been considered in the balance for the values in (**d**)	(h)	= 0 because there is no organic carbon
(d)	Values from Table 4-19	(i)	= 0 because N_2O is not a by-product of the feedstock in recycling
(e)	Taken from Table 4-6	(j)	= Sum of columns (**g**) through (**i**)

Table 4-21: Summary of net GHG flux for the components of MW&RP (kg CO2eq/ton)

Component	Share	Landfill			Incineration			Gasification		Composting			AD		Recycling
		Base Case	Best Case	Restoration Layer	Mass Burn	Elec. Only	CHP	Elec. Only	CHP	Open	Closed	Home	Elec. Only	CHP	
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)
Paper & cardboard	29%	367	-577	-849	30	-129	-571	-235	-677	-85	-80	-103	-166	-289	-313
Yard Trimmings	8%	718	-187	-448	30	-71	-352	-139	-419	-52	-47	-71	-131	-249	0
Organics	28%	856	-15	-266	30	-46	-256	-96	-306	-30	-25	-49	-119	-255	0
Plastics	9%	10	10	10	2,099	1,754	795	1,524	565	0	0	0	0	0	-2,955
Glass	3%	10	10	10	30	30	30	30	30	0	0	0	0	0	-110
Metals	5%	10	10	10	-851	-851	-851	-851	-851	0	0	0	0	0	-2,258
Textiles	2%	77	-357	-482	712	529	22	408	-100	0	0	0	0	0	-3,180
Other	16%	295	-216	-364	285	178	-118	107	-189	0	0	0	0	0	0
MW&RP - Unsorted	**100%**	**452**	**-226**	**-422**	**221**	**93**	**-262**	**8**	**-348**	**0**	**0**	**0**	**0**	**0**	**0**

The GHG values in this table are drawn from the last columns of the previous tables

4.1 Comparison

Based on the methodology explained above and the calculations performed, the various waste-related management practices can now be compared. Table 4-21 summarizes the net GHG fluxes for each MW&RP component. In general recycling is by far the most favourable, since the extraction and refinement of raw resources is very energy intensive. In addition, there are many other avoided environmental effects associated with recycling which are not quantified here, which is also the case with the other processes. The following text will discuss the results obtained.

In general, the net GHG emissions are reduced as better technology is applied to the various waster-related management activities. It is not hard to imagine that as technology and techniques progress, the processes will improve and become more efficient. However, some of the technological assumptions made here may never achieve their full potential in reality. For example, the gasification of MW&RP with combined heat and electricity recovery may never be applied to all potential feedstock due to financial, social, geographical or even political reasons. Therefore the emission estimates in these cases should be seen as best case scenarios, but not necessarily practical approaches. This logic will be applied in the following analysis.

4.1.1 Landfill

The three (3) scenarios compared for landfills – Base case, Best case and Restoration Layer – have an increasingly dramatic effect on the GHG flux. The base case (current Canadian situation) demonstrates the largest positive effect on global warming within the landfill options and compared to the other alternatives. Once landfill gas collection is increased from 22% to 80% (Best Case) the released methane is converted to CO_2, creating a much smaller positive GHG flux. For the Restoration layer, the uncollected methane is oxidized further improving the negative flux of the process. However, the last two options may not be feasible in reality.

As discussed previously, the theoretical maximum landfill gas capture is thought to be only 19% over the lifetime of the products. The current Canadian figures estimate that 22% of the landfill gas is collected; however this might be an overstatement. First, the methane generated could have been underestimated. Secondly, the reported capture figures were recorded for that year and are not averaged over the life of the landfill. Based on the known degradation of organics in landfills, the process still occurs 100 years after being landfilled. Therefore a 22% capture of landfill gas may be an overstatement over the lifespan on the site.

With regard to the restoration layer, this appears to be an effective way to mitigate methane release into the atmosphere. But being only a futuristic approach, it has not been proven in practice and so it is considered unfeasible for the subsequent calculations.

Another important factor of the landfill GHG flux is the level of biogenic carbon that is assumed to be degraded or sequestered. This factor depends on the degree of DDOC, which can vary greatly and is subject to much debate. Table 4-10 shows the effect of the DDOC on the emissions. For unsorted MW&RP the net GHG emission vary from 165 to 773 kg CO_{2eq}/ton for low and high DDOC figures, respectively. The greater the DDOC, the more carbon is released and consequently the quantity of methane increases. Knowing the deviation range in these figures, the averages are used for all the scenarios.

In other words the Base Case for landfills seems to be the only reasonable estimate of current and future emissions for this type of waste-related activity. Therefore, landfills are by far the least favourable disposal method.

4.1.2 Incineration

Similar to landfills, as the technology improves, the net GHG emissions are reduced. However, this is directly related to the amount of energy recovery (energy recycling). In the case of incineration with no energy recovery the emissions for unsorted MW&RP are strongly positive. It represents about half of the net GHG emissions of landfills but is estimated as the second worst waste-related management alternative. Regardless, the conclusion can still be made that, on average, incineration with no energy recovery is better than landfills. If energy recovery is applied, the process is far more favourable than landfill. In addition, it was previously seen that incineration has many advantages over landfills in relation to other environmental impacts.

As for the various technologies applied, it is clear that a combined heat and power process is more advantageous than only one of the two or none. In practice it is much easier to produce electricity than it is to recover heat. For heat to be recovered there needs to be a demand close to the incineration source or have a centralised heating system. This can be useful for places like hospitals which have a continuous supply of hazardous waste and a need for heat and power. On larger scale facilities, within cities for example, it is difficult to distribute the heat effectively, but not impossible. Although it is greatly advantageous to apply CHP technologies, it is assumed that in Canada only incineration with electricity recovery is reasonably applicable in these scenarios. However, it is foreseeable that future incinerators will be located closer to the source and consequently gasification technologies with CHP recovery are quite probable.

Another important note is that incinerators will never use unsorted MW&RP as a fuel source, since not all materials are suitable for combustion. Therefore, incineration is not a single solution to the waste-related problems. Considering that sorting is a precursor to incineration, this approach is well suited to be used in tandem with other solutions, such as AD and recycling.

4.1.3 Composting and AD

The net GHG emissions for both anaerobic digestion and composting are all negative, due to carbon sequestration and avoided inorganic fertiliser use. The emissions are further reduced by minimising process energy (home composting vs. open or closed) or increasing the energy recovery (AD or CHP vs. Elec. only). In all cases, it is more favourable to use anaerobic digestion of the organics since energy is recovered. But the same issue as with incineration applies here, regarding proximity of the facility to point of use. Farms for example are excellent locations for AD facilities.

Although AD is better from a GHG flux perspective, many people prefer to compost at home to produce their own fertiliser. But on a macro scale, the model shows that AD is more favourable overall, with the same fertiliser outputs. Centralised AD facilities with electricity recovery may be the most advantageous solution for organics.

In addition this process only applies to organic materials such as yard trimming, food scraps and paper. Separation is required and so it is well suited for use with other waste-related processes.

4.1.4 Recycling

Recycling shows the highest avoided emissions for all applicable products. It is the most favourable waste-related management option, compared to the other disposal processes (note that reuse is still more favourable than recycling in the hierarchy). On the other hand, a portion of the recyclables (10%) will always be unusable due to the degradation of material quality over time. Therefore recycling cannot be used as the only solution. It also needs to be applied with other processes.

4.1.5 Material specific

The following is a brief discussion of the favoured processes based on the type of material.

4.1.5.1 Unsorted MW&RP

As a starting point, unsorted MW&RP is generally only suitable for landfill or incineration since all other processes are more component specific. Incineration requires some degree of separation prior to combustion but it can process most materials if required. Figure 4-5 shows a comparison of these two waste-related activities. By far, landfills with current standards have the largest positive GHG flux. Future landfill techniques may drastically improve this, but as discussed, this is unlikely.

