Methane Emissions through the Anaerobic Digestion of Organic Waste: Possible Courses of Action in Newfoundland and Labrador

Crystal-Lee Jones
SRM 4950
Grenfell Campus, Memorial University of Newfoundland

Introduction

Approximately 60 percent of global methane emissions are triggered by anthropogenic sources, in which a little above 20 percent can be traced back to waste emissions (Environment Canada, 2014). Compared to the average of 610 kilograms of waste in a study of 17 countries, Canada is considered to be the largest producer of municipal solid waste per capita globally with over 1000 kilograms of waste per year. Overall, Canada produces 35 million tonnes of waste a year in which 27 million tonnes is disposed into landfills (Hird *et al.,* 2014). Methane is the chief compound released through municipal solid waste through the anaerobic digestion of organic materials found in waste. Methane is considered to be more hazardous than carbon dioxide with an increased residence time in air as it captures and absorbs 25 times more infrared radiation than carbon dioxide (Govindan & Agamuthu, 2014). Methane is one of the foremost forces behind climate change, therefore it is imperative that it is appropriately managed to ensure the high quality of basic living needs such as clean air and water are met. If the amount of methane and other greenhouse gases emitted into the atmosphere from landfills are diminished, then it can serve as an excellent mitigation effort for climate change (Environment Canada, 2013).

There are numerous different reasons as to why landfills are hazardous to the environment. An assessment from Mukherjee et al. (2014) debates the diverse consequences that an increased quantity of methane and other leachates can have on the local environment. These negative consequences that often occur as a result of old and badly engineered landfills include: toxicity, carcinogenic effects, and genotoxicity in humans. Also, as previously stated, methane is the most potent greenhouse gas therefore has the ability to rapidly increase global warming in the near future.

A. Background

Solid waste management decisions are typically the responsibility of the municipal government, therefore forcing decision makers to determine the methodology behind local waste management. There are eight different regions across Newfoundland that are responsible for the implementation of waste diversion and recycling programs within their specific region. There are also four regions in Labrador that are responsible for these projects (Dillon Consulting, 2014). Each region is also expected to provide public education on the importance of the above programs in hopes to encourage residents to participate.

Newfoundland and Labrador has the highest amount of waste deposited at landfills originating from a residential source with 53 percent deposited in 2008 alone, while the Canadian average was approximately 33 percent. Overall, 30 percent of waste generated in the province is organic and could be potentially diverted (Dillon Consulting, 2014). The typical waste composition of a Canadian household can be seen in Figure 1 which shows that on average, 40 percent of waste is organic, 40 percent is bulky goods, 10 percent is recyclables, and 10 percent is composed of other waste (Environment Canada, 2013). It is vital that Newfoundland and Labrador take the necessary steps to reduce methane emissions throughout the province that are a result of municipal solid waste. The province has already made progress in recent years with the installation of a methane capture system at Robin Hood Bay, and the ongoing efforts of the Waste Management Strategy released in 2002. There is still a lot of work to be done within the province, and by researching other waste management practices in North America, a comprehensive management plan can be implemented to continue the provinces fight against methane emissions.

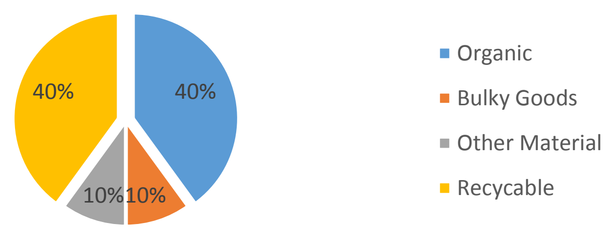
B. The Process of Anaerobic Digestion

Through the anaerobic digestion of organic waste, biogas and organic fertilizers can be produced from various sectors including municipal, industrial and agricultural.

