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WATERLOO ENVIRONMENT

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# ENERGY AND ECONOMIC VALUES OF NON-RECYCLED PLASTICS (NRP) CURRENTLY LANDFILLED IN CANADA

A study by

**M.E. Haight and N. Antadze**

**December, 2012**

## Executive Summary

The diversion quantities of all waste materials have continued to increase in Canada, approximately 10% more in 2008 compared to 2006 (Statistics Canada 2011). As a category, end-of-life plastic materials prepared for recycling experienced greater increases, up 40% in 2008 compared to 2006 (Statistics Canada 2011). However, the overall amount of all diverted material is still small compared to the waste sent for disposal. Overall diversion in Canada is estimated to be 24% of all waste based on 8 million tonnes diverted and 26 million tonnes disposed (Statistics Canada 2011). A similar trend is characteristic of plastic wastes – 324,731 tonnes of plastic materials were diverted in 2008 compared to 2.8 million tonnes disposed (Statistics Canada 2011, Kelleher Environmental, 2012).

Plastics recycling will continue to increase through the efforts of the Canadian Plastics Industry Association (CPIA), governments, stewardship organizations, industry and others; however, as experienced in other countries around the world, there appear to be limits to the efficient recycling of plastics. At their end-of-life, plastics that are not recycled, can be re-purposed and used as an alternative energy source.

As all of the common plastics are variations of hydrocarbons, they have high intrinsic energy value which can be recovered using various forms of thermal processes such as mass burn with energy recovery, gasification, pyrolysis, or the manufacture of refuse derived fuel (RDF), etc. In fact, the most common plastics that are landfilled all have energy values almost higher than coal and almost as high as natural gas and oil. Landfilling of non-recycled plastics (NRP) is a loss of this valuable energy resource. Alternatively, thermal processes are a recovery option that could recapture the energy resource in plastics that are either unrecyclable or unrecycled.

To help promote the concept of energy recovery, the CPIA requested Professor Murray Haight of the University of Waterloo to quantify the potential energy and economic value of capturing the energy inherent in plastics, not captured for recycling, through thermal treatment rather than landfilling the material, as currently practiced. The CPIA also had the University of Waterloo expand its study beyond plastics and estimate the energy value lost from the landfilling of all combustible solid wastes in Canada.

**Key Findings**

- The amount of non-recycled plastics (NRP) disposed in Canada was estimated at 2.8 million tonnes. The chemical energy contained in this material was more than 87 million GJ. This amount of energy is equivalent to:
    - 3.4 million tonnes of coal, or
    - 14 million barrels of oil, or
    - 79 billion cubic feet of natural gas.

- Hypothetically, if all the NRP that are currently disposed were source separated and converted by pyrolysis to a fuel oil, they would produce an estimated 9,245,046 barrels of oil per year (at 3.3 bbl/tonne) or enough to power more than 637,589 cars for one year.The economic value of

9,245,046 barrels of oil derived from NRP, at the current price of USD$ 85.00/barrel, is more than 786 million dollars.

- If all the NRP that are landfilled annually were to be source-separated and used as fuel in specially designed power plants, the electricity produced would be 20 million GJ, enough to supply 499,232 households with electricity. This would also reduce coal consumption by 681,453 tonnes (with the assumption that 1 tonne of coal equivalent produces 8.14 MWh energy).

- Hypothetically, if 100% of the total landfilled combustible solid waste stream was diverted from disposal to new Waste-to-Energy (WTE) power plants, it would produce 61.2 million GJ of electricity, enough to power more than 1.5 million households for one year. (In this report, combustible solid waste refers to the total amount of residential and IC&I wastes that can be thermally treated, e.g. has been pre-treated by removing non-combustible materials such as glass, concrete, bricks, etc.)

- The study examined the effect of new WTE capacity on reducing coal consumption in provinces that now import coal. One tonne of combustible solid waste used as fuel in new WTE plants would produce the energy equivalent of about 0.4 tonnes of coal. Accordingly, 25% diversion of combustible solid waste currently landfilled to new WTE plants would avoid mining 2.6 million tonnes of coal; 100% diversion of current landfilling by means of new WTE capacity would reduce coal mining by 10.3 million tonnes.

- In 2010, the Canadian cement manufacturing industry used 25 million GJ of energy that was derived from coal. Diversion of 25% of currently disposed plastics could produce 22 million GJ, that would mostly offset coal used for energy generation by the cement production industry in Canada. This would reduce coal consumption by 750,614 tonnes (with the assumption that 1 tonne of coal equivalent produces 8.14 MWh energy).

- Increased WTE capacity would reduce the carbon footprint of waste management in Canada. For example, a 25% diversion of combustible solid waste from landfilling to new WTE facilities will result in greenhouse gas (GHG) reduction of 3.2 to 6.4 million tonnes of carbon dioxide equivalent, depending on the degree of landfill gas capture in present landfills.

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# 1. Introduction

## 1.1 The need for this project

The diversion quantities of all waste materials have continued to increase in Canada, approximately 10% more in 2008 compared to 2006 (Statistics Canada 2011). As a category, end-of-life plastic materials prepared for recycling experienced greater increases, up 40% in 2008 compared to 2006 (Statistics Canada 2011). However, the overall amount of all diverted material is still small compared to the waste sent for disposal. Overall diversion in Canada is estimated to be 24% of all waste based on 8 million tonnes diverted and 26 million tonnes disposed (Statistics Canada 2011). A similar trend is characteristic of plastic wastes – 324,731 tonnes of plastic materials were diverted in 2008 compared to 2.8 million tonnes disposed (Statistics Canada 2011, Kelleher Environmental, 2012).

Plastics recycling will continue to increase through the efforts of the Canadian Plastics Industry Association (CPIA), governments, stewardship organizations, industry and others; however, as experienced in other countries around the world, there appear to be limits to the efficient recycling of plastics. At their end-of-life, plastics that are not recycled, can be re-purposed and used as an alternative energy source.

As all of the common plastics are variations of hydrocarbons, they have high intrinsic energy value which can be recovered using various forms of thermal processes such as mass burn with energy recovery, gasification, pyrolysis, or the manufacture of refuse derived fuel (RDF), etc. In fact, the most common plastics that are landfilled all have energy values almost higher than coal and almost as high as natural gas and oil. Landfilling of non-recycled plastics (NRP) is a loss of this valuable energy resource. Alternatively, thermal processes are a recovery option that could recapture the energy resource in plastics that are either unrecyclable or unrecycled.

To help promote the concept of energy recovery, the CPIA requested Professor Murray Haight of the University of Waterloo to quantify the potential energy and economic value of capturing the energy inherent in plastics, not captured for recycling, through thermal treatment rather than landfilling the material, as currently practiced. The CPIA also had the University of Waterloo expand its study beyond plastics and estimate the energy value lost from the landfilling of all combustible solid wastes in Canada.

## 1.2 Scope of work

The aim of this report is to identify and collect information on non-recycled plastics (NRP) that are currently disposed in Canada and quantify the potential energy and economic value of recovering this material. Projects similar to this - which help to quantify the scale and availability of an energy source - are crucial in helping to identify fuel sources which will aid policy makers.

### 1.3 Methodology

The calculations of the potential energy lost through disposal of NRP plastics in each province, as well as on national basis, were made based on the data supplied by the Canadian Plastics Industry Association (CPIA) and information publicly available by Statistics Canada. Data on the lower heating values of various plastic resins were provided by Themelis et al. (2011). It should be noted, that certain methodological limitations may exist as the report is based on the estimated amounts of different categories of plastics that are being disposed. The report was modeled after a similar study by the Earth Engineering Center at Columbia University that investigated the energy and economic values of NRP and municipal solid waste currently landfilled in the United States (Themelis et al., 2011).

## 2. Estimates of solid waste generation in Canada

According to the latest estimates by Statistics Canada, the amount of waste sent for disposal in 2008 amounted to 26 million tonnes. Variations were observed among the provinces as well as different sources of waste. For example, in New Brunswick waste disposal was reduced by 6% from 2006-2008, whereas Saskatchewan saw an increase of 8% during this timeframe. As for the different sources of waste generation, in 2008 the amounts of disposed residential waste decreased by 4% compared to 2006. In contrast, the amount of disposed non-residential waste increased by 2%. In general, the major fraction of disposed waste comes from non-residential sources and only 33% of the disposed waste is residential waste. Alberta has the greatest share of waste disposed from non-residential sources at 76% (Statistics Canada, 2008). This is not surprising, as the oil sands' industry is mainly located in Alberta and is considered to be the largest solid waste producer in the country (Statistics Canada, 2012). In contrast, Newfoundland and Labrador has the lowest proportion of non-residential waste disposal at 47% (See Figure 1) (Statistics Canada, 2008).