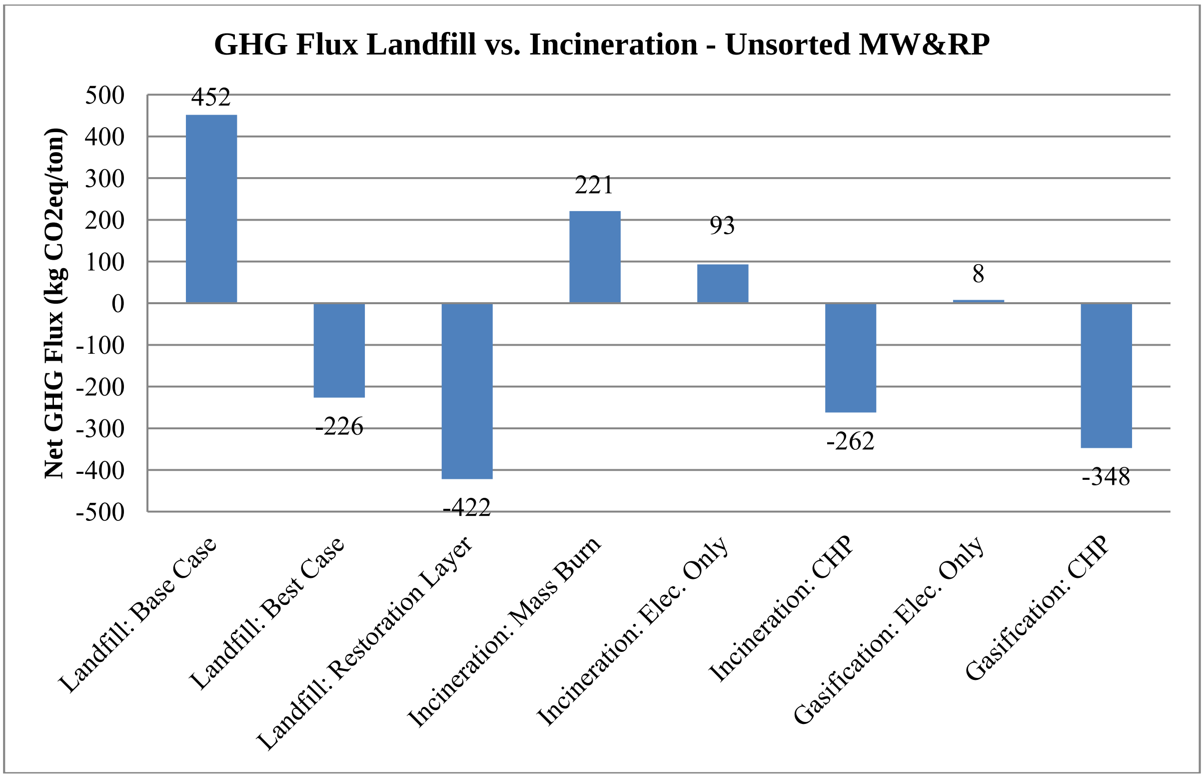


Figure 4-5: GHG Flux of landfill vs. incineration of unsorted MW&RP

In general it is more favourable to incinerate MW&RP even with current technology. With CHP facilities, the offset utilities make the process quite advantageous.

In all these cases, it assumes that no separation (at source or centralized) is being done. Since all the other waste-related processes require material separation the subsequent analysis assumes that this is the case. The figures for unsorted MW&RP are included only for discussion purposes and are not recommended as a solution.

4.1.5.2 Organics

Organics (food scraps, yard trimmings, paper & cardboard) are assumed to be comprised of biogenic carbon. In essence all this carbon is considered as short cycle. Consequently, if allowed to decompose properly it has no net effect on the GHG emissions. Disposing of organics in landfills prevents this organic decomposition and promotes the creation of methane, which is very difficult to control and capture. That said, organics should never go to landfill since they have such a positive impact on the GHG emissions.

Figure 4-6, Figure 4-7 & Figure 4-8 compare all the analysed processes for paper & cardboard, yard trimmings and food scraps respectively. The most favourable destination for organics is either incineration, composting or AD. But the probability of high moisture organics (food scraps and some yard trimmings) being used in incinerators is low, since drying the material requires more energy and some heating value can be lost during drying/storage. In practice, it is more probable that high moisture organics will be either composted or sent for AD.

With regards to paper & cardboard, there is also a value in recycling which cannot be ignored. These materials are suitable for incineration but depending on the efficiency of the heat recovery system, it may be more beneficial to recycle paper & cardboard.

4.1.5.3 Recyclables

For all recyclable materials (plastics, glass, metals and some textiles) it is far more favourable to recover and recycle compared to any other processes. However, a certain portion (10%) still needs to be disposed of due to attrition. Therefore, landfill or incineration still needs to be considered in tandem with recycling.