By sealing the production of methane from anaerobic digestion from the surrounding environment, managers are able to seal the gas within the system, which will have countless environmental benefits. Anaerobic digestion occurs in multiple steps through a collection of metabolic reactions (Anjum, Mahmood, Khalid, & Arshad, 2011). The order of these steps are: (1) Hydrolysis, (2) Fermentation, (3) Acidogenesis, and (4) Methanogenesis (Anjum *et al*, 2011). During hydrolysis, extracellular enzymes simplify complex organic polymers into soluble molecules. Carbohydrates become sugars, proteins become amino acids and lipids become long-chain fatty acids. These simplified compounds then undergo fermentation in which fermentative bacteria convert the compounds to short chain volatile fatty acids and other small products such as acetic acid, hydrogen and carbon dioxide. Finally, the organic compounds are subjected to methanogenesis in which methanogenic bacteria that produce methane through the consumption of the acideogenic phase products (Li, Park, Zhu, 2011). The limitations associated with anaerobic digestion is in relation to the long retention time and the low efficiency associated with the reduction of organic waste. Although, with the appropriate pre-treatments in place the biodegradation rate may be increased (Anjum *et al*, 2011).

Co-digestion of organic waste is considered a method that can increase the yield associated with the anaerobic digestion of organic waste. Co-digestion is when numerous types of waste are mixed with one another. There are many benefits associated with this particular process including an increase in stabilization and digestion rate, the reduction in toxic compounds, a better balance of nutrients and there are higher yields associated with the production of biogas, amongst other benefits. According to Anjum *et al* (2011) a study found that co-digestion of municipal solid waste and industrial sludge had the largest produced yield of methane.

Figure 1: Typical Waste Composition of a Canadian Household



Through the research it will be determined which techniques will have the utmost efficiency in reducing the amount of methane released. Through analyzing data and estimating the efficiency of different management techniques such as waste diversion, composting, and methane capturers, I will show which combination will yield the best results. The purpose of this paper is to provide answers for my research questions which are as follows: (1) Which management techniques should Newfoundland & Labrador implement to decrease the amount of methane released from local landfills? (2) If practices are already implemented, are there any additional methods that can be established within Newfoundland & Labrador? Also, this paper will inform the public on different techniques individuals can do at home to reduce their personal methane emissions from waste. Education is key to decreasing methane emissions as household waste activities will make the difference in waste emissions in the future.

Methodology

When determining which waste management methods would be best for the reduction of methane emissions, an analysis was conducted consisting of data found from other studies to determine which management techniques had the better results. Information was obtained through a search of government reports and the use of Statistics Canada to obtain numerical data in relation to other provinces and territories in Canada. Also, information was obtained about the current state of waste management in Newfoundland and Labrador, and patterns were noted. Information was difficult to obtain via the internet, therefore contact with officials at Robin Hood Bay and Central Waste Facility occurred. Contact was attempted with MMSB but there was no response.

An analysis consisting of numerous calculations to view the impacts of a particular technique was shown and then related to the province of Newfoundland and Labrador. Information obtained consisted of the following: (1) The progress of the Waste Management Strategy that was released in 2002, (2) Disposal of solid waste at Robin Hood Bay within the past 5 years, (3) Methane emissions captured at the Robin Hood Bay facility since the landfill gas capture system was implemented, (4) Methane emissions generated in each province in 2012, (5) The percent of greenhouse gases that consisted of methane across Canada, (6) Percent difference in methane emissions once management methods improved across Canada, (7) Newfoundland and Labrador methane emissions compared to other provinces and territories, and (8) The percentage of Newfoundlanders and Labradorians that participate in composting activities of organic waste. When undertaking calculations, numerical values were obtained from other studies in which many used the Scholl Canyon Model to predict methane generation within their respected province or territory. I was unable to use the model for Newfoundland and Labrador as many important variables were missing.

A literature review of waste diversion activities was also conducted. The impact of these activities were noted to view how important it was in relation to reducing methane emissions. The progress of Newfoundland and Labrador waste management strategies were studied to see if an increase in efforts should occur, and to view local community efforts in waste diversion.

There was also a review of large-scale composting facilities that breaks down organic waste through aerobic digestion, along with landfill gas systems that captures gas released from the anaerobic digestion of organic waste to either convert to carbon dioxide to be released, or creates biogas to generate heat and electricity.

The final stage that occurred was conducting research on the effective ways to educate the public on waste management techniques that has the potential reduce methane emissions. Within this section there was a focus on waste diversion efforts, including composting at a residential scale and also on a community based scale.