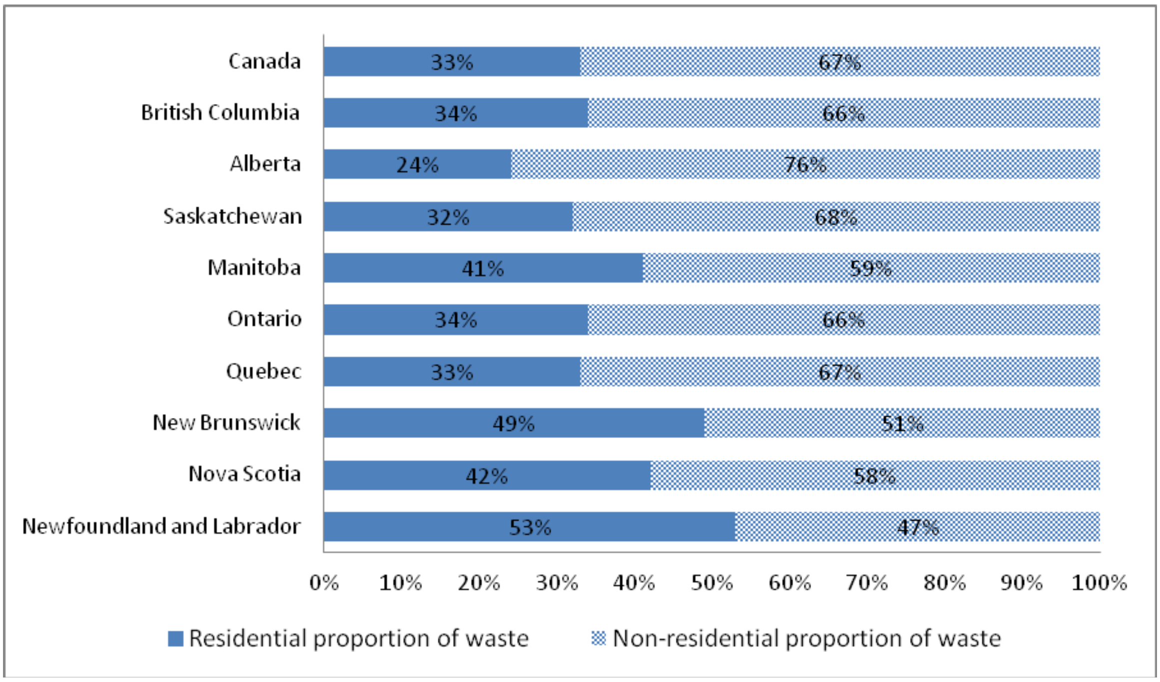


**Figure 1 Disposal of waste by source, province and territory, 2008**

Note: Data are not available for Prince Edward Island
Source: Statistics Canada, 2008

The per capita generation of solid waste did not experience much change during the period of 2006-2008. In 2008, per capita production of waste totaled 1,031 kg. Similarly to the overall national statistics, per capita generation varies throughout the country. Nova Scotia, for example, had the lowest per capita waste disposal of 378 kg/cap, while Alberta had the highest at 1122 kg/cap (See Figure 2)(Statistics Canada, 2008).

## 3. Estimates of solid waste diverted and disposed in each province

The average production of solid waste in 2008 amounted 1,031kg per person. The majority of waste - 777 kg was disposed (landfilled or incinerated) and only a relatively smaller portion was diverted-254 kg. Nationwide, little less than half of the diverted waste was attributed to non-residential sources (Statistics Canada, 2008).

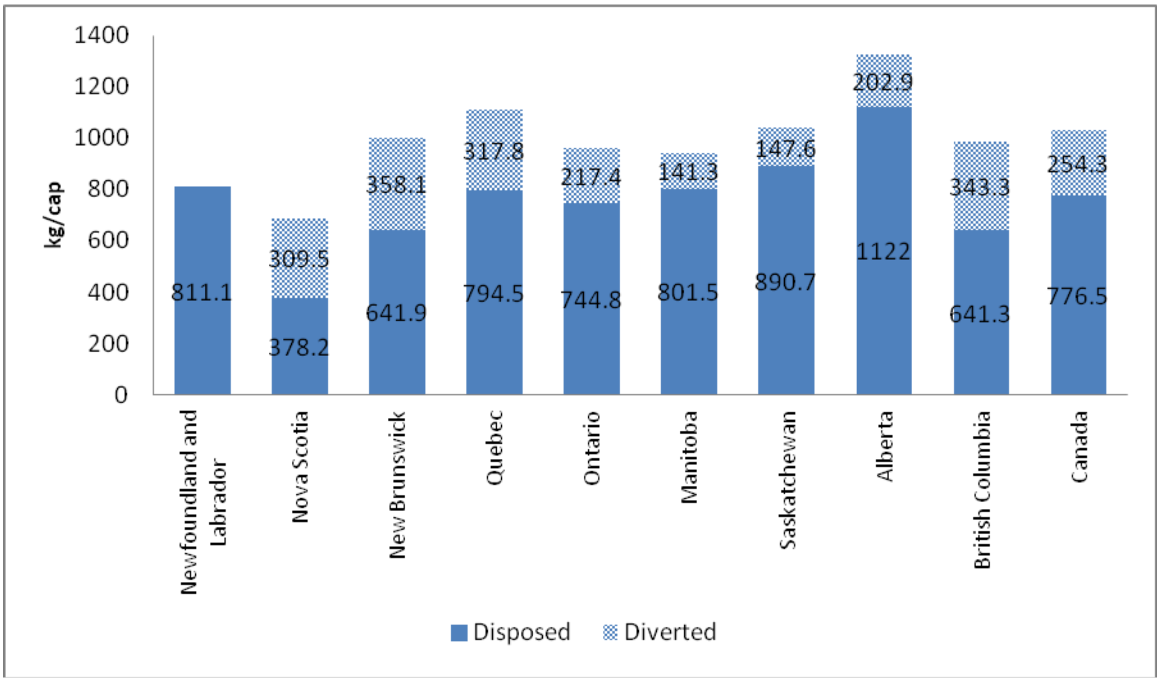


**Figure 2 Disposal and diversion of waste by province and territory, 2008**

Note: Data are not available for Prince Edward Island, Yukon, Northwest Territories and Nunavut. The data on diversion are not available for Newfoundland and Labrador.
Source: Statistics Canada, 2011.

Across the country, the overall trend has been an increase in the diversion rates for solid wastes. During the period of 2004-2008,for example, the average diversion rate increased from 22% to 25%; however, significant differences can be observed among the provinces and different recyclable fractions (see Figure 3). In 2008, for example, the largest increases of recycling and composting rates were recorded in New Brunswick and Nova Scotia, while in Manitoba diversion rates mostly remained unchanged and Alberta experienced a slight decrease in diversion rates compared to 2004. Interestingly, the diversion rates of waste from residential sources increased by 56% from 2002 to 2008; while, the diversion rates of non-residential waste increased only by 7% during the same time period (Statistics Canada, 2012).

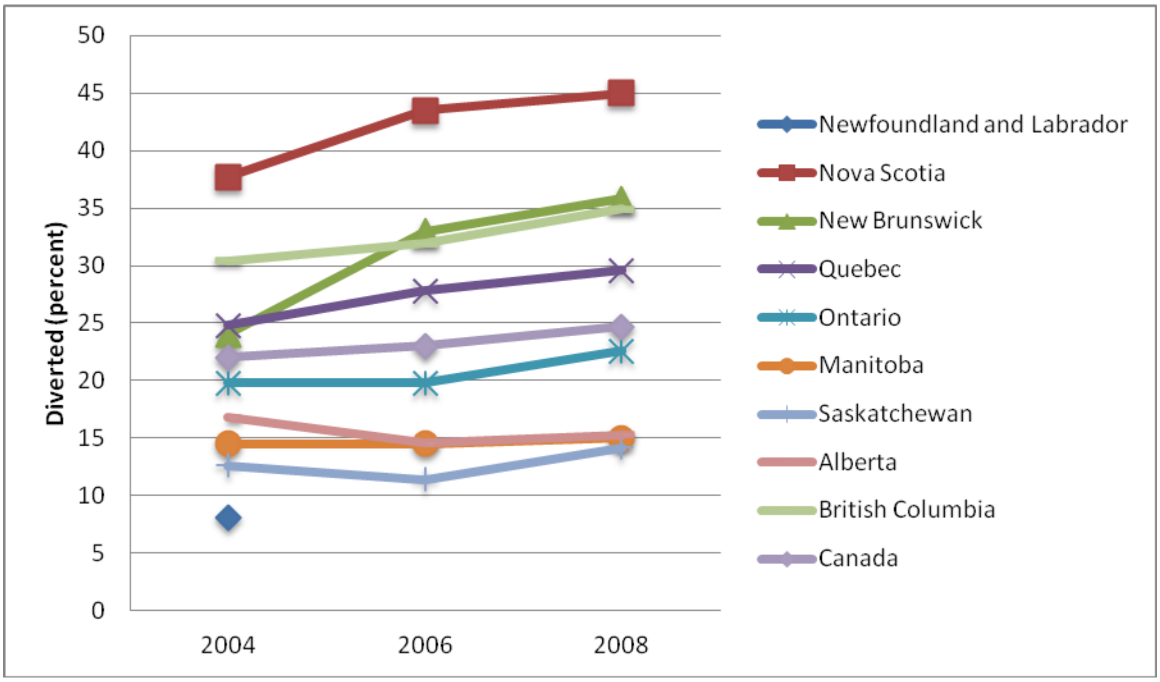


**Figure 3 Diversion rates (percentage) by province and territory, 2004, 2006, 2008**

Note: Data are not available for Prince Edward Island and Yukon, Northwest Territories and Nunavut. For Newfoundland and Labrador the data are available only for 2004.
Source: Statistics Canada, 2011.

The highest increase of diversion rates were recorded for electronic materials -up 115% and plastics -up 40%. However, despite a significant increase in diversion rates, plastics represent only a small share of the overall diversion results. Paper fibers (including newsprint, mixed paper, cardboard),as illustrated in Figure 4,represent the largest  portion of diverted materials, followed by organic materials (Statistics Canada, 2008).