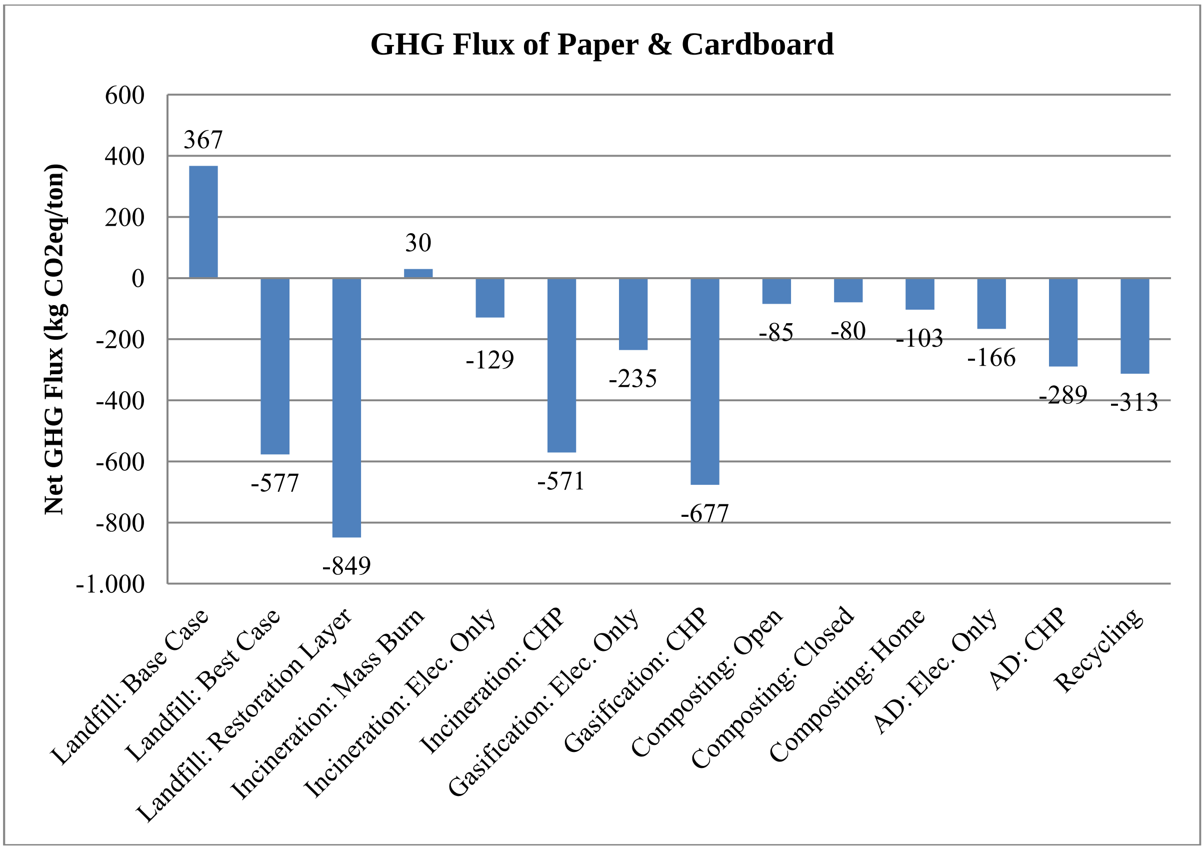


Figure 4-6: GHG flux of Paper & cardboard

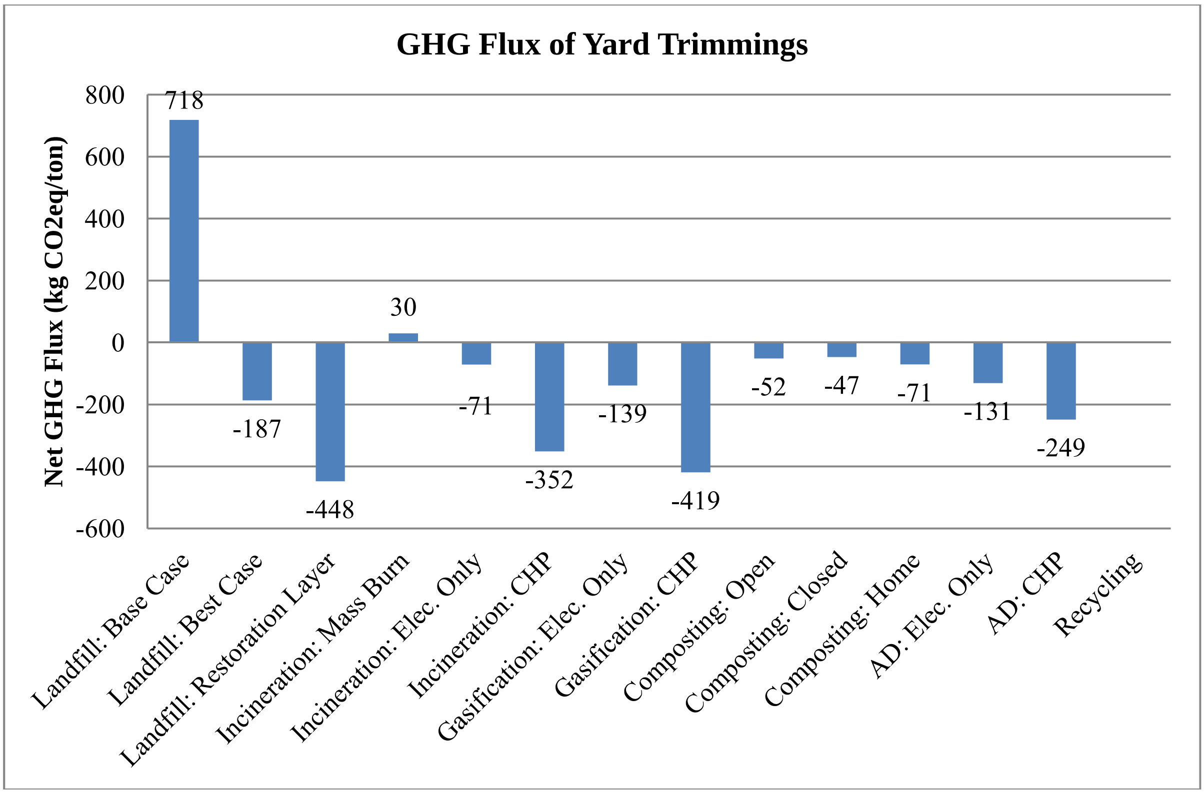


Figure 4-7: GHG flux of Yard Trimmings

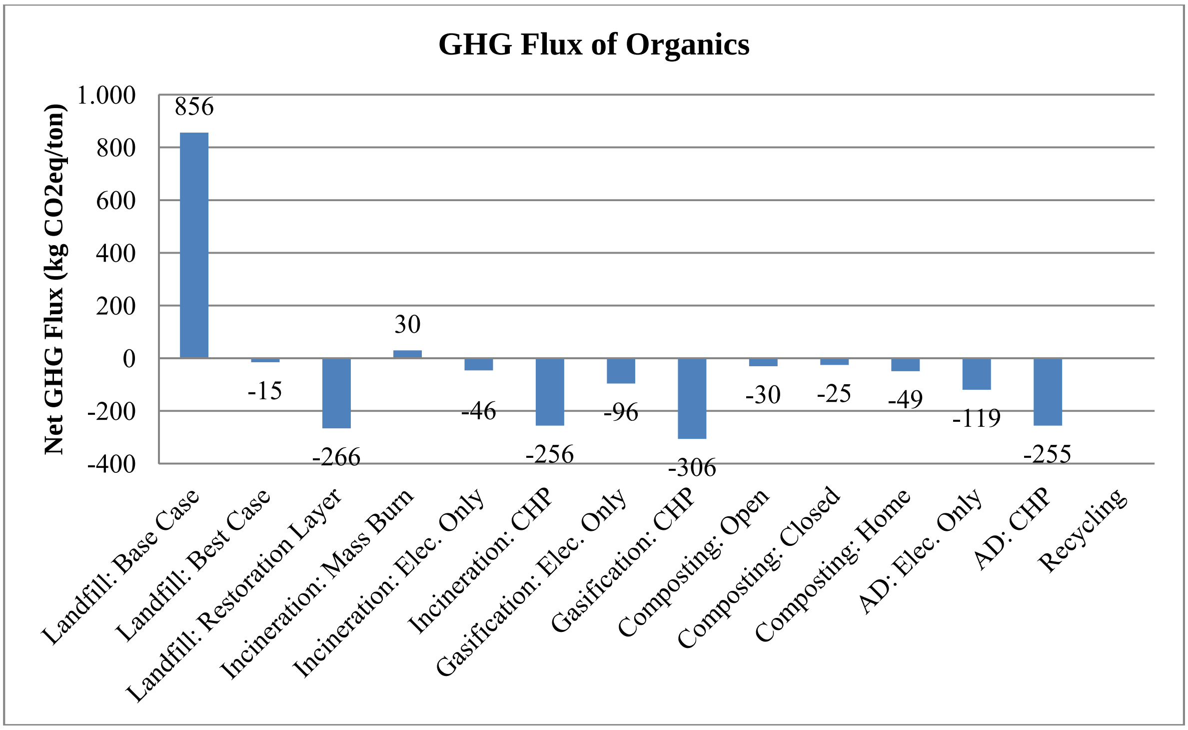


Figure 4-8: GHG Flux of Food Scraps

4.1.5.4 Others

Others are a mix of miscellaneous combustibles, non-combustibles and fines. Since the composition is not exactly known, it is assumed to be suitable for either landfill of incineration. Based on the figures of Table 4-21, any form of incineration is more favourable than the base case of landfill.

4.2 Scenarios

The following section uses the GHG estimates previously calculated to compare various waste-related management scenarios for Canada. The scenarios are all based on 2004 Canadian data as follows:

1. Base case – Current Situation
2. Maximum diversion – Composting and Recycling
3. Maximum WRPtE – AD and incineration
4. Optimised diversion and WRPtE
5. Improved Base Case 1 – 2x Diversion, 2x WRPtE
6. Improved Base Case 2 – +20% Diversion & 50% WRPtE
7. Maximum Landfill

The Base Case considers only current Canadian data and waste-related management practices. This would mean that of the generated MW&RP in 2004, 74.0% went to landfill, 2.3% was incinerated and 23.7% was diverted. The diverted information is taken from Statistics Canada [27]. The rest of the products sent to landfill or incineration were scaled based on the remaining balance. Table 4-22 summarizes the emissions for each product based on this information.

The subsequent two (2) scenarios are extremes of various waste-related management practices (maximum diversion & maximum WRPtE), which are derived from the first base case. The purpose is simply to demonstrate the limits of the related emissions if one single practice is observed. The conclusions are presented for discussion purposes.

The scenario with Maximum Diversion assumes that all possible material is recycled or composted. In this case, all recyclables including paper and cardboard are recycled and all organics are composted. With regards to the recyclables, a 10% attrition rate is assumed, and the materials are sent to landfill. All others are sent to landfill. The summary of this scenario is presented in Table 4-23.

For Maximum WRPtE the energy recovery is maximised, based on reasonable technology assumption discussed early. All organics are sent to an AD facility with electrical production only. All other carbon materials are sent to incineration with only electricity produced. Ferrous metals are recovered from the incineration process and sent to recycling (not shown in summary, but included in the GHG flux for incineration). Glass is sent to landfill. The summary of this scenario is shown in Table 4-24.

Next, the Optimised scenario combines the best of the previous extreme scenarios. The scenario assumes that the materials are being sorted and sent to the most appropriate facility based on their GHG potential. In this case, all recyclables are sent for recycling. 10% of the recyclables are disposed of (due to attrition): metals and glass are sent to landfill and plastics and textiles are incinerated. All organics are sent to a digester and the ‘other’ material is incinerated. The results of this scenario are presented in Table 4-25.

The following two scenarios are more realistic, whereas they are practical improvements on the Base Case.

The first of these practical scenarios (scenario #5) assumes that the diversion rate is doubled from the base case, from 23.7% to 43.7% (the totals are not exactly doubled since the ‘Not

Considered' category is not doubled but is part of the recycled content). In this scenario, it is also assumed that the WRPtE is doubled (from 2.3% to 4.6% of the total). The figures are shown in Table 4-26.

The second practical scenario (scenario #6), assumes a more conservative increase of 20% in diversion rate over the base case, with a more aggressive WRPtE increase, in this case 50% of what is not diverted is sent to either incineration or anaerobic digestion, depending on the type of material. The balance is sent to landfill. The results are shown in Table 4-27.

The final scenario #7 is a worst case; if all waste-related products were send to landfill, with no diversion or energy recovery, as seen in Table 4-28. The emissions consider the base case for landfills, where a certain portion of the generated methane is collected and used for energy recovery.

Table 4-22: GHG Summary - Base Case

Material	Material Destination (ton)						Net GHG Emission (ton CO2eq)					
		Disposed		Diverted			Landfill	Incinerate	Compost	AD	Recycle	Total
	Generated	Landfill	Incinerate	Compost	AD	Recycle	Base Case	Elec. Only	Open	Elec. Only		
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(h)
Paper & cardboard	9,254,437	5,788,562	179,028	0	0	3,286,848	2,124,694	-23,133	0	0	-1,028,338	**1,073,223**
Yard Trimmings	2,414,201	2,341,775	72,426	0	0		1,682,500	-5,161	0	0	0	**1,677,339**
Organics	8,986,193	7,097,536	219,511	1,669,145	0		6,076,544	-10,056	-50,412	0	0	**6,016,075**
Plastics	2,950,690	2,679,512	82,871	0	0	188,307	27,586	145,332	0	0	-556,447	**-383,529**
Glass	1,072,978	653,478	20,211	0	0	399,290	6,728	600	0	0	-43,922	**-36,594**
Metals	1,475,345	537,961	16,638	0	0	920,746	5,538	-14,159	0	0	-2,079,044	**-2,087,665**
Textiles	766,106	743,123	22,983	0	0		57,139	12,168	0	0	0	**69,307**
Other	5,001,152	4,690,335	145,062	0	0	165,755	1,385,505	25,856	0	0	0	**1,411,361**
[a] Not Considered	1,234,559	0	0	0	0	1,234,559	0	0	0	0	0	**0**
Total	**33,155,662**	**24,532,282**	**758,730**	**1,669,145**	**0**	**6,195,505**	**11,366,234**	**131,447**	**-50,412**	**0**	**-3,707,751**	**7,739,517**
Share	100.00%	74.0%	2.3%	5.0%	0.0%	18.7%						

[1] Not Considered (White goods, Electronics, Tires, Construction & Demolition Waste)

For **Table 4-22** the values were tabulated as follows:

Column	Reference / Calculation	Column	Reference / Calculation
(a)	Adapted from Canadian data [27]	(g)	= (**b**) x (**b**) of Table 4-21
(b)	= {(**a**) – (**f**)} x 97% (share of disposed W&RP sent to landfill in Canada)	(h)	= (**c**) x (**f**) of Table 4-21
(c)	= {(**a**) – (**f**)} x 3% (share of disposed W&RP sent to incineration in Canada)	(i)	= (**d**) x (**j**) of Table 4-21
(d)	From Canadian data [27]	(j)	= (**e**) x (**m**) of Table 4-21
(e)	From Canadian data [27]	(k)	= (**f**) x (**o**) of Table 4-21
(f)	From Canadian data [27]	(h)	= Sum of (**g**) through (**h**)

Table 4-23: GHG Summary - Maximum diversion

	Material Destination (ton)						Net GHG Emission (ton CO2eq)					
		Disposed		Diverted			Landfill Base Case	Incinerate Elec. Only	Compost Open	AD Elec. Only	Recycle	Total
Material	**Generated (a)**	**Landfill (b)**	**Incinerate (c)**	**Compost (d)**	**AD (e)**	**Recycle (f)**	**(g)**	**(h)**	**(i)**	**(j)**	**(k)**	**(h)**
Paper & cardboard	9,254,437	925,444	0	0	0	8,328,994	339,684	0	0	0	-2,605,845	**-2,266,161**
Yard Trimmings	2,414,201	0	0	2,414,201	0	0	0	0	-124,905	0	0	**-124,905**
Organics	8,986,193	0	0	8,986,193	0	0	0	0	-271,404	0	0	**-271,404**
Plastics	2,950,690	295,069	0	0	0	2,655,621	3,038	0	0	0	-7,847,361	**-7,844,323**
Glass	1,072,978	107,298	0	0	0	965,680	1,105	0	0	0	-106,225	**-105,120**
Metals	1,475,345	147,535	0	0	0	1,327,811	1,519	0	0	0	-2,998,196	**-2,996,677**
Textiles	766,106	76,611	0	0	0	689,496	5,891	0	0	0	-2,192,471	**-2,186,580**
Other	5,001,152	5,001,152	0	0	0	0	1,477,319	0	0	0	0	**1,477,319**
[a] Not Considered	1,234,559	0	0	0	0	1,234,559	0	0	0	0	0	**0**
Total	**33,155,662**	**6,553,107**	**0**	**11,400,394**	**0**	**15,202,161**	**1,828,556**	**0**	**-396,309**	**0**	**-15,750,098**	**-14,317,851**
Share	100.0%	19.8%	0.0%	34.4%	0.0%	45.9%						

[1] Not Considered (White goods, Electronics, Tires, Construction & Demolition Waste)

For **Table 4-23** the values were tabulated as follows:

Column	Reference / Calculation	Column	Reference / Calculation
(a)	Adapted from Canadian data [27]	(g)	= (**b**) x (**b**) of Table 4-21
(b)	= (**a**) x 10% of recyclables (due to attrition sent to landfill) This excludes yard trimmings and organics	(h)	= (**c**) x (**f**) of Table 4-21
(c)	= 0, Material disposed must go to landfill	(i)	= (**d**) x (**j**) of Table 4-21
(d)	= Only yard trimmings and organics	(j)	= (**e**) x (**m**) of Table 4-21
(e)	= 0, AD not considered in this scenario	(k)	= (**f**) x (**o**) of Table 4-21
(f)	= (**a**) – (**b**) This excludes yard trimmings and organics	(h)	= Sum of (**g**) through (**h**)

Table 4-24: GHG Summary - Maximum WRPtE

	Material Destination (ton)						Net GHG Emission (ton CO2eq)					
		Disposed			Diverted		Landfill	Incinerate	Compost	AD	Recycle	Total
Material	**Generated (a)**	**Landfill (b)**	**Incinerate (c)**	**Compost (d)**	**AD (e)**	**Recycle (f)**	**Base Case (g)**	**Elec. Only (h)**	**Open (i)**	**Elec. Only (j)**	**(k)**	**(h)**
Paper & cardboard	9,254,437	0	0	0	9,254,437	0	0	0	0	-1,539,546	0	**-1,539,546**
Yard Trimmings	2,414,201	0	0	0	2,414,201	0	0	0	0	-315,703	0	**-315,703**
Organics	8,986,193	0	0	0	8,986,193	0	0	0	0	-1,073,441	0	**-1,073,441**
Plastics	2,950,690	0	2,950,690	0	0	0	0	5,174,638	0	0	0	**5,174,638**
Glass	1,072,978	1,072,978	0	0	0	0	11,047	0	0	0	0	**11,047**
Metals	1,475,345	0	1,475,345	0	0	0	0	-1,255,539	0	0	0	**-1,255,539**
Textiles	766,106	0	766,106	0	0	0	0	405,608	0	0	0	**405,608**
Other	5,001,152	0	5,001,152	0	0	0	0	891,410	0	0	0	**891,410**
[a] Not Considered	1,234,559	0	0	0	0	1,234,559	0	0	0	0	0	**0**
Total	**33,155,662**	**1,072,978**	**10,193,293**	**0**	**20,654,831**	**1,234,559**	**11,047**	**5,216,116**	**0**	**-2,928,690**	**0**	**2,298,473**
Share	100.0%	3.2%	30.7%	0.0%	62.3%	3.7%						

[a] Not Considered (White goods, Electronics, Tires, Construction & Demolition Waste)

For **Table 4-24** the values were tabulated as follows:

Column	Reference / Calculation	Column	Reference / Calculation
(a)	Adapted from Canadian data [27]	(g)	= (**b**) x (**b**) of Table 4-21
(b)	All materials are used to create energy. Glass cannot do this, it is sent to landfill.	(h)	= (**c**) x (**f**) of Table 4-21
(c)	Plastics, metals, textiles and others are incinerated	(i)	= (**d**) x (**j**) of Table 4-21
(d)	Nothing composted	(j)	= (**e**) x (**m**) of Table 4-21
(e)	Organics are sent for AD	(k)	= (**f**) x (**o**) of Table 4-21
(f)	Only the not considered is recycled.	(h)	= Sum of (**g**) through (**h**)

Table 4-25: GHG Summary - Optimised Waste-Related Management

	Material Destination (ton)						Net GHG Emission (ton CO2eq)					
		Disposed			Diverted		Landfill Base	Incinerate Elec.	Compost	AD	Recycle	Total
Material	**Generated (a)**	**Landfill (b)**	**Incinerate (c)**	**Compost (d)**	**AD (e)**	**Recycle (f)**	**Case (g)**	**Only (h)**	**Open (i)**	**Elec. Only (j)**	**(k)**	**(h)**
Paper & cardboard	9,254,437	0	0	0	925,444	8,328,994	0	0	0	-153,955	-2,605,845	**-2,759,800**
Yard Trimmings	2,414,201	0	0	0	2,414,201	0	0	0	0	-315,703	0	**-315,703**
Organics	8,986,193	0	0	0	8,986,193	0	0	0	0	-1,073,441	0	**-1,073,441**
Plastics	2,950,690	0	295,069	0	0	2,655,621	0	517,464	0	0	-7,847,361	**-7,329,897**
Glass	1,072,978	107,298	0	0	0	965,680	1,105	0	0	0	-106,225	**-105,120**
Metals	1,475,345	147,535	0	0	0	1,327,811	1,519	0	0	0	-2,998,196	**-2,996,677**
Textiles	766,106	0	76,611	0	0	689,496	0	40,561	0	0	-2,192,471	**-2,151,910**
Other	5,001,152	0	5,001,152	0	0	0	0	891,410	0	0	0	**891,410**
[a] Not Considered	1,234,559	0	0	0	0	1,234,559	0	0	0	0	0	**0**
Total	**33,155,662**	**254,832**	**5,372,831**	**0**	**12,325,838**	**15,202,161**	**2,624**	**1,449,434**	**0**	**-1,543,099**	**-15,750,098**	**-15,841,139**
Share	100.0%	0.8%	16.2%	0.0%	37.2%	45.9%						

[1] Not Considered (White goods, Electronics, Tires, Construction & Demolition Waste)

For **Table 4-25** the values were tabulated as follows:

Column	Reference / Calculation	Column	Reference / Calculation
(a)	Adapted from Canadian data [27]	(g)	= (**b**) x (**b**) of Table 4-21
(b)	10% of glass and metals are sent to landfill due to attrition	(h)	= (**c**) x (**f**) of Table 4-21
(c)	10% of plastics, textiles and others are incinerated due to attrition	(i)	= (**d**) x (**j**) of Table 4-21
(d)	Nothing composted	(j)	= (**e**) x (**m**) of Table 4-21
(e)	Maximum organics are sent to AD (only 10% of paper)	(k)	= (**f**) x (**o**) of Table 4-21
(f)	Maximum recycling is done (less attrition).	(h)	= Sum of (**g**) through (**h**)