3. Results

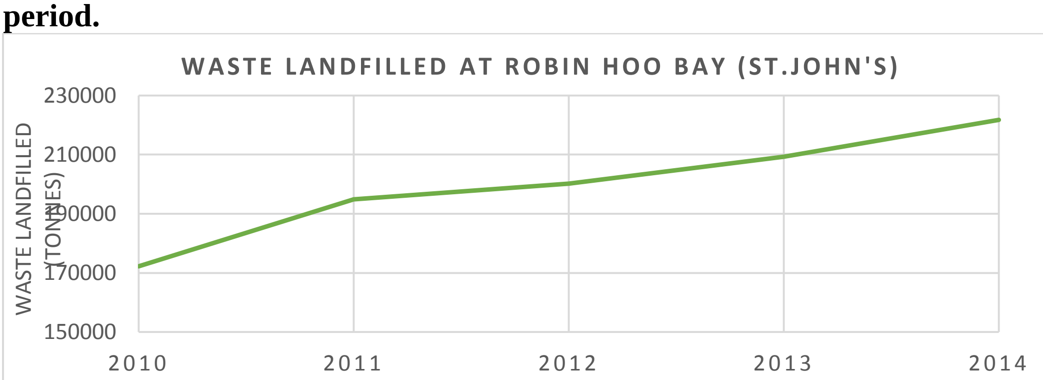
Currently there are 88 active landfills located in Newfoundland and Labrador, which have been reduced by 63 percent. There has also been a reduction of 63 percent in open burning and incineration sites. Currently, 65 percent of the population have access to a lined landfill, and 51 percent of the population have access to a material recovery facility (Government of Newfoundland & Labrador, 2014). Newfoundland has made improvements in the past decade, but there is always room for improvement. To see the complete progress of the Waste Management Strategy (2002) refer to Table 1.

The amount of municipal solid waste, excluding recyclables that has been landfilled at Robin Hood Bay is represented in Figure 2. The graph represents the increase in waste brought to landfills in the previous five years. In 2010 the total amount of waste landfilled was 172,251 tonnes, which represents the lowest amount over the five year time period. In 2011 there was a 13 percent increase in waste landfilled compared to 2010. In 2012 there was a 2.7 percent increase, 2013 a 4.6 percent increase, and in 2014 a 5.9 percent increase in waste landfilled compared to the previous year. The highest amount of waste landfilled was in 2014 with 221,751 tonnes landfilled (J. Murphy, personal communication, February 27th, 2015). Also, at the Central Waste Facility in Norris Arm, there were 46,000 tonnes of waste landfilled in 2014 which served a population of 70,000 individuals (30,500 homes) and 22,000 businesses (E.Evans, February 27th, 2015). The 2014 data for Central Waste Facility is not included in Figure 2.

Table 1: Progress of 2002 Waste Management Strategy in Newfoundland & Labrador as of 2012.

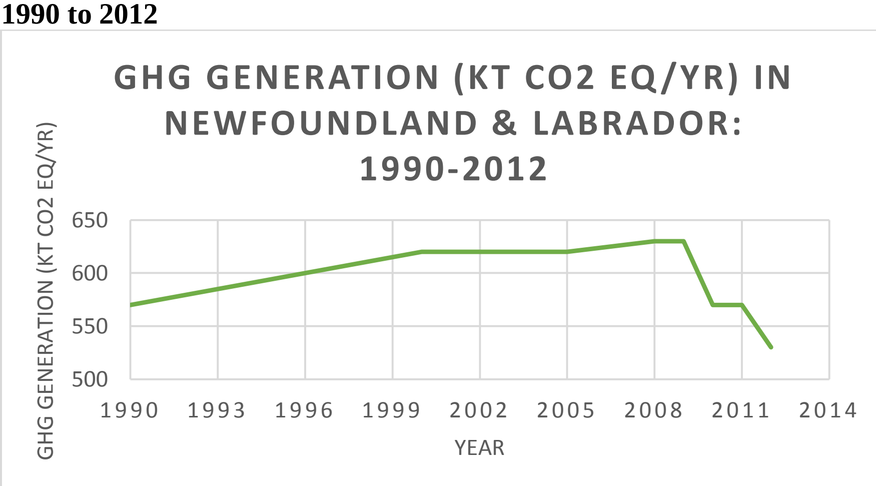
Goal	Indicator	Goal Measuremer	Baseline	Progress
50 % Waste Diversion	i) No. of Communities	591	0	153
	ii) No. of Regions	8	0	1
	iii) Population	100%	0	51%
	iv) Metric tonnes of Waste Diverted	473,000	33,000	137,913
	v) Percent of Waste Diverted	100%	7%	27.60%
80% Reduction in Disposal Sites	Total Disposal Sites	236	0	148
	No. Closed	100%	0%	63%
	Percent Closed	236	0	95
	No.Environmentally Closed	100%	0%	40%
	Percent Environmentally Closed			
Open Burning/ Incineration Closure	No. Eliminated	176	0	140
	Percent Eliminated	100%	0%	80%
Elimination of Unlined Landfills	No. Closed	216	0	133
	Percent Closed	100%	0%	62%
	No. Environmentally Closed	216	0	86
	Percent Environmentally Closed	100%	0%	40%
Access to Lined Landfills	No. of Communities	591	0	254
	No. of Regions	8	0	2
	Population	100%	0%	65%