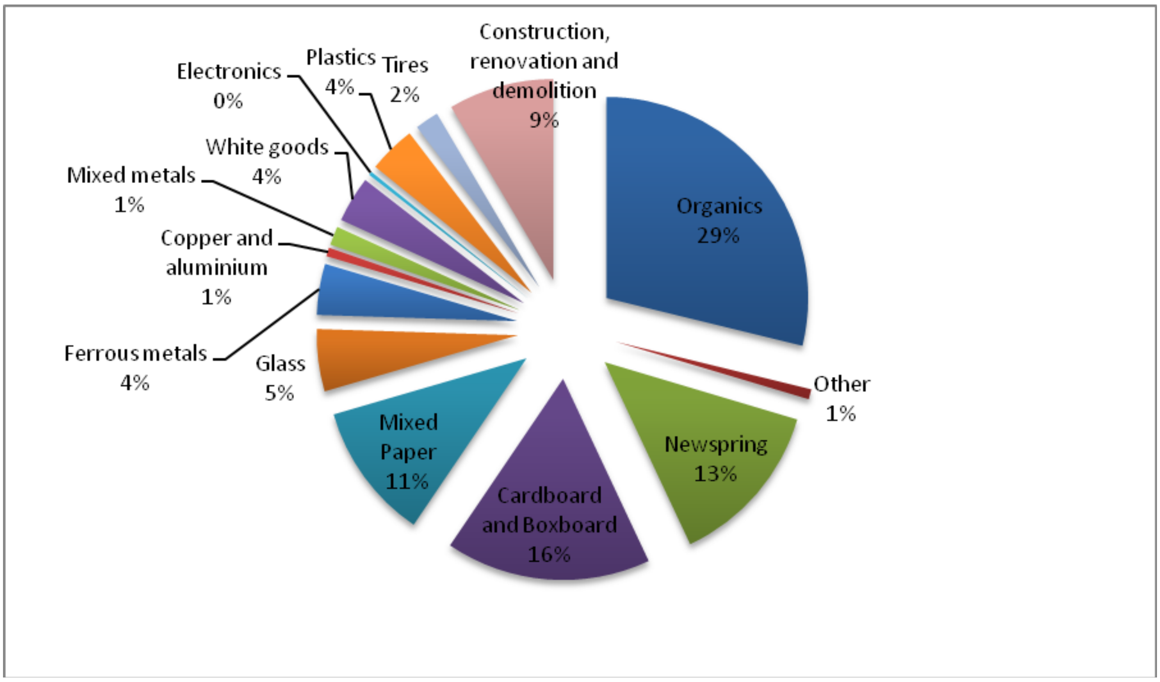


**Figure 4 Material prepared for recycling, by weight, 2008**

Source: Statistics Canada, 2012

# 4. Estimate of plastics generated, disposed and diverted in each province

## 4.1. Categories of plastics

Plastic waste is not a homogeneous mixture and usually, is comprised of different types of plastic materials. The overall stream of plastic waste can be divided into one of two categories: packaging and non-packaging plastics. Not surprisingly, packaging plastic includes a wide variety of different types of plastic materials ranging from PET bottles to plastic wraps. The list of non-packaging plastic is comparatively shorter. Table 1 presents a detailed list of plastic categories. Most categories are packaging plastics.

**Table 1 Categories of plastics**

| **Packaging Plastics** |
|---|
| Bottles/Jugs/Jars - PET |
| Bottles/Jugs/Jars - HDPE |
| Bottles/Jugs/Jars - PVC |
| Bottles/Jugs/Jars - other bottles, jars and jugs (#4 LDPE, #5 PP, #7) |
| Other Rigid Containers - #6 PS packaging |
| Other Rigid Containers - Wide mouth containers and lids (#2, #4, #5) |
| Other Rigid Containers - All other rigid plastic packages (blister packaging, plant pots, toothpaste, deodorant, |
| Film Packaging - Polyethylene plastic bags and film - non carry-out bags (bread bags, produce bags, net bags) |
| Film Packaging - Polyethylene retail and grocery carry-out bags |
| Film Packaging - Laminates (vacuum sealed products, meat and fish wrap, cheese wrap, cereal liners, chip bags etc.) |
| **Non-Packaging Plastics** |
| Film Non Packaging - Polyethylene plastic bags and film (kitchen catchers, garbage bags, zip-lock, cling wrap) |
| Durable Plastic Products - Non-packaging (VCR tapes, CDs, toys, garden hose, lawn furniture) |
| Durable Plastic Products - Vinyl Siding etc. |

Source: Kelleher Environmental, 2012.

## 4.2. Residential plastic wastes disposed in Canada and in each province

It is estimated that the total residential plastic waste disposed in Canada amounted to 719,796 tonnes (21.17kg/cap.), out of which 542,887 tonnes (16kg/cap) were packaging plastics. Table 2 below presents the breakdown of disposed residential packaging and non-packaging plastics according to the provinces (Kelleher Environmental, 2012):

**Table 2 Residential disposed plastic packaging and non-packaging by province**

| Province | Population | Residential Packaging Plastics (kg/cap) | Residential Non-packaging Plastics (kg/cap) | Total Residential Plastics (kg/cap) | Residential Packaging Plastics (tonnes) | Residential Non-packaging Plastics (tonnes) | Total Residential Plastics (tonnes) |
|---|---|---|---|---|---|---|---|
| **British Columbia** | 4530960 | 16.93 | 8.34 | 25.27 | 76,696 | 37,793 | 114,489 |
| **Alberta** | 3720946 | 16.93 | 8.34 | 25.28 | 63,009 | 31,045 | 94,054 |
| **Saskatchewan** | 1045622 | 22.63 | 6.94 | 29.57 | 23,662 | 7,257 | 30,919 |
| **Manitoba** | 1235412 | 22.61 | 6.93 | 29.55 | 27,938 | 8,567 | 36,505 |
| **Ontario Single Family** | 13210667 | 9.92 | 3.40 | 13.31 | 131,015 | 44,879 | 175,894 |
| **Ontario Multi-family** | | 3.27 | 0.93 | 4.20 | 43,211 | 12,337 | 55,548 |
| **Quebec** | 7907375 | 15.39 | 4.43 | 19.82 | 121,731 | 35,031 | 156,762 |
| **New Brunswick** | 751755 | 23.71 | n/a | n/a | 17,822 | n/a | 17,822 |
| **Nova Scotia** | 942506 | 23.71 | n/a | n/a | 22,345 | n/a | 22,345 |
| **Prince Edward Island** | 142266 | 23.71 | n/a | n/a | 3,373 | n/a | 3,373 |
| **Newfoundland and Labrador** | 509739 | 23.71 | n/a | n/a | 12,085 | n/a | 12,085 |
| **Canada** | **33997248** | **15.97** | **5.20** | **21.17** | **542,887** | **176,909** | **719,796** |

Source: Kelleher Environmental, 2012

## 4.3. Industrial Commercial and Institutional (IC&I) plastic wastes disposed in Canada and in each province

Table 3 presents the amounts of plastic waste disposed in the IC&I waste stream in each province.

**Table 3 Disposed IC&I waste in each province**

| Province | Population | Disposed ICI Waste | Packaging Plastic Disposed in IC&I Waste Stream | Non-Packaging Plastic Disposed in IC&I Waste Stream | Total Plastic Disposed in IC&I Waste Stream |
|---|---|---|---|---|---|
| | | **tonnes** | **Tones** | **tonnes** | **tonnes** |
| NL | 509,739 | 193,598 | 20,040 | 11,172 | 31,212 |
| NS | 942,506 | 206,171 | 37,056 | 20,656 | 57,712 |
| NB | 751,755 | 245,758 | 29,558 | 16,476 | 46,034 |
| PEI | 142,266 | `65,397 | 5,594 | 3,118 | 8,712 |
| QC | 7,907,375 | 4,105,970 | 310,888 | 173,299 | 484,187 |
| ON | 13,210,667 | 6,400,160 | 519,393 | 289,528 | 808,921 |
| MB | 1,235,412 | 478,968 | 48,572 | 27,076 | 75,648 |
| SK | 1,045,622 | 613,182 | 41,108 | 22,916 | 64,024 |
| AB | 3,720,946 | 3,070,895 | 146,293 | 81,548 | 227,841 |
| BC | 4,530,960 | 1,851,097 | 178,141 | 99,301 | 277,442 |
| **Canada** | **33,997,248** | **17,231,196** | **1,336,643** | **745,090** | **2,081,733** |

Source: Kelleher Environmental, 2012

## 4.4 Plastic waste diverted in Canada and in each Province

Overall, 324,731 tonnes of plastic waste were diverted from the final disposal in Canada in 2008. Amounts vary across the country. According to per capita diversion rate, the largest amount of the plastic waste was diverted in Quebec and British Columbia and the lowest amount - in New Brunswick (Statistics Canada, 2011) (See Table 4).

**Table 4 Plastic waste diverted in each province, 2008**

| Province | Population | Diverted Plastic Waste | Diverted Plastic Waste |
|---|---|---|---|
| | | per/cap kg | tonnes |
| Newfoundland and Labrador | 509739 | | |
| Nova Scotia | 942506 | 6.69 | 6303 |
| New Brunswick | 751755 | 2.02 | 1518 |
| Prince Edward Island | 142266 | | |
| Quebec | 7907375 | 14.29 | 113000 |
| Ontario | 13210667 | 7.46 | 98594 |
| Manitoba | 1235412 | 7.48 | 9247 |
| Saskatchewan | 1045622 | 4.65 | 4863 |
| Alberta | 3720946 | 7.08 | 26342 |
| British Columbia | 4530960 | 14.32 | 64864 |
| Canada | 33997248 | 9.55 | 324731 |

Note: Data on diverted plastic waste are not available for Newfoundland and Labrador and Prince Edward Island. Source: Statistics Canada, 2011.

Figure 5 shows the amount of total disposed plastic (residential and IC&I) and the amount of diverted plastic in each province. Compared to the overall generation of the plastic waste, smaller amount is diverted. The major share of the produced plastic waste is disposed. For example, in Quebec, where the amount of the diverted plastics is the highest among the provinces, only 113,000 tonnes of plastic waste is diverted in contrast to the generated plastic waste of more than 640,949.