Table 4-26: GHG Summary - Diversion x2, WRPtE x2

	Material Destination (ton)						Net GHG Emission (ton CO2eq)					
		Disposed			Diverted		Landfill Base Case	Incinerate Elec. Only	Compost Open	AD Elec. Only	Recycle	Total
Material	**Generated (a)**	**Landfill (b)**	**Incinerate (c)**	**Compost (d)**	**AD (e)**	**Recycle (f)**	**(g)**	**(h)**	**(i)**	**(j)**	**(k)**	**(h)**
Paper & cardboard	9,254,437	2,322,686	358,055	0	0	6,573,696	852,543	-46,267	0	0	-2,056,675	-1,250,399
Yard Trimmings	2,414,201	2,269,349	144,852	0	0	0	1,630,464	-10,322	0	0	0	1,620,142
Organics	8,986,193	5,208,880	439,023	3,338,290	0	0	4,459,574	-20,112	-100,824	0	0	4,338,637
Plastics	2,950,690	2,408,333	165,743	0	0	376,614	24,794	290,664	0	0	-1,112,894	-797,436
Glass	1,072,978	233,977	40,421	0	0	798,580	2,409	1,200	0	0	-87,844	-84,235
Metals	1,475,345	-399,423	33,276	0	0	1,841,492	-4,112	-28,318	0	0	-4,158,089	-4,190,519
Textiles	766,106	720,140	45,966	0	0	0	55,372	24,336	0	0	0	79,708
Other	5,001,152	4,379,518	290,124	0	0	331,510	1,293,691	51,712	0	0	0	1,345,403
[a] Not Considered	1,234,559	0	0	0	0	1,234,559	0	0	0	0	0	0
Total	**33,155,662**	**17,143,460**	**1,517,461**	**3,338,290**	**0**	**11,156,451**	**8,314,734**	**262,893**	**-100,824**	**0**	**-7,415,502**	**1,061,301**
Share	100.0%	51.7%	4.6%	10.1%	0.0%	33.6%						

[1] Not Considered (White goods, Electronics, Tires, Construction & Demolition Waste)

For **Table 4-26** the values were tabulated as follows:

Column	Reference / Calculation	Column	Reference / Calculation
(a)	Adapted from Canadian data [27]	(g)	= (**b**) x (**b**) of Table 4-21
(b)	= (**a**) – (**c**) – (**d**) – (**e**) – (**f**)	(h)	= (**c**) x (**f**) of Table 4-21
(c)	= (**c**) from Table 4-22 x 2	(i)	= (**d**) x (**j**) of Table 4-21
(d)	= (**d**) from Table 4-22 x 2	(j)	= (**e**) x (**m**) of Table 4-21
(e)	= (**e**) from Table 4-22 x 2	(k)	= (**f**) x (**o**) of Table 4-21
(f)	= (**f**) from Table 4-22 x 2	(h)	= Sum of (**g**) through (**h**)

Table 4-27: GHG Summary - Diversion +20%, WRPtE 50%

	Material Destination (ton)						Net GHG Emission (ton CO2eq)					
		Disposed		Diverted			Landfill	Incinerate	Compost	AD	Recycle	Total
Material	Generated (a)	Landfill (b)	Incinerate (c)	Compost (d)	AD (e)	Recycle (f)	Base Case (g)	Elec. Only (h)	Open (i)	Elec. Only (j)	(k)	(h)
Paper & cardboard	9,254,437	2,655,110	0	0	2,655,110	3,944,218	974,559	0	0	-441,698	-1,234,005	-701,144
Yard Trimmings	2,414,201	1,207,101	0	0	1,207,101	0	867,268	0	0	-157,851	0	709,417
Organics	8,986,193	3,491,609	0	2,002,974	3,491,609	0	2,989,335	0	-60,495	-417,089	0	2,511,752
Plastics	2,950,690	1,362,361	1,362,361	0	0	225,968	14,026	2,389,178	0	0	-667,737	1,735,467
Glass	1,072,978	296,915	296,915	0	0	479,148	3,057	8,812	0	0	-52,706	-40,838
Metals	1,475,345	185,225	185,225	0	0	1,104,895	1,907	-157,629	0	0	-2,494,853	-2,650,575
Textiles	766,106	383,053	383,053	0	0	0	29,453	202,804	0	0	0	232,257
Other	5,001,152	2,401,123	2,401,123	0	0	198,906	709,282	427,978	0	0	0	1,137,260
[a] Not Considered	1,234,559	0	0	0	0	1,234,559	0	0	0	0	0	0
Total	**33,155,662**	**11,982,497**	**4,628,677**	**2,002,974**	**7,353,820**	**7,187,694**	**5,588,887**	**2,871,143**	**-60,495**	**-1,016,638**	**-4,449,301**	**2,933,596**
Share	100.0%	36.1%	14.0%	6.0%	22.2%	21.7%						

[1] Not Considered (White goods, Electronics, Tires, Construction & Demolition Waste)

For **Table 4-27** the values were tabulated as follows:

Column	Reference / Calculation	Column	Reference / Calculation
(a)	Adapted from Canadian data [27]	(g)	= (**b**) x (**b**) of Table 4-21
(b)	= (**a**) – (**c**) – (**d**) – (**e**) – (**f**)	(h)	= (**c**) x (**f**) of Table 4-21
(c)	= {(**a**) – (**d**) – (**f**)} x 50% for non-organics	(i)	= (**d**) x (**j**) of Table 4-21
(d)	= (**d**) from Table 4-22 + 20%	(j)	= (**e**) x (**m**) of Table 4-21
(e)	= {(**a**) – (**d**) – (**f**)} x 50% for organics	(k)	= (**f**) x (**o**) of Table 4-21
(f)	= (**f**) from Table 4-22 + 20%	(h)	= Sum of (**g**) through (**h**)

Table 4-28: GHG Summary – Maximum landfill

	Material Destination (ton)						Net GHG Emission (ton CO2eq)					
		Disposed			Diverted		Landfill	Incinerate Elec. Only	Compost	AD Elec. Only	Recycle	Total
Material	**Generated (a)**	**Landfill (b)**	**Incinerate (c)**	**Compost (d)**	**AD (e)**	**Recycle (f)**	**Base Case (g)**	**(h)**	**Open (i)**	**(j)**	**(k)**	**(h)**
Paper & cardboard	9,254,437	9,254,437	0	0	0	0	3,396,845	0	0	0	0	3,396,845
Yard Trimmings	2,414,201	2,414,201	0	0	0	0	1,734,536	0	0	0	0	1,734,536
Organics	8,986,193	8,986,193	0	0	0	0	7,693,514	0	0	0	0	7,693,514
Plastics	2,950,690	2,950,690	0	0	0	0	30,378	0	0	0	0	30,378
Glass	1,072,978	1,072,978	0	0	0	0	11,047	0	0	0	0	11,047
Metals	1,475,345	1,475,345	0	0	0	0	15,189	0	0	0	0	15,189
Textiles	766,106	766,106	0	0	0	0	58,906	0	0	0	0	58,906
Other	5,001,152	5,001,152	0	0	0	0	1,477,319	0	0	0	0	1,477,319
[a] Not Considered	1,234,559	0	0	0	0	1,234,559	0	0	0	0	0	0
Total	**33,155,662**	**31,921,103**	**0**	**0**	**0**	**1,234,559**	**14,417,733**	**0**	**0**	**0**	**0**	**14,417,733**
Share	100.0%	96.3%	0.0%	0.0%	0.0%	3.7%						

[1] Not Considered (White goods, Electronics, Tires, Construction & Demolition Waste)

For **Table 4-28** the values were tabulated as follows:

Column	Reference / Calculation	Column	Reference / Calculation
(a)	Adapted from Canadian data [27]	(g)	= (**b**) x (**b**) of Table 4-21
(b)	= (**a**) for 100% lanfill	(h)	= (**c**) x (**f**) of Table 4-21
(c)	= 0	(i)	= (**d**) x (**j**) of Table 4-21
(d)	= 0	(j)	= (**e**) x (**m**) of Table 4-21
(e)	= 0	(k)	= (**f**) x (**o**) of Table 4-21
(f)	= 0	(h)	= Sum of (**g**) through (**h**)

4.3 Results & Conclusions

The scenarios described above clearly show that current Canadian waste-related management practice has a significant positive effect on the GHG emissions produced. The results also show that incineration alone in not the best alternative. Although better than the current predominately landfill scenario, incineration still generates greenhouse gases and has a net positive GHG flux.

Recycling is an important part of a sustainable waste-related management scenario. The negative effect it has on GHGs cannot be ignored. However, with recycling there will always be a portion of unusable material, which in the case of the Optimised scenario, shows that there is still a value to WRPtE in a sustainable waste-related management program. The results for all seven scenarios are summarised in Table 4-29.