Figure 2: The total amount of waste landfilled at Robin Hood Bay, St. John's over a 5 year period.



In Figure 3 the GHG generation from 1990 to 2012 is represented for the province of Newfoundland and Labrador. Each number is represented in kt CO_2 equivalent per year. The results do not show a specific pattern of steady increase or decrease to represent all years. Over a decade long period from 1990 to 2000, the GHG generation did increase by 50 kt CO_2 eq/yr from 570 kt CO_2 eq/yr to 620 kt CO_2 eq/yr in 2000. From 2000 to 2005 there was a 30 kt CO_2 eq/yr increase, and a 10 kt CO_2 eq/yr increase between 2005 and 2008. During the following year there was not an increase in GHG generation in Newfoundland and Labrador, but in 2010 there was a 60 CO_2 eq/yr decrease. In 2011 the GHG generated remained the same as 2010, but in 2012 it once again decreased by 30 kt CO_2 eq/yr (Government of Newfoundland and Labrador, 2014).

Figure 3: Greenhouse Gas generation (kt CO_2 Eq/yr) in Newfoundland and Labrador from 1990 to 2012



In Table 2**,** there were multiple calculations carried out including methane (in kilotonnes and the percentage) and greenhouse gas generation from solid waste, and the percent of methane generated per province in 2012. British Colombia has the highest percent of methane generated from organic waste than any other province at 96.9 percent of greenhouse generation, while the lowest was in Nunavut and the Yukon at 52.5 percent. Newfoundland and Labrador was one of the top provinces with the highest amount of methane generated from organic waste at 95.5 percent. With the exception of Prince Edward Island (PEI) and Nova Scotia, at 80.2 and 84 percent respectively, all provinces generated over 90 percent of methane from organic waste. Overall, the amount of methane generated in Canada from the anaerobic digestion of organic waste in 2002 was 900 kilotonnes. The province that contributed the majority of the methane is Ontario, followed by British Colombia and Quebec. Newfoundland and Labrador contributed 2.2 percent of the overall methane, while the territories contributed less than 1 percent. Robin Hood Bay estimated that the amount of methane destroyed at the landfill gas flare was approximately 3,023,348 cubic meters in 2013 and 2,655,095 cubic meters in 2014 (J.Murphy, personal communication, February 27th, 2015).

Table 2: Methane generation in kt and kt CO2 eq/yr, and the percent of methane from solid waste in all provinces and territories in Canada in 2012.