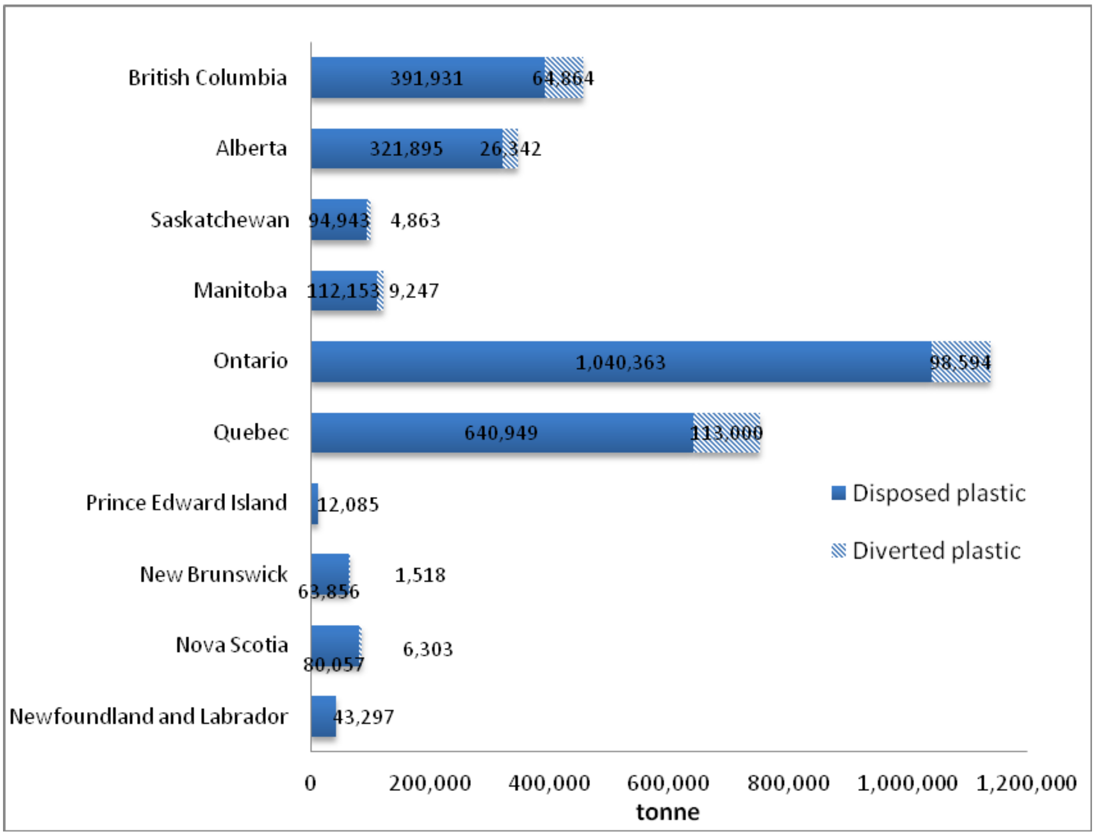


**Figure 5 Disposed and diverted plastic waste in each province**

Note: Plastic waste diversion data is not available for Newfoundland and Labrador and Prince Edward Island. Disposed plastic waste includes residential and IC&I plastic waste.

Source: Kelleher Environmental, 2012, Statistics Canada, 2011

# 5. Potential for energy recovery from NRP that are now landfilled

## 5.1 Energy value of non-recycled plastics

This chapter presents the results of calculations of the chemical heat contained (i.e., calorific value) in mixed plastic wastes that are currently disposed in Canada. The calculations are based on the Lower Heating Values (LHV) of various plastic categories provided by Themelis et al. (2011) and the amounts of disposed plastics provided by Kelleher Environmental (2012). The energy of NRP is calculated for both residential and IC&I waste (See Tables 5 and 6) and amounts to 22,464,889 Gj and 64,250,561 Gj, respectively. When combined the total energy contained in NRP amounts to 86,715,450 Gj. This analysis also shows that residential non-recycled plastics have a higher Lower Heating Value (31.21 MJ/kg) compared to IC&I non-recycled plastics (30.86 MJ/kg). The overall LHV for non-recycled plastics is estimated to be 30.95 MJ/kg.

**Table 5 Energy contained in Residential Non-recycled plastics**

| Residential Sector | Canada | LHV (GJ/tonne) | Total Energy Content (GJ) |
|---|---|---|---|
| Plastic Category | tonnes | | |
| Bottles/ Jugs/Jars | | | |
| PET Bottles/Jugs/Jars | 50,265 | 24 | 1,206,360 |
| HDPE Bottles/Jugs/Jars | 39,038 | 44 | 1,717,672 |
| PVC Bottles/Jugs/ Jars | 1,850 | 19 | 35,150 |
| Other Bottles/Jugs/Jars | 11,041 | 25 | 276,025 |
| (1) TOTAL Plastic Bottles | 102,194 | | 3,235,207 |
| PS Packaging | 71,467 | 41 | 2,930,147 |
| Wide-mouth containers | 42,831 | 44 | 1,884,564 |
| Other rigid packaging | 65,292 | 24 | 1,615,460 |
| (2) Total Non Bottle Rigid Plastics | 179,590 | | 6,430,171 |
| Polyethylene bags and film | 114,796 | 28 | 3,214,288 |
| Polyethylene (Mixed HDPE & LDPE) | 36,831 | 36 | 1,325,916 |
| Laminates (Plastic film and bags that are at least 85% (by weight) plastic with up to 15% (by weight) other closely bonded or impregnated materials. | 109,476 | 28 | 3,065,328 |
| (3) Total Plastic Film Packaging | 261,103 | | 7,605,532 |
| Total Residential Plastic Packaging Disposed | 542,887 | | 17,270,910 |
| Polyethylene Plastic Bags & Film – Non-Packaging (garbage bags, kitchen catchers, bags for recyclables etc.) | 70,114 | 36 | 2,524,104 |
| Durable Plastic Products Non-packaging (VCR tapes, CDs, toys, games etc.) | 82,303 | 25 | 2,057,575 |
| Other Mixed - Non packaging | 24,492 | 25 | 612,300 |
| (4) Total Residential Non Packaging Plastic Disposed | 176,909 | | 5,193,979 |
| **Total Residential Plastics Disposed** | **719,796** | | **22,464,889** |

Source: Themelis et al. 2011 Kelleher Environmental, 2012

**Table 6 Energy contained in IC&I non-recycled plastics**

| IC&I Sector | Canada | LHV (GJ/tonne) | Total Energy Content (GJ) |
|---|---|---|---|
| Population: | 33997248 | | |
| Plastic Resin | tonnes | | |
| PET Bottles/Jugs/Jars | 43,824 | 24 | 1,051,776 |
| HDPE Bottles/Jugs/Jars | 59,523 | 44 | 2,619,012 |
| PVC Bottles/Jugs/Jars - | 3,133 | 19 | 59,527 |
| Other Bottles/Jugs/Jars - other bottles, jars and jugs (#4 LDPE, #5 PP, #7) | 16,448 | 25 | 411,200 |
| (1) Total Bottles/ Jugs | 122,928 | | 4,141,515 |
| PS Packaging | 287,480 | 41 | 11,786,680 |
| Wide mouth containers | 193,452 | 44 | 5,103,459 |
| Other rigid packaging | 120,668 | 24 | 2,977,566 |
| (2) Total Rigid containers | 601,600 | | 19,867,705 |
| Polyethylene bags and film | 123,742 | 28 | 3,464,776 |
| Polyethylene (Mixed HDPE & LDPE) | 53,957 | 36 | 1,942,452 |
| Laminates | 434,416 | 28 | 12,163,648 |
| (3) Total Film & Bags Packaging | 612,115 | | 17,570,876 |
| Film Non Packaging - Polyethylene plastic bags and film (ie. garbage bags) | 367,565 | 36 | 13,232,340 |
| Durable Plastic Products - Non-packaging | 320,984 | 25 | 8,024,600 |
| Durable Plastic Products - Other etc. | 56,541 | 25 | 1,413,525 |
| (4) Total Non Packaging | 745,090 | | 22,670,465 |
| Total Packaging Plastic Disposed in IC&I Waste Stream | 1,336,643 | | 41,580,096 |
| Total Non-Packaging Plastic Disposed in IC&I Waste Stream | 745,090 | | 22,670,465 |
| **Total Plastic Disposed in IC&I Waste Stream** | **2,081,733** | | **64,250,561** |

Source: Themelis et al., 2011, Kelleher Environmental, 2012

## 5.2 Energy equivalence of NRP to coal, oil, and natural gas

Conversions have been made in order to compare the LHV of the NRP with that of various fossil fuels. Based on these conversions, below we present the comparisons of LHV for residential and IC&I NRP, as well as for the total combined NRP (See Figure 6). Based on the calculations given in Table 5, the total energy of residential NRP is estimated to be 22,464,889 GJ. According to the same table, the total amount of disposed residential NRP is 719,796 tonnes. Based on these data, the conversions have been made to calculate MJ/Kg. To calculate MJ/Kg for IC&I NRP, the data from Table 6 was used - total energy of IC&I (64,250,561 GJ) and total amount of IC&I NRP (2,081,733tonnes). To calculate the total energy of combined NRP, the data on total energy of residential and IC&I NRP were summed up (GJ), as well as the total amounts of residential and IC&I NRP (tonnes). Corresponding conversions were made to calculate MJ/kg.

| | MJ/KG |
|---|---|
| **RESIDENTIAL NRP ENERGY** | **31.21** |
| **IC&I NRP ENERGY** | **30.86** |
| **COMBINED NRP ENERGY** | **30.95** |

| Fossil fuel | MJ/KG |
|---|---|
| Natural gas | 47 |
| Crude oil | 43 |
| Petroleum coke | 30 |
| U.S. coal | 23 – 26 |
| Wood | 14 |
| **Residential non-recycled plastics** | **31** |
| **IC&I non-recycled plastics** | **31** |
| **Combined non-recycled plastics** | **31** |

Note: Two values for U.S. coal show the range of possible LHVs.
Source: LHW of fossil fuels are taken from Themelis et al., 2011