Table 4-29: Summary of GHG flux for four scenarios

		Scenario						
	Generated	Base Case	Divert +20%, WRPtE 50%	Max Diversion	Max WRPtE	Optimised	Divert x2 WRPtE x2	Max Landfill
Material	**(ktons)**	**(ktons of CO2eq, based on 2004 data)**						
Paper / cardboard	9,612	1,073	-701	**-2,266**	-1,540	-2,760	-1,250	3,397
Yard Waste	2,507	1,677	709	-125	**-316**	-316	1,620	1,735
Organics	9,333	6,016	2,512	-271	**-1,073**	-1,073	4,339	7,694
Plastics	3,065	-384	1,735	**-7,844**	5,175	-7,330	-797	30
Glass	1,114	-37	-41	**-105**	11	-105	-84	11
Metals	1,532	-2,088	-2,651	**-2,997**	-1,256	-2,997	-4,191	15
Textiles	796	69	232	**-2,187**	406	-2,152	80	59
Other	5,194	1,411	1,137	1,477	**891**	891	1,345	1,477
Not Considered[a]	1,235	0	0	0	0	0	0	0
Total	**34,389**	**7,740**	**2,934**	**-14,318**	**2,298**	**-15,841**	**1,061**	**14,418**

[a] (White goods, Electronics, Tires, Construction & Demolition Waste)

It is important to remember that the estimated emissions for these scenarios do not consider any other benefits or drawbacks relating to the environment. This information should be used in conjunction with the analysis done in the previous chapters, and most importantly the hierarchy of sustainable waste-related management must be observed.

In summary, the following major conclusions can be drawn from this process:

1. Each material in MW&RP is best suited for a specific process and no process is optimised for unsorted MW&RP.
2. In order to achieve any positive results, waste-related products need to be sorted; either at the source or at central facilities.
3. Recycling is by far the favoured solution for paper, metals, plastics, glass and textiles due to the significant materials and energy required during the extraction and production of new things.
4. Organics and yard waste are better suited for composting and in some cases are suitable for energy conversion via anaerobic digestion.
5. There will always be the need for disposal, either from attrition (degradation in quality of materials as they are recycled) and ash or residue from WRPtE processes. But these amounts are small and WRPtE is always a good first step instead of landfill.

In summary, the model developed in this chapter has allowed the greenhouse gasses associated with the waste-related industry to be quantified over the 100 year time horizon. By analysing each process and its components the bigger picture of the waste-related management activities can be considered. Furthermore, the overall benefits of one process over another are abundantly clear. The results obtained give credence to the conclusions of the previous chapters and the importance of a SIWRM hierarchy.

Although many qualified assumptions were made in order to account for the regional uncertainty of the data, the results are still credible and allow for future adjustments to be made as information comes available. In the other hand, comparable results from other reports were used which substantiates the methods used in this model.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Overview

Throughout this paper it has become clear that traditional waste-related management practices are no longer sufficient to meet the needs of today or future generations. A proper integrated and sustainable approach is required, which has the ability to include all waste-related products. At the outset, even the current use of the word *waste* should be revisited since it has the tendency to imply that a product is no longer useful. The word *waste* is often used to describe something that is no longer useful to the user or owner, but in most cases it is still useful to others and so labelling it *waste* in the first place is erroneous. Going one step further it has even been proposed that classifying a material *waste* can actually hinder sustainable waste-related practices.

Waste-related products are no longer what they used to be. Pre-industrial revolution, *waste* was in fact products that no longer had any use and were generally organic. Since humanity has been able to produce more than it needs, our *waste* has also changed to include non-biodegradable components such as metals, plastics, glass, textiles, etc. So it is only logical that the way we deal with and refer to *waste* has changed and is changing.

Unfortunately, our wasteful habits (generation and disposal) have gone unchecked for quite some time. The prime movers in the waste-related industry have been financial and political. Recycling and other so called environmentally sound practices have been implemented to help reduce the load on landfills and avoid building more, further from urban centers. However we are now at a crossroad, where the environmental impacts of our traditional waste-related management approach must be considered.

The sustainable and integrated waste-related management approach not only respects the environment, but also attempts to include all aspects of these activities and stakeholders, in an effort to minimise generation and disposal of waste-related products and maximise recovery and re-use. Ultimately the quantity of waste-related products going for disposal is an indicator of inefficiencies in a society. SIWRM improves the efficiency of waste related management and must be an integral part of any sustainable effort.

The updated SIWRM hierarchy attempts to discourage disposal by revealing that waste & recoverable products going for disposal are wasted resources. Of primary importance in this hierarchy is prevention and minimisation of waste & recoverable products: reduction of demand for new products, promotion of durable products, prevention of *wasteful* product generation, and minimisation of what is ultimately discarded. Importantly, these principles need to be applied at the appropriate levels of government, through public education, national initiatives, and participation of industry with incentives to promote the right behaviours.

Once we minimise the quantity of waste-related products that are no longer useful, the balance must then be either sent for disposal or diverted, the preferred option. Diversion is beneficial since it ensures that a product will be employed in another useful purpose, as opposed to being thrown in the trash. However, in most cases additional energy and resources may be required to transport, transform and/or re-package a diverted product. This is why re-using products in their current state is the preferred diversion method. The next best option is to process products into raw material so they can be recycled into new products. This still avoids a large amount of energy and resources required for the extraction and processing of raw materials and hence is still favourable compared to disposal.

Not all waste-related products can be prevented and/or minimised. Some organics, such as a paper and wood can be re-used or recycled, but others such as food scraps and yard waste need to be dealt with. These items, which are considered carbon neutral, should never go to landfills. Instead they should be diverted from the *waste* stream and composted. Even better, some very simple technologies exist to recover methane from the decomposition of organics which can offset emissions from other energy producers. It can be argued that composting or anaerobic digestion are disposal methods, but in reality they both can be considered re-use or recycling processes. In composting, the organic carbon is oxidised and returns to the atmosphere as CO_2 to continue the photosynthesis process for the growth of other plants. In anaerobic digestion, the methane generated is captured to produce useful energy. In both cases nutritious fertilisers are created. Therefore, diverting organics from disposal is considered as re-use and recycling.

In any event, almost all products that are no longer useful to the original owner can be diverted from disposal.

Even with optimal prevention, minimisation and diversion there will always be some disposal to deal with. Although undesirable the reality is that some products, due to attrition, will eventually require disposal. Modern habits necessitate disposal methods for now and the foreseeable future, until we can fully implement SIWRM systems. Some disposal methods are better than others and wherever energy can be recovered, the *waste* can be considered a resource. Landfills are always a last resort.

Converting waste-related products to energy requires many considerations. There are many different technologies which are best suited for different types of products. It is important to match each waste-related product with an appropriate technology, depending on input (paper, plastic, organics, etc.) and desired output (gas, electricity, heat, etc.). Typically, the WRPtE can be separated into two categories: biochemical and thermal.

Biochemical WRPtE, such as anaerobic digestion, is fairly passive and has few environmental side effects. It uses the natural decomposition action of organic carbon to generate energy. Organic material is allowed to decompose under an oxygen starved and controlled environment to increase methane output and speed up decomposition. Although additional energy is required to collect, transport and process organics in AD facilities, it has its merits over composting, depending on the application.

Thermal WRPtE has the potential to create more environmental side effects since high temperatures are required to transform the waste-related products. Most of the environmental concerns relate to the potentially harmful emissions and toxic solid and liquid by-products. However it has been shown that most of these effects can be mitigated using modern flue cleaning and combustion technologies, such as plasma gasification. Furthermore any energy generated from WRPtE facilities, offsets emissions from other power generating plants and consequently reduces the overall generated emissions. Another advantage of this process is that waste-related products can be treated close to the source to reduce the volume of the residual waste and minimise transportation.

Modern landfills are also capable of capturing methane to generate heat and/or electricity. But this assumes that organics have been sent to landfills, and in any waste-related management system this should never happen. Furthermore, it’s proposed that the estimates for the recoverable energy are grossly overestimated, making this disposal method unfavourable. Regardless, there will always be a need for the disposal of residual wastes. Even the most efficient SIWRM system, will generate a portion of waste that is no longer useful due to attrition and by-products from thermal processing. In general however, these products should be inert and should have gone through a full and useful life. Landfills, although undesirable in the modern context, must be part of any SIWRM scheme.

Integral to any SIWRM strategy is the greenhouse gas effect of the various processes. Within this context, the benefits and drawbacks of each activity becomes even clearer. Without a doubt recycling is the best alternative for metals, plastics, glass, textiles and sometimes paper & cardboard. Organics, yard trimmings, paper & cardboard are suitable for energy recycling. The unknown balance classified as ‘other’ can be incinerated for energy recovery and to minimise the volume.

The point remains however, that each waste-related product is better suited for one process over another and consequently sorting is a pre-requisite. Sorting allows for the right products to go to the right process in order to minimise our requirements for new resources and energy.

In Canada, the current W&RP management structure (federal, provincial/territorial, regional) is quite good in adapting to local economies and requirements. But a unified Canadian strategy is desperately needed. The provinces/territories are doing the best they can to treat W&RP in an environmentally, socially, economically and politically sound manner. However, they have no goals or targets to achieve other than the ones they set for themselves. This is why the figures on this topic vary so greatly from coast to coast.

The federal government’s current involvement is too weak. Environment Canada has put together its Waste Prevention Program, a good start but it lacks benchmarks and targets. The program is more of a tool than a statement of unified objectives. The CCME, although doing some positive things for the environment, has not focussed on the topic of waste-related products and management. The National Packaging Protocol was a success, but where are we now? What is the next step?

The federal government needs to step up, set minimum standards and goals for the country. This means adopting the SIWRM hierarchy and putting in place measures and targets for each component from prevention down to landfill. In addition more funding to encourage newer technologies should be provided.