Location	CH4 Generation (kt)	GHG Generation (kt CO2 eq/yr)	Overall CH4 Generation from Waste (kt CO2 eq/yr)	Percent (%) of GHG that is CH4 from MSW	Percent (%) of CH4 Generated per Province
NL	25	525	550	95.5	2.2
NS	18	378	450	84.0	2.0
NB	20	420	450	93.3	2.2
PEI	4.2	88	110	80.2	0.5
QB	180	3780	4300	87.9	20.0
ON	330	6930	7500	92.4	36.7
MB	42	882	920	95.9	4.7
SK	34	714	750	95.2	3.8
AB	71	1491	1600	93.2	7.9
BC	180	3780	3900	96.9	20.0
YT	0.08	1.7	3.2	52.5	0.0
NWT	0.14	2.9	5.5	53.5	0.0
NU	0.11	2.3	4.4	52.5	0.0
Canada	900	18900	21000	90.0	

When comparing the amount of methane generated and the amount of methane that is released into the atmosphere before and after the implementation of a Landfill Gas (LFG) Capturer, the highest percent difference was in Quebec with a 30.7 percent decrease in methane emissions. Quebec has 12 LFG capture projects in place as of 2005. Ontario follows Quebec with 19 LFG projects with a decrease of 27.1 percent. Newfoundland and Labrador, PEI, New

Brunswick, Manitoba, Saskatchewan, and the three territories did not have any LFG projects in place as of 2005. Robin Hood Bay did acquire one in 2013 for the Avalon region of Newfoundland. For the remainder of the provinces and percent differences in methane emissions, refer to Table 3 (J.Murphy, personal communication, February 27th, 2015).

Table 3: Percent (%) Difference in methane emissions in Canadian provinces that have implemented LFG projects to capture methane.

Province	Number of LFG Projects	Percent (%) Difference in Methane Emissions
NL	0	0.0
PEI	0	0.0
NS	1	13.6
NB	0	0.0
QC	12	30.7
ON	19	27.1
MB	0	0.0
SK	0	0.0
AB	2	5.2
BC	13	14.7
NWT	0	0.0
NU	N/A	N/A
YK	0	0.0
Canada	47	21.3

Results located in Table 4 show that composting behavior has been increasing across Canada, with 45 percent of households composting kitchen waste and 68 percent of households composting yard waste such as grass and leaves. The two provinces with the highest rate of composting for kitchen and/or yard waste were PEI and Nova Scotia with 96 percent and 94 percent respectively. The lowest percentage of composting was in Newfoundland and Labrador and Quebec with 43 percent and 42 percent respectively. Kitchen waste was recycled by 27 percent of residents in Newfoundland and Labrador, while 41 percent of residents composted yard waste. The overall average of Canadians composting yard or kitchen waste was 61 percent, with 45 percent composting kitchen waste and 68 percent composting yard waste. The survey also showed that there was a positive correlation between income and education level and the participation in composting activities. There was also a positive correlation between single dwelling households with yard space with composting, while residents living in apartments were less likely to participate in composting (Mustapna, 2013).

Table 4: The participation of households from each province in composting of kitchen and yard waste (2013)

Province	Kitchen/Yard Waste	Kitchen Waste (%)	Yard Waste (%)
NL	43	27	41
PEI	96	95	69
NS	94	92	76
NB	58	43	53
QB	42	25	51
ON	75	62	82
MB	56	27	67
SK	47	28	53
AB	56	30	59
BC	64	41	77
Canada	61	45	68

Discussion

In 2002, the Government of Newfoundland and Labrador released the Waste Management Strategy which consisted of the following four primary goals: (1) Waste diversion rate of 50 percent, (2) 80 percent reduction in the number of waste disposal sites, (3) Elimination of open burning and incineration, and (4) phase out unlined landfills. The government hoped to achieve each target by 2020. At current rate of progress I expect that all goals will not be met, specifically the diversion rate of 50 percent unless new diversion programs are implemented in the near future. The province is currently discussing ways in which they can process organic waste, including a pilot project on a waste-to-energy facility, and also a large scale composter (Government of Newfoundland & Labrador, 2002).

1. <u>Estimation Models for Methane</u>

There are several models available that can be used to estimate methane emissions released from landfills. Numerous models use a Life Cycle Assessment (LCA) to calculate the amount of methane released, while others use different mathematical models to calculate methane emissions. An example of a study that used the LCA model to estimate methane emissions was conducted by Starostina et al., (2014) to determine the environmental performance of the Alexandrovsky landfill located in the Irkutsk Region of Russia. Through the use of LCA the authors were able to determine the amount of methane that is generated through the anaerobic digestion of organic waste at different points of its life.