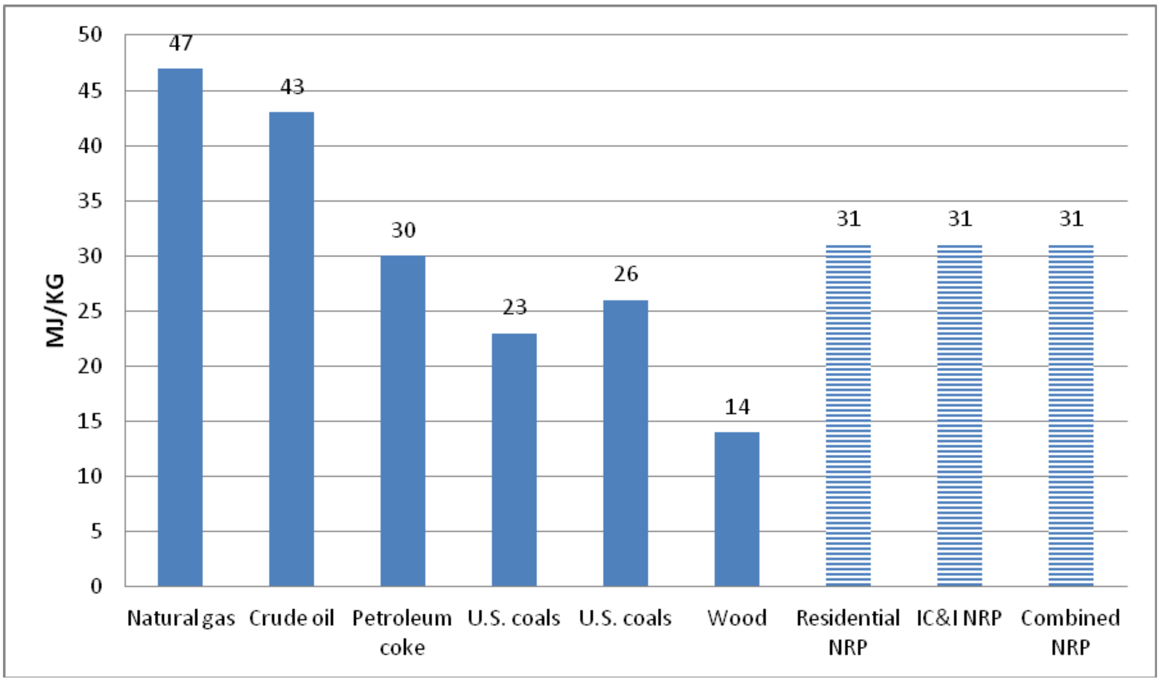


**Figure 6 Comparison of LHV (MJ/kg) for fossil fuels and NRP**

Note: Two values for U.S. coal refer to the possible maximum and minimum LHVs for U.S. coal.
Source: The LHV of fossil fuels is from Themelis et al., 2011

Table 7 shows the tonnes of coal, barrels of oil and cubic feet of natural gas of equivalent heating value to the tonnes of NRP currently landfilled in each province. The heating values used in calculating the equivalence were the following:
*1 tonne NRP -30.95 GJ*
*1 tonne coal– 25.6 GJ*[1]
*1 barrel oil –6.1 GJ*
*1000 standard cubic feet of natural gas -1.1 GJ*

**Table 7 Fossil fuel equivalent quantities to tonnes of NRP landfilled in each province**

| | | | Equivalent Amounts | | |
|---|---|---|---|---|---|
| **Province** | **Tonnes of NRP disposed** | **GJ lost in NRP disposed** | **Coal (tonnes)** | **Oil (barrels)** | **Natural gas (1000 standard cubic feet)** |
| **British Columbia** | 391,931 | 1.21E+07 | 473,838 | 1,988,568 | 11,027,513 |
| **Alberta** | 321,895 | 9.96E+06 | 389,166 | 1,633,221 | 9,056,955 |
| **Saskatchewan** | 94,943 | 2.94E+06 | 114,785 | 481,719 | 2,671,351 |
| **Manitoba** | 112,153 | 3.47E+06 | 135,591 | 569,039 | 3,155,578 |
| **Ontario** | 1,040,363 | 3.22E+07 | 1,257,783 | 5,278,563 | 29,272,032 |
| **Quebec** | 640,949 | 1.98E+07 | 774,897 | 3,252,028 | 18,033,974 |
| **Prince Edward Island** | 12,085 | 3.74E+05 | 14,611 | 61,317 | 340,028 |
| **New Brunswick** | 63,856 | 1.98E+06 | 77,201 | 323,991 | 1,796,676 |
| **Nova Scotia** | 80,057 | 2.48E+06 | 96,788 | 406,191 | 2,252,513 |
| **Newfoundland and Labrador** | 43,297 | 1.34E+06 | 52,345 | 219,679 | 1,218,220 |
| **TOTAL** | 2,801,529 | 8.67E+07 | 3,387,005 | 14,214,315 | 78,824,839 |

Figure 7 shows the amount of coal that would be replaced by diverting 100% or 25% of the NRP and compares this amount with the amount of the coal used to produce electricity in 2007.

[1]According to Themelis et al. (2011), 1 ton coal has a heating value of 22 million Btu. The current report uses the metric system and conversions have been made to calculate GJ for 1 metric tonne of coal.

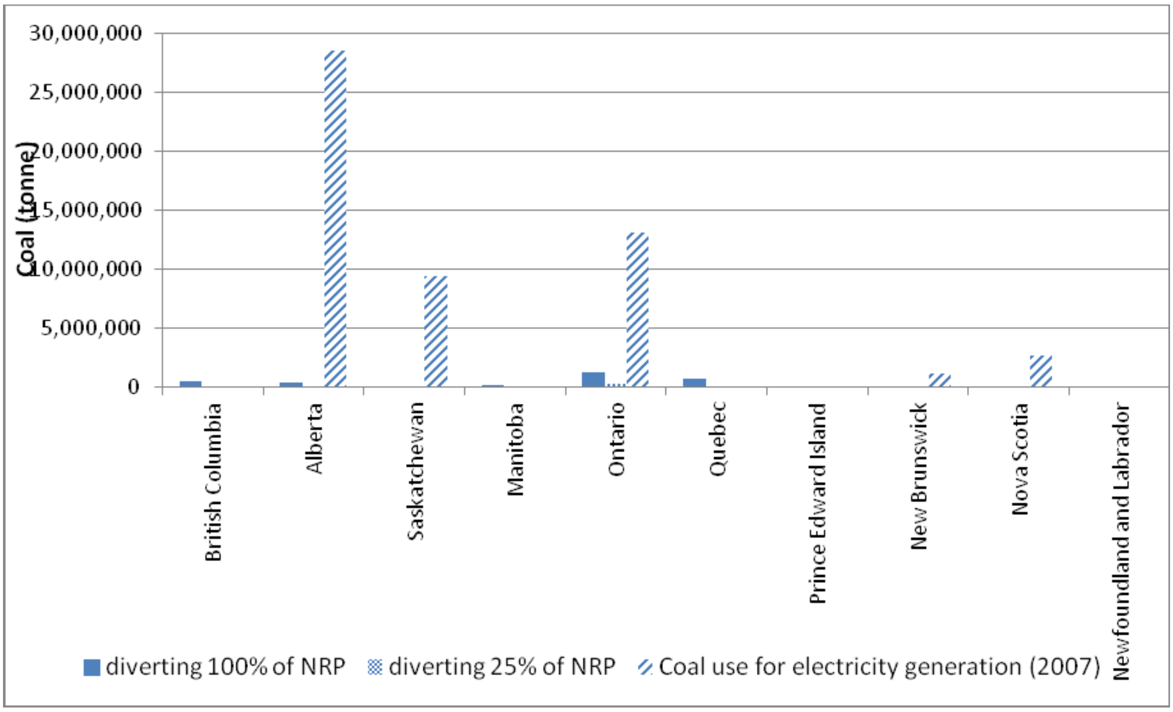


**Figure 7 Tonnes of coal replaced by diverting NRP from disposal and the amount of coal used for electricity generation in 2007**

Source: Kelleher Environmental, 2012, Statistics Canada, 2011, Statistics Canada, 2007b

According to the report prepared for the Cement Association of Canada (Nyboer and Bennett, 2012), the energy used for cement production in Canada that was derived from coal amounted to 24,701 TJ in 2010. In general, coal is the largest contributor in energy generation for the Canadian cement manufacturing industry and its share has risen from 41% in 1990 to 44% in 2010 (Nyboer and Bennett, 2012). Figure 8 compares the energy that could be diverted from the NRP with that derived from coal and used in cement production.

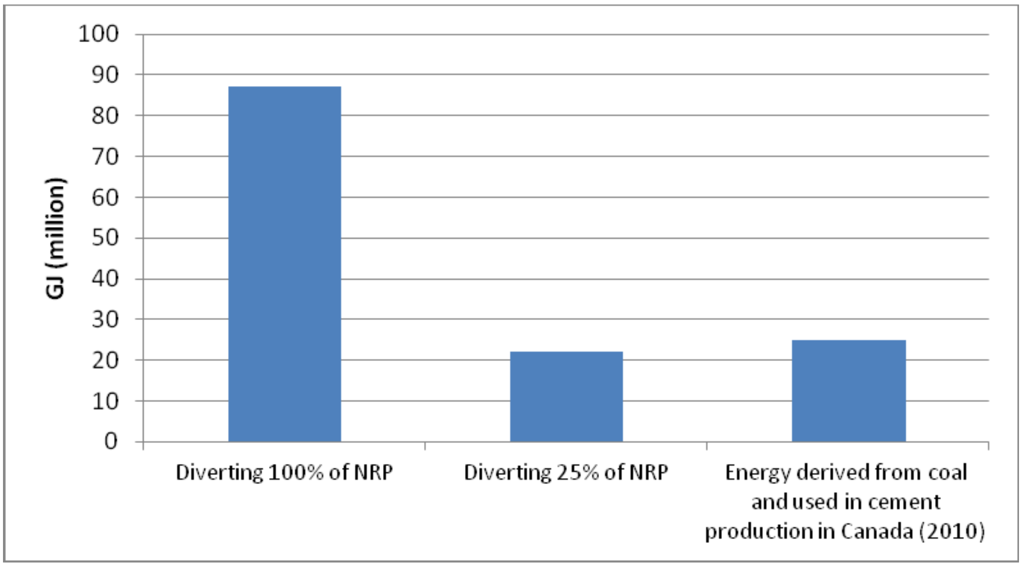


**Figure 8 Amount of energy derived in case of diverting 100% and 25% of NRP and the amount of energy derived from coal that is used in cement production in Canada (2010).**

Source: Kelleher Environmental, 2012; Nyboer and Bennett, 2012

## 5.3 Transforming of NRP to oil by means of pyrolysis

Non-recycled plastics can be converted into fuel oil by pyrolysis. Pyrolysis is the thermal treatment technology that takes place in the absence of oxygen and breaks down organic waste under the temperatures of about 400-600$^{o}$C. Oil derived from pyrolysis has a complex chemical composition but can be used as a fuel conveniently because of its higher energy density compared to solid waste (Williams, 2005). Figure 9 shows the potential of converting non-recycled plastics to synthetic oil for each province.