The provinces and territories should not be left to fend for themselves. The environment is a global issue. It is the responsibility of the national leaders to act as one voice for Canada’s environmental policy and waste & recoverable products must be an integral part of this policy.

5.2 Conclusions

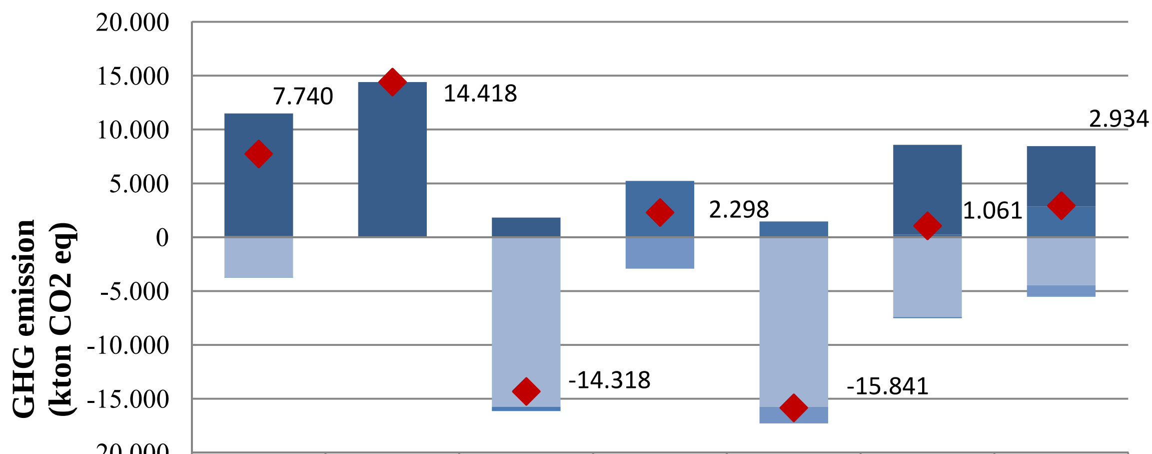
MW&RP accounts for only a small portion of the total W&RP we generate globally (5% to 26% depending on the country). If 15% is taken as an average, Canadians produced 33.2 million tons of MW&RP and 221.0 million tons of waste-related products, or 1,037 and 6,913 kg/person respectively, and we are generating more each year (13.9% increase from 2002 to 2006). We are amongst the largest generators per capita in the world and are only surpassed by a few nations such as the USA and Australia.

Based on the Canadian GHG inventory report, the waste-related industry accounts for 3.7% of the overall emissions generated (from a total of 747 Mton CO_{2eq}). This value is diminished because of the energy industry in Canada which constitutes 81.5% of all GHG emissions. But the fact remains that the emissions relating to W&RP are an important consideration in a sustainability policy and potential cuts in this sector are estimated to be in the same order of magnitude as those from improved energy efficiency.

Using the model developed in chapter 4, it has been estimated that the net emissions associated with the municipal waste and recoverable product industry accounts for 7.7 Mton CO_{2eq}. This is based on the 2004 data of 33.2 million tons of MW&RP generated which is comprised of an average diversion rate of 23.7% (composting and recycling), 74.0% sent to landfill and 2.3% incinerated. This net emissions generated might seem small, but it is important to remember that MW&RP only accounts for a fraction of the total and some processes are considered as emission sinks.

Using the estimated GHG emissions calculated for the base case scenario, the comparative benefits are clear. In the optimised scenario, where every product is sorted and sent to its optimum process the net emissions could be -15.8 Mt CO_{2eq}. In this scenario 83.0% is diverted (AD and recycling), 16.2% is incinerated (with electricity recovery) and 0.8% is sent to landfill (these scenario's include the 'Not considered' category). Not only is the optimised scenario far better, but it actually contributes as a sink, to offset some of the other emissions being released to the environment. This is primarily due to the benefits of recycling and avoided new energy and resources required for the extraction and processing of raw materials. The net GHG emission for the seven scenarios are summarised in Figure 5-1.

Ultimately, recycling and AD yield the best results, which support all diversion efforts.



	Base Case	Max Landfill	Max Diversion	Max WRPtE	Optimised	Diversion x2 WRPtE x2	Diversion +20%, WRPtE 50%
Landfill	11.366	14.418	1.829	11	3	8.315	5.589
Incineration	131	0	0	5.216	1.449	263	2.871
Compost	-50	0	-396	0	0	-101	-60
AD	0	0	0	-2.929	-1.543	0	-1.017
Recycling	-3.708	0	-15.750	0	-15.750	-7.416	-4.449
Net	7.740	14.418	-14.318	2.298	-15.841	1.061	2.934

Figure 5-1: Comparison of the various scenarios

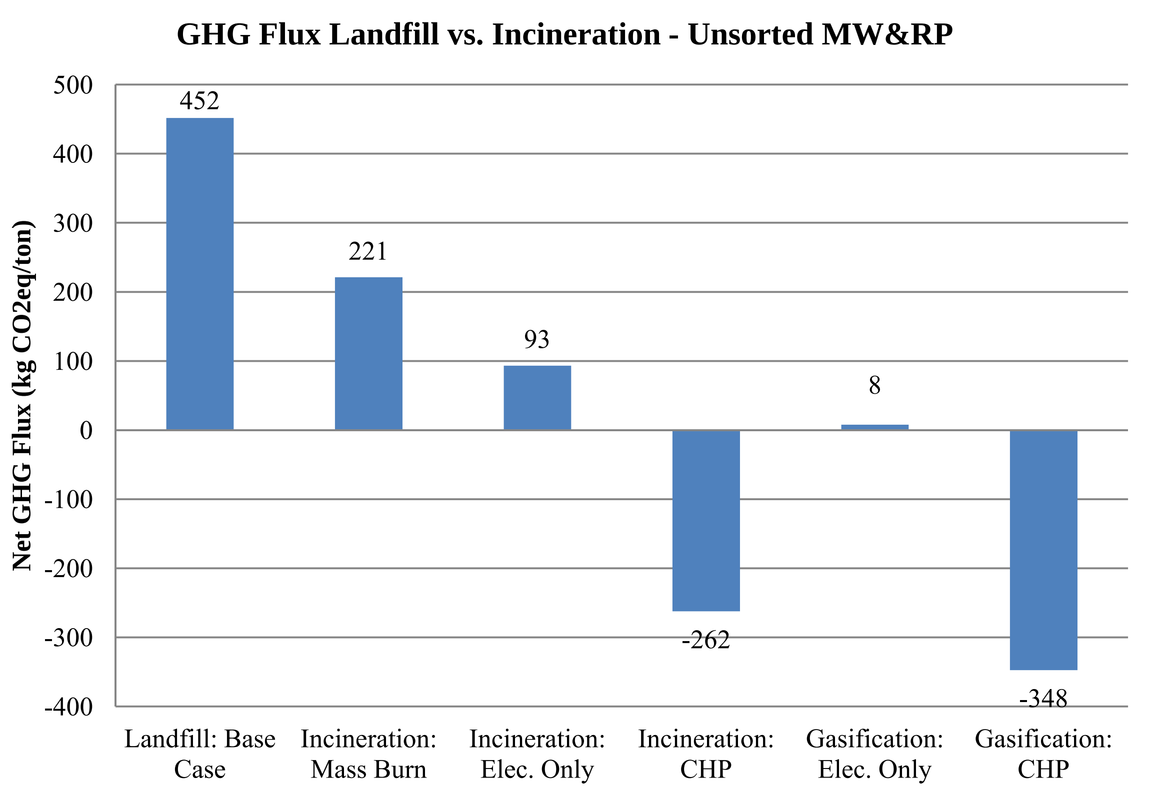


Figure 5-2: GHG Flux of landfill vs. incineration of unsorted MW&RP

In the scenarios WRPtE is clearly better than landfills, but still has a positive effect on the GHG flux. However, it is important to remember that the offset energy for the WRPtE process only considers modest electricity generation efficiency and no heat recovery. This was done to give a reasonable picture of the current potential for energy recycling.

Figure 5-2 is taken from a previous comparison in chapter 4. It shows that even the mass burn of unsorted MW&RP (no energy recovery) produces fewer emissions than a typical landfill model. Going one step further, newer gasification technologies with CHP energy recycling can have an appreciable effect as a GHG sink.

Based on the optimised scenario, if all MW&RP were diverted or incinerated based on their potential, it is estimated that approximately 92.5% of what is generated could be recovered for useful purposes (85.4% which is composted, AD or recycled and 7.1% incinerated with electricity generation). Table 5-1 summarises the potential based on 2004 MW&RP statistics. In this case a 10% attrition rate is assumed for recyclables. If this material can be thermally converted then it will produce ash, which is estimated at 15% of the initial mass. Furthermore, 50% of the ash is assumed to the diverted for asphalt. The remainder is residual waste which requires disposal in landfills. There is no residual waste from organics, since the by-products can be reused in their entirety for numerous applications.