Mathematical models used to calculate estimated methane emissions normally consist of data in relation to moisture content, temperature, the availability of nutrients, waste density, particle size and also the buffer capacity. Each mentioned variable has an impact on the amount of methane that is generated from a landfill. For anaerobic digestion to occur, there is a need for the presence of water within the waste. Therefore, depending on the amount of water available will determine the amount of methane generated. The amount of methane generated and released not only depends on methogenic potential but also other landfill conditions. The methogenic potential can be explained through the example of wet food waste versus woody biomass. The wet food waste will produce a higher methane yield per tonne due to the high moisture content. Temperature is also an important variable for the process of anaerobic digestion as it is considered an exothermic process. As temperature increases the rate of bacteria also increases until it reaches a peak point. If temperatures tend to vary, then the microbial activity will be impacted and decomposition may decrease, affecting the amount of methane released. Furthermore, for anaerobic digestion to occur there must be hydrogen, carbon, nitrogen and phosphorus present in the organic waste composition. There will be an increase in the quantity of methane generated depending on the density and particle size of the organic waste. Production will increase when there is a larger surface area, and this occurs when particles are decreasing in size. Depending on how dense the waste is within a landfill, it will influence the production of methane as the higher the density the higher the difficulty for moisture and nutrient transport. The final variable involved in the production of methane emissions is the pH of the waste. If the pH is too acidic then methane will not be produced, so it is important to have a neutral pH if methane is being generated for energy purposes (Government of Canada, 2014).

An example of a mathematical model used to estimate methane emissions was the Scholl Canyon model which was used in calculations for the “Inventory of Landfill Gas Recovery and Utilization in Canada” (2012) report. The report mentions that their calculations were a result of using the Scholl Canyon Model and then subtracting the amount of methane captured by landfill gas capture systems to determine the amount of methane that would actually be released into the atmosphere. This model is considered to be the best option as it takes into consideration population growth in the future. This process will occur for multiple decades until the quantity of methane produced gradually declines. When estimating methane emissions for the future, it is important to consider not only waste disposed in previous decades but also the waste present today as it will eventually produce methane. Normally when calculating future methane emissions researchers will use the "methane commitment" method, while previously disposed waste will be estimated using the "waste-in-place" method. Both methods use a first order exponential decay function which uses the ultimate methagenic potential of different types of organic waste and also the quantity of each type of organic waste. The "methane commitment" method base their estimations on waste that is currently being disposed of and the sum of the timeframe that the estimates are based upon (ICF International, 2007). The “waste-in-place" method estimates the types and quantities of the waste that is landfilled, while the. The above methods uses a constant which represents the time of the decay function which is related to landfill conditions.

Unfortunately most of the above variables were not available for my research so I based my calculations on estimates calculated by others to determine the carbon dioxide equivalent of methane within each province. Also, some data may be inaccurate as it is normally based on the amount of waste that is disposed in a landfill, but the amount of waste landfilled may be inaccurate due to no weight scales or by calculating waste based on the population of a location (Government of Canada, 2008).

When calculating the percent of methane generated for each province the variance of percentages can be attributed to population. This can explain why Newfoundland and Labrador represents only 2.2 percent of the overall greenhouse gas emissions from waste in Canada, versus Ontario which represents 36.7 percent even though they divert 64 percent of waste compared to Newfoundland’s 28 percent diversion rate. Newfoundland has a much smaller population size compared to Ontario, therefore Newfoundland contributes less greenhouse gas to the atmosphere compared to other provinces, but emit more greenhouse gases on a per capita basis.

2. <u>Waste Diversion</u>

Approximately 50 percent of human food is discarded into landfills which contributes an additional 6 million tonnes of waste each year (Curry *et al*, 2011). With an estimate of approximately 30 percent of waste generated in Newfoundland and Labrador consisting of organic waste, it is important that diversion efforts are increased in the future. Currently, Newfoundland and Labrador has a diversion rate of 28 percent with a target of 50 percent diversion rate by 2020 (Government of Newfoundland & Labrador, 2002). The importance of diverting organic waste for methane emissions is due to the fact that when anaerobic digestion breaks down organic waste, it results in methane being released into the atmosphere. By diverting one tonne of organic waste greenhouse gas emissions can be reduced by one tonne of CO_2 equivalent in comparison to landfilling (Environment Canada, 2013). Therefore, if organic waste is diverted then it will not reach landfills located in Newfoundland and waste managers can deal with the organic waste in an appropriate manner. The reduction in methane and other greenhouse gases are not the only benefits of waste diversion, it also means that less space is used in the landfill. This is especially important because of the following reasons: (1) The lifespan of the landfill is extended which has both environmental and economic benefits, and (2) As urban areas increase in size the competition for land increases and it becomes more difficult to find a suitable site for a landfill (Nuss *et al.*, 2012).