It is estimated that one ton of NRP can be converted to 3 barrels of oil by a fully industrialized pyrolysis process (Themelis et al., 2011). This is equivalent to 3.3 barrels of oil per 1 metric tonne. Consequently, the 2,801,529 tonnes of NRP that are disposed in Canada could produce 9,245,046 barrels of oil. Assuming a current price of USD 85.00/barrel, the economic value of 9,245,046 barrels of oil would be USD 785,828,910.

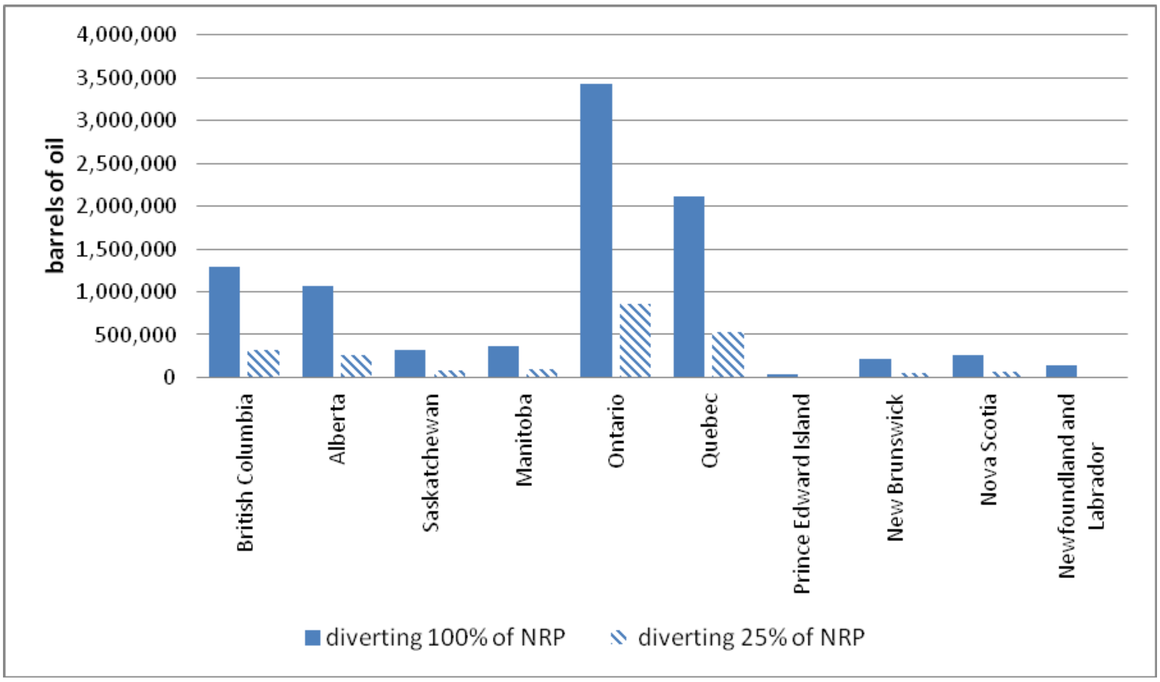


**Figure 9 Potential for synthetic oil production by pyrolysis of source separated NRP across Canada**

## 5.4 Potential of using source-separated NRP in dedicated power plants

Aside from pyrolysis, source-separated non-recycled plastics can be treated by combusting in waste-to energy (WTE) plants to produce electricity. Such waste-to-energy plants produce more than 0.66 MWh per tonne of solid waste (Themelis et al., 2011). The NRP has as much as three times higher calorific value (30.95MJ/kg) than regularly mixed solid waste stream. Consequently, if waste-to-energy plants were modified to combust exclusively NRP, they could generate a net of 1.98 MWh per tonne of NRP. Assuming that 100% of source-separated NRP is treated in a waste-to-energy plant, the net electricity produced would amount to 5,547,027 MWh which is 19,969,299 GJ. Based on Statistics Canada's (2007a) estimate of an average energy use per household of 40 GJ, 19,969,299 GJ is enough to supply 499,232 households with electricity.

Table 8 shows the amount of electricity that could be produced in each province, if the NRP would be combusted.

**Table 8 The amount of electricity produced if NRP is combusted and electricity used by households in each province, 2007**

| Province | Tons of NRP disposed (tonnes) | Electricity produced if NRP is combusted (MWh) | Electricity produced if NRP is combusted (Gj) | Total electricity use (2007) by households (GJ) |
|---|---|---|---|---|
| **British Columbia** | 391,931 | 776,023 | 2,793,684 | 62,442,000 |
| **Alberta** | 321,895 | 637,352 | 2,294,468 | 33,704,000 |
| **Saskatchewan** | 94,943 | 187,987 | 676,754 | 11,699,000 |
| **Manitoba** | 112,153 | 222,063 | 799,427 | 20,215,000 |
| **Ontario** | 1,040,363 | 2,059,919 | 7,415,707 | 154,995,000 |
| **Quebec** | 640,949 | 1,269,079 | 4,568,684 | 189,948,000 |
| **Prince Edward Island** | 12,085 | 23,928 | 86,142 | 1,667,000 |
| **New Brunswick** | 63,856 | 126,435 | 455,166 | 18,240,000 |
| **Nova Scotia** | 80,057 | 158,513 | 570,646 | 1,482,000 |
| **Newfoundland and Labrador** | 43,297 | 85,728 | 308,621 | 12,518,000 |
| **Canada** | 2,801,529 | 5,547,027 | 19,969,299 | 506,910,000 |

Source: The data on electricity use is from Statistics Canada, 2007a

Figure 10 shows the amount of electricity that can be produced by combusted 100% and 25% of the currently generated NRP.

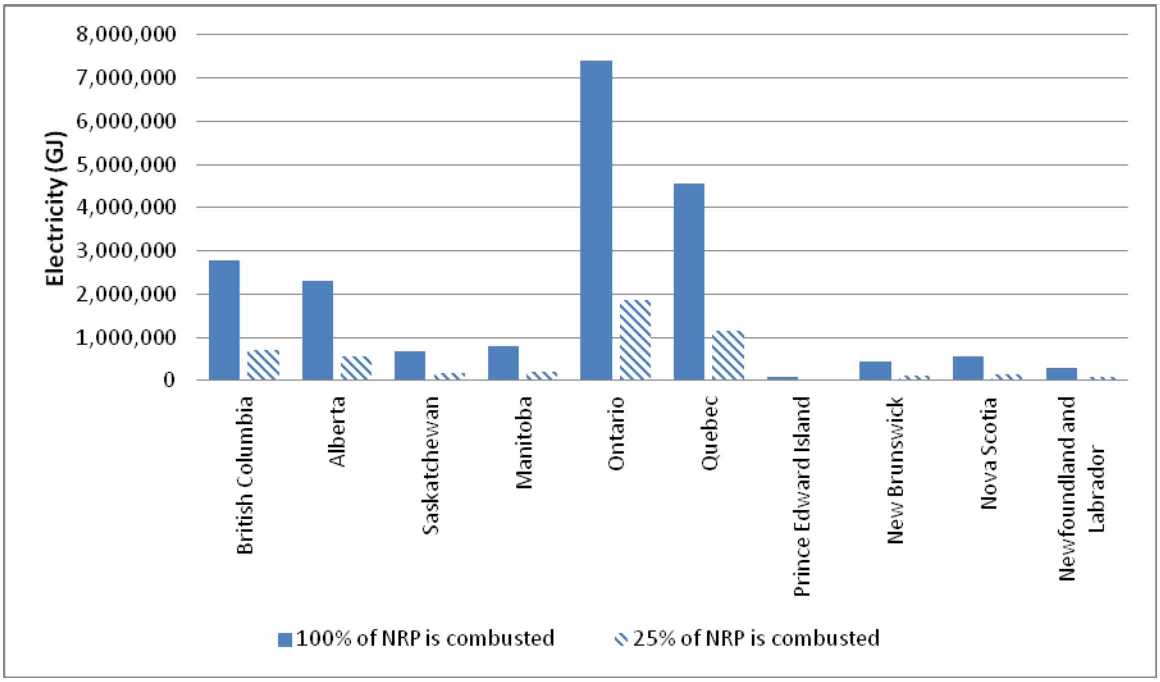


**Figure 10 Electricity production if 100% or 25% of NRP is combusted**

Note: Based on the aassumption that combustion of one tonne of NRP produces 1.98 MWh of electricity

## 5.5. Increased utilization of NRP by means of increased waste-to-energy capacity in Canada

In Canada, most of the generated solid waste is currently being landfilled and only a small share is treated thermally in waste-to-energy facilities. Although the data are not available on exactly how much NRP is sent to WTE plants, it can be assumed that at present the amount is negligible compared to landfilling. Energy recovery from plastics could be achieved by increasing the WTE capacity. This section discusses the implication of increasing WTE capacity and comparing the results in terms of displacement of coal.