Table 5-1: Theoretical residual waste

Material	Share [c] (%)	Diversion/Disposal Method	Disposal (%) Landfill	Incinerate	Diverted (%) AD / Compost	Recycle
Paper & Cardboard	29	90% recycling, 10% AD	0.0	0.0	2.9	26.1
Yard Trimmings	8	100% AD	0.0	0.0	7.6	0.0
Organics	28	100% AD	0.0	0.0	28.2	0.0
Plastics	9	90% recycle, 10% WRPtE	0.0	0.9	0.0	8.3
Glass	3	90% recycle, 10% landfill	0.3	0.0	0.0	3.0
Metals [a]	5	90% recycle, 10% landfill	0.5	0.0	0.0	4.2
Textiles	2	90% recycle, 10% WRPtE	0.0	0.2	0.0	2.2
Other [b]	16	15% recycle (misc. non-comb.), 46% WRPtE (misc. comb.), 38% landfill (fines)	6.0	7.2	0.0	2.4
Direct Total	**100**		**6.8**	**8.4**	**38.6**	**46.2**
Ash from WRPtE		15% of Initial mass		-1.3		
		50% recycle, 50% landfill	0.6			0.6
Total			**7.5**	**7.1**	**38.6**	**46.8**
			Disposal	**14.6%**	**Diverted**	**85.4%**
	33.2	**million tons, 2004**		**4.8 Mt**		**28.3 Mt**

a Metals are comprised of 4% ferrous and 1% non-ferrous metals. Information based on [58].
b Other is assumed to be 7% misc. combustibles, 2% misc. non-combustibles and 6% fines (dust). Information based on [58].
c The Share, excludes the 'Not Considered' category discussed earlier and used in the previous figure.

Of course the ability to recover 92.5% of all MW&RP generated might be a non-realistic scenario, but considering only 26.0% is currently being recovered, there is room for improvement.

In summary, the Canadian waste-related policy leaves much to be desired. Considering that:

1. Each Canadian generates about 1ton of MW&RP per year, amongst the highest in the world
2. Canadians divert and energy recycle far less than other countries
3. Even with Canada's large amount of land, approximately 3 million tonnes of non-hazardous W&RP generated in Canada is exported to the United Sates
4. On average, Canada recovers 26.0% of all MW&RP going to landfill, with a potential of 92.5%
5. The waste-related management industry in Canada, if managed properly, could be a GHG sink, but instead contributes 3.7% of the total Canadian GHG emissions
6. WRPtE is generally non-existent and new policies with strict environmental criteria might incent developers to build landfills instead of energy recycling facilities.

In has been shown throughout this paper that waste-related management is a complex topic which requires leadership, partnership and analysis in a modern context. In Canada there appears to be no clear direction in terms of common national policy, initiatives, targets or incentives. The regions are doing the best they can to satisfy their constituents, but do not have the bigger picture of a truly sustainable & integrated waste-related management strategy. The following section offers some recommendations on how Canada can work towards a sustainable future.

5.3 Recommendations for Canada

Canada has a lot of potential and room for improvement in its waste-related management strategies. Some major changes and strong leadership would be required to motivate the public towards a sustainable future, starting with a national strategy regarding the environment. Integral to this strategy should be improvements to the current waste-related management initiatives. The following are suggested improvements based on the analysis in this paper.

The major improvements required are fairly simple; Accountability and Cooperation. All levels of government, manufacturers, large industry, and consumers all need to get involved and do their part. A major paradigm shift is required to change the way *waste* is perceived, what is consumed, what is generated and what effect it has on the environment. Individuals, corporations, and governments also need to be responsible for their actions. The first step is education about the full consequences of our consumer lifestyles. Once we are all on the same page, then it's time to change our habits.

For that to happen however, leadership is required to promote and support a common goal we can all be proud of working towards…together. The following is a list of changes or recommendations which are integral to a SIWRM strategy. These initiatives are summarised by level of government in Table 5-2.

Some of the elements that should be further investigated to improve the Canadian waste-related management policies are;

- Redefining *waste* and *Sustainable & Integrated Waste-related Management*
- Intergovernmental cooperation
- Public education, changing lifestyle, reducing consumption
- Banning of export/import or refuse, if *waste* is a local problem, it should be treated locally (note export/import of recyclables in Canada may be required since re-processing facilities may not be financially feasible for the size and dispersion of the population)
- Extended producer responsibility, manufacturer pays for LCA of his products
- Life-cycle costing of products reflected on labels
- Produce durable, repairable and reusable products
- User-pay systems to tax and charge lifestyle not income, giving Canadians price signals about the W&RP they produce
- Diversion targets and recycled content
- Minimum WRPtE requirements
- Maintain and increase funding for R&D on Canadian Technologies
- Improve measuring, reporting and monitoring.
- Develop recovery programs for various items (e.g. used tires, paints, electronics batteries, other hazardous materials, etc.)

Table 5-2: Responsibility of the various governments in W&RP

	Role & Responsibility		
Method	**Federal**	**Provincial/Territorial**	**Regional/Local**
Minimization/Prevention			
• Accountability • Reduce consumption • Public Education • Promote durable and reusable products • Lead a simpler lifestyle • Extended producer responsibility • Use recyclables in new products • Life-cycle costing of materials	• Publish guides to clean living • Ban import/export of 'waste' • Set-up minimum standards for quality of products (e.g. warranties) and quantity of recyclables used in all products sold • Make producers assume the diversion and disposal cost of their products • Enforce LCA labels on all products sold in Canada • Tax and charge lifestyle, not income	• Promote clean living/LCA awareness • Ban import/export of 'waste' • Enforce manufacturers and industry to include waste disposal in cost of products. • Give incentives for use of recyclable materials. • Tax and charge lifestyle, not income	• Avoid transporting 'waste' away, dispose close to source. • Instate user-pay fees (charge for waste disposal)
Diversion			
• Reuse products • Divert organics for energy recycling • Divert organics for composting • Recycle non-reusable materials	• Set minimum diversion goals for the country • Invest in biochemical WRPtE technologies • Promote durable products • Create a recycling market by enforcing minimum recycled content in goods	• Enforce and develop diversion strategies • Invest in biochemical WRPtE technologies • Develop composting infrastructure	• Participate in promoting re-use (urban flea markets) • Develop WRPtE and composting infrastructure • User-pay fees and/or fines for not recycling • Source separation
Disposal			
• Promote WRPtE (energy recycling) • Disposal close to the source • Landfill as a last resort	• Set minimum energy recycling targets • Set minimum environmental standards • Invest in WRPtE technologies • Research and promote 'clean' WRPtE • Promote engineer landfills	• Enforce and develop energy recycling strategies • Invest in WRPtE technologies • Set & enforce minimum environmental standards	• Keep disposal close to the source • Educate public on WRPtE • Investigate combining waste streams

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KRATKA BIOGRAFIJA

Patrick Fowler rođen je 13. studenog 1981. godine u Kanadi. Poslije završetka osnovnog obrazovanja upisao se na Sveučilište Otava (University of Ottawa) gdje je 2004. stekao diplomu u primjenjenoj znanosti, područje strojarstva. Tijekom studiranja je sudjelovao u programu stručnog usavršavanja (co-op program) – komunalno inženjerstvo (Gatineau Kanada), inženjerstvo okoliša (Gatineau Kanada), kontrola kvalitete (Leuven, Belgium).

Godine 2006. upisuje studij Sustainable Energy Engineering na Fakultetu strojarstva i brodogradnje, Sveučilištu u Zagrebu, gdje se specijalizira za područje održive proizvodnje električne energije. U okviru studija posebno se bavio značajem biomase u razvoju održive energetike, što rezultiralo i objavom jednog znanstvenog rada u časopisu International Journal of Hydrogen Energy.

U dosadašnjoj karijeri, Pat Fowler je bio na pozicijama suradnika i voditelja više nacionalnih i interdisciplinarnih projekata, a trenutno radi u građevinskoj konzultantskoj tvrtki kao strojarski inženjer i projektant sustava HVAC (grijanje, ventilacija, klimtizacija), vodovodnih i protupožarnih sustava. Aktivni je član Komore inženjera Ontaria (Professional Engineeris of Ontario), udruge ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers) i kanadske komore CaGBC (Canada Green Building Council).

SHORT BIOGRAPHY

Patrick Fowler was born on November 13th 1981 in Canada. After completing his primary education he enrolled at the University of Ottawa and graduated in 2004 with a Bachelor's of Applied Science in Mechanical Engineering. Throughout university he was enrolled in the co-op program which allowed him to apply the technical skills in his roles as utilities engineer (Gatineau, Canada), environmental engineer (Gatineau, Canada) and quality control engineer (Leuven, Belgium).

In 2006 he enrolled in the Sustainable Energy Engineering program at the Faculty of Mechanical Engineering at the University of Zagreb, where he specialized in the field of Sustainable Power Generation. He wrote several papers for the course work and published a study in the International Journal of Hydrogen Energy.

In his professional career, Pat Fowler works for a building consulting firm as a mechanical and sustainable engineer and designer for HVAC, plumbing and fire protection systems. He has also worked as project manager on national and multi-disciplinary projects. He is currently an active member of the PEO (Professional Engineers of Ontario), ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers) and CaGBC (Canada Green Building Council).