Currently WTE facilities can produce a net of 0.6 MWh/ton from solid waste that can replace about 0.4 tons of coal (Themelis et al., 2011). The equivalent metric values are 0.66 MWh of energy produced by treating 1 tonne of combustible solid waste in WTE facilities, which is equivalent of 0.4 tonnes of coal. In metric units 1 tonne of combusted solid waste can produce 0.66 MWh energy that would replace about 0.4 tonnes of coal. Figure 11 shows the potential of replacing coal by diverting 100% and 25% of currently disposed combustible solid waste[2].

[2]In this report, "combustible solid waste" refers to the sum of residential and IC&I waste that can be sent for thermal treatment (e.g. non-combustible materials such as concrete, brick, etc. have been removed from the waste stream).

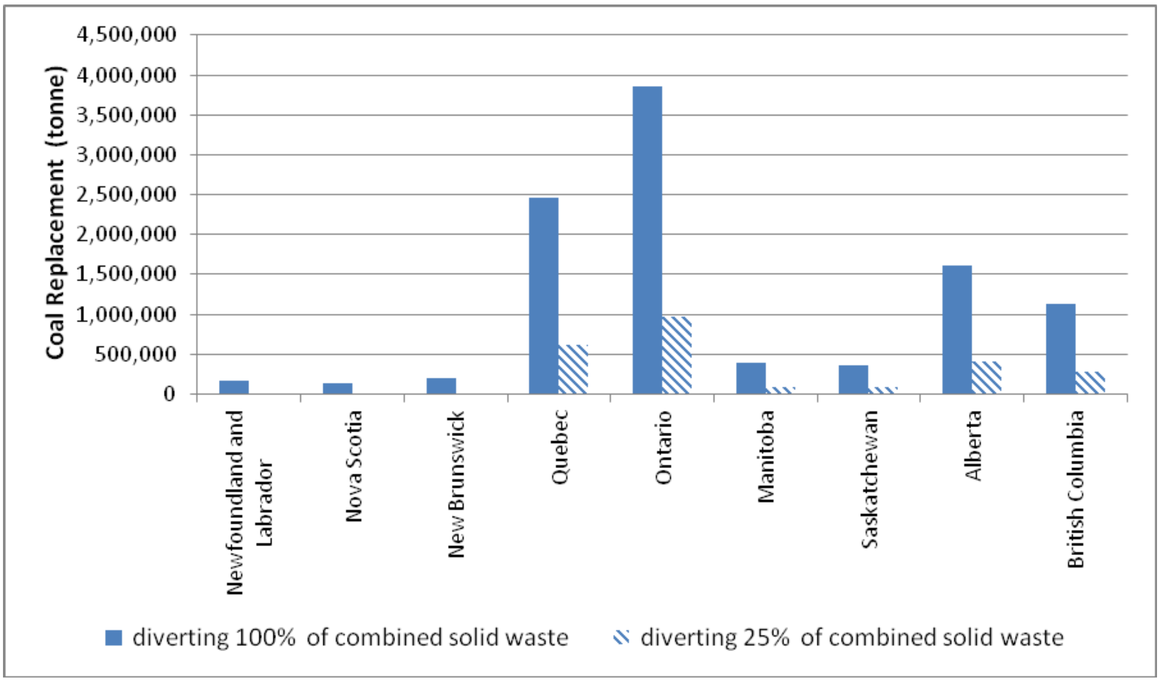


**Figure 11 Potential for replacing coal by diverting 100% and 25% of combustible solid waste from disposal to WTE**

Source: Statistics Canada, 2008

The replacement of coal by increased WTE capacity may prove particularly important for provinces that import significant amounts of coal.

## 5.6 Greenhouse gas (GHG) benefit of increasing WTE capacity

Solid waste has a heterogeneous composition and among other materials contains a percentage of organic materials. Once landfilled, organic materials decompose and produce methane gas. The production of methane gas continues even after the landfill closure. Methane is considered to be one of the Greenhouse gases that contribute to the global climate change. Therefore, increased WTE capacity will not only increase the energy recovery from plastics, but can also contribute to the reduction of the greenhouse gas (GHG) emissions. It is estimated that one tonne of solid waste diverted from landfill to a WTE reduces GHG emissions, depending on the degree of landfill gas capture, by 0.5 to 1 tonnes of carbon dioxide equivalent (Themelis et al., 2011 assumed that 1 ton of solid waste diverted from landfilling to WTE reduces GHG emissions by 0.5 to 1 ton of carbon dioxide equivalent). Figure 12 and Figure 13 show the amount GHG emissions that can be prevented by thermally treating 25% and 100% of currently landfilled combustible solid waste in each province.

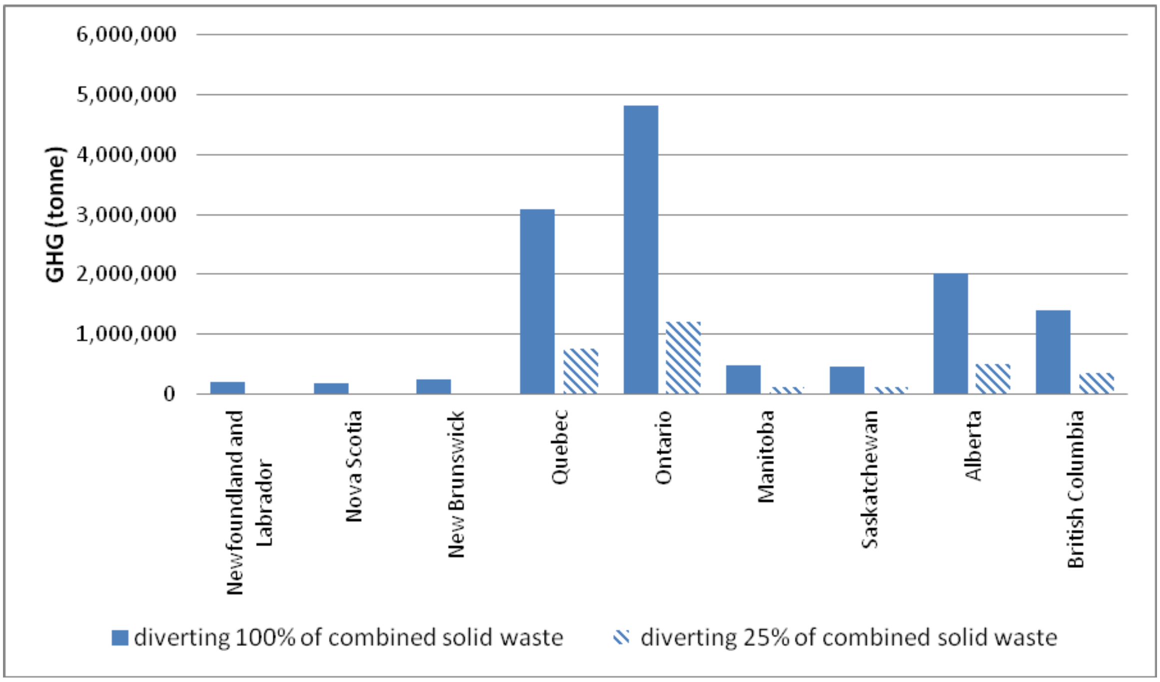


**Figure 12 GHG benefit of diverting 100% or 25% of combustible solid waste landfilled to WTE**

Note: with the estimation that 1 tonne of combustible solid waste can reduce 0.5 tonnes of carbon dioxide equivalent
Source: Statistics Canada, 2008, Kelleher Environmental, 2012

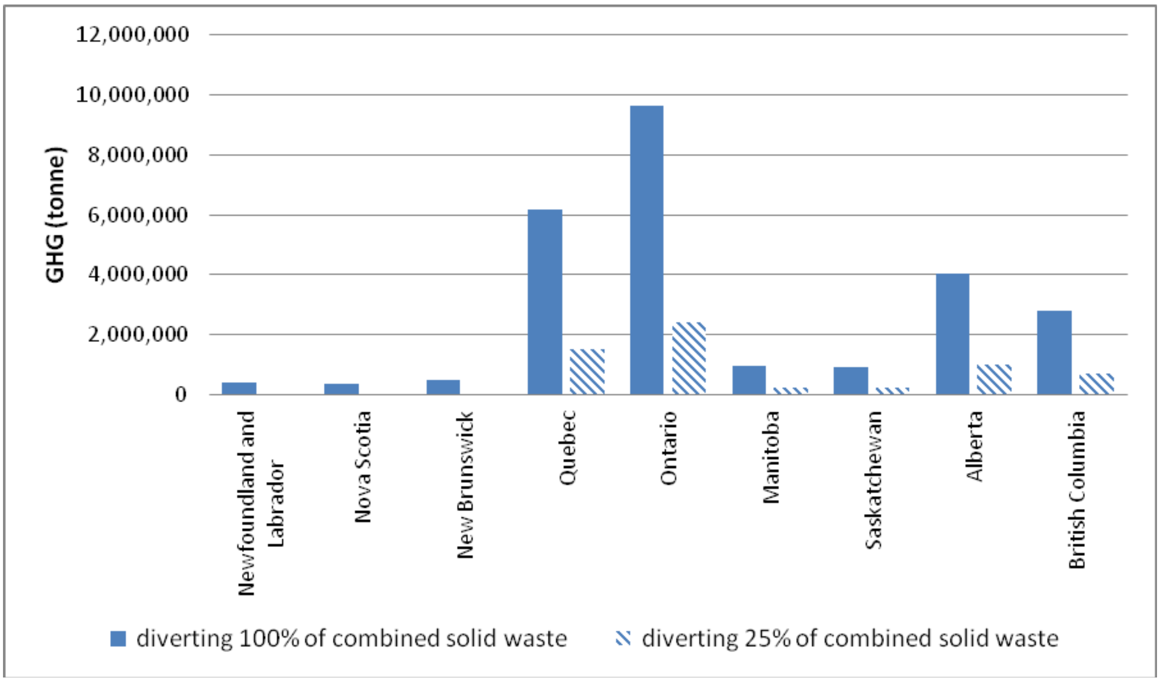


**Figure 13 GHG benefit of diverting 100% or 25% of combustible solid waste landfilled to WTE**

Note: with the estimation that 1 tonne of combustible solid waste can reduce 1 tonnes of carbon dioxide equivalent
Source: Statistics Canada, 2008, Kelleher Environmental, 2012

As new WTE facilities can produce 0.66MWh of electricity per tonne of solid waste combusted. Figure 14 shows the projected production of electricity in each province if 100% or 25% of solid wastes are diverted to a WTE facility. It is also estimated that the value of electricity generated through thermal treatment of waste is $100/MWh. The latter estimation is based on the fact that fossil fuel costs are currently rising and the solid waste can be considered as a source of renewable energy as more than half of the energy contained in solid waste is biogenic (Themelis et al., 2011).

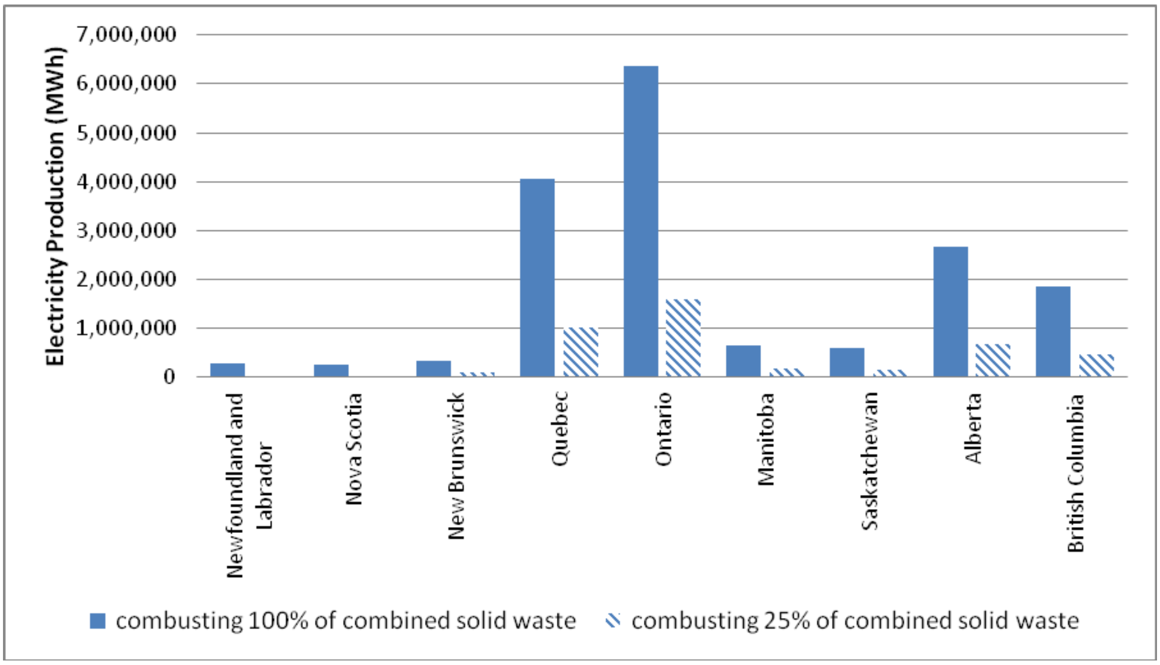


**Figure 14 Electricity production in case of diverting 100% and 25% of currently landfilled combustible solid waste to WTE facilities.**

Source: Statistics Canada, 2008, Kelleher Environmental, 2012

Figure 15 shows the economic value of the electricity that could be produced through combusting combustible solid waste in WTE facilities in each province. By combusting only 25% of the currently landfilled combustible solid waste, 4,247,783MWh of electricity can be generated annually throughout the country. Given that the average annual consumption of electricity in Canada is estimated to be 40Gj per household (Statistics Canada, 2007a), the above amount of electricity will be sufficient for 382,500 households. The value of this energy, assuming a price of $100/MWh, is close to 400 million US dollars. If all of the currently landfilled combustible solid waste was combusted in WTE facilities, it would generate, 16,991,130 MWh annually, an amount sufficient for use by 1,530,000 households.

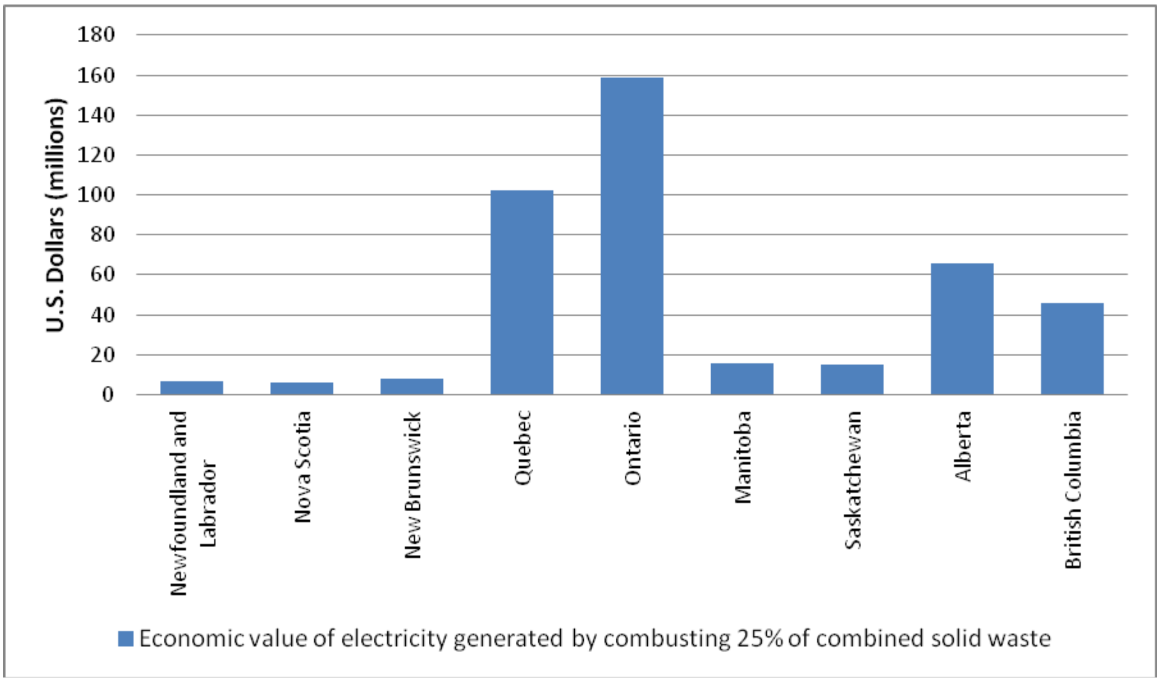

**Figure 15 Economic value of electricity generated by combusting 25% of currently landfilled combustible solid waste.**

Note: Assuming the price of generated electricity is 100 $/MWh.
Source: Statistics Canada, 2008, Kelleher Environmental, 2012

# 6. Conclusions

- The amount of non-recycled plastics (NRP) disposed in Canada was estimated at 2.8 million tonnes. The chemical energy contained in this material was more than 87 million GJ. This amount of energy is equivalent to:
    - 3.4 million tonnes of coal, or
    - 14 million barrels of oil, or
    - 79 billion cubic feet of natural gas.

- Hypothetically, if all the NRP that are currently disposed were source separated and converted by pyrolysis to a fuel oil, they would produce an estimated 9,245,046 barrels of oil per year (at 3.3 bbl/tonne) or enough to power more than 637,589 cars for one year.The economic value of 9,245,046 barrels of oil derived from NRP, at the current price of USD$ 85.00/barrel, is more than 786 million dollars.

- If all the NRP that are landfilled annually were to be source-separated and used as fuel in specially designed power plants, the electricity produced would be 20 million GJ, enough to supply 499,232 households with electricity. This would also reduce coal consumption by 681,453 tonnes (with the assumption that 1 tonne of coal equivalent produces 8.14 MWh energy).

- Hypothetically, if 100% of the total combustible solid waste stream, was diverted from disposal to new Waste-to-Energy (WTE) power plants, it would produce 61.2 million GJ of electricity, enough to power more than 1.5 million households for one year. (In this report, combustible solid waste refers to the total amount of residential and IC&I wastes that can be thermally treated, e.g. has been pre-treated by removing non-combustible materials such as glass, concrete, bricks, etc.)

- The study examined the effect of new WTE capacity on reducing coal consumption in provinces that now import coal. One tonne of combustible solid waste used as fuel in new WTE plants would produce the energy equivalent of about 0.4 tonnes of coal. Accordingly, 25% diversion of combustible solid waste currently landfilled to new WTE plants would avoid mining 2.6 million tonnes of coal; 100% diversion of current landfilling by means of new WTE capacity would reduce coal mining by 10.3 million tonnes.

- In 2010, the Canadian cement manufacturing industry used 25 million GJ of energy that was derived from coal. The diversion of the 25% of currently disposed plastics can produce 22 million GJ,that can mostly offset the coal use for energy generation in cement production industry in Canada. This would reduce coal consumption by 750,614 tonnes (with the assumption that 1 tonne of coal equivalent produces 8.14 MWh energy).

- Increased WTE capacity would reduce the carbon footprint of waste management in Canada. For example, a 25% diversion of combustible solid waste from landfilling to new WTE facilities will result in greenhouse gas (GHG) reduction of 3.2 to 6.4 million tonnes of carbon dioxide equivalent, depending on the degree of landfill gas capture in present landfills.

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