When implementing waste diversion activities across Newfoundland and Labrador, modifications to the existing practices will have to occur. Collection will require the possibility of additional fleets, and residents would need to separate their waste by different classes of waste. For example, organic waste would have to be disposed separately from other types of waste such as recyclables and bulky items in either coloured bags or in separate bins. The modifications in collection practices pose one of the main limitations to waste diversion. The cost of waste collection accounts for about 80 percent of operational costs so additional fleets would result in an increase cost for collection (Yoshida *et al.*, 2012). Also, residents argue against the idea of having to purchase additional coloured garbage bags due to the cost with many arguing that they cannot afford to purchase the supplies needed for residential waste diversion. In order to successfully increase waste diversion within Newfoundland and Labrador there are four pieces of criteria for success: (1) Partnerships and collaborations, (2) Convenient options, (3) Policy and legislation, and (4) Education and promotion (FCM, 2009).

Other provinces successfully implemented strict waste diversion methods on residents through economic instruments and consumer education to encourage a zero waste community. An example of an economic instrument would be the Pay-As-You-Throw (PAYT) method which makes residents pay a fee based on the volume of their waste, while other provinces may use fines to punish individuals who dispose of waste that is contaminated by not being separated based on the source. Municipalities have also been encouraging waste diversion through bylaws that recommend to purchase products with minimum packaging as well as reusing products (FCM, 2009).

One of the leading cities in Canada for waste diversion would be Toronto, Ontario. The City of Toronto was one of the first cities to have an anaerobic digestion facility in all of North America. The Dufferin Organics Processing Facility processes diverted organic waste from curbside collection for a total of 500,000 households. The waste diversion program is successful due to the cities high diversion goal of 70 percent in which they have succeeded, diverting 64 percent of waste in 2011. Due to the success of the first anaerobic digestion facility a second one was constructed in 2012 (Pagnotta, 2012).

Once residents and businesses separate their waste by source it can be sent to waste facilities and undergo sustainable technologies to avoid landfilling. A couple of these technological processes include: (I) undergoing anaerobic digestion with resultant gases being transformed into carbon dioxide, (II) converted into energy, or (III) undergo aerobic digestion in a large scale composting facility.

I. Landfill Gas Capture System

When organic waste is landfilled, multiple gases are released which can have hazardous impacts on the local environment. As previously noted, methane is the most potent greenhouse gas released from landfills through the process of anaerobic digestion. The composition of landfill gas is typically 55 to 65 percent methane, 35 to 45 percent carbon dioxide and small traces of other gases. Depending on the composition of the waste the concentration of methane in landfill gas can vary. The purpose of a landfill gas capturing system is to minimize the amount of methane released into the atmosphere by capturing the methane gas, which then undergoes flaring to be transformed into carbon dioxide. The carbon dioxide is then released into the atmosphere as it is less potent than methane. In waste management, methane is considered a greenhouse gas while carbon dioxide is recognized as being a part of the natural carbon life cycle (Golder Associates Ltd., 2008). Numerous provinces have landfill gas capture systems implemented in their province with a total of 81 systems across Canada in 2012. In 2013 the Robin Hood Bay facility implemented a landfill gas capturing system to aid in the reduction of methane emissions. Unfortunately, there are no estimates for the amount of methane released from the landfill before the system was implemented. Because of this, there is no baseline to compare the system that allows us to discover the percent reduction in emissions. The effectiveness was thereby calculated by studying the percent difference in methane emissions in other provinces after a capturing system was put into place. The estimates in percent differences were taken from data collected in 2005 as there was no recent information to be obtained. The results showed that Quebec had the greatest decrease in methane emissions but this can be explained by the number of landfill gas systems that were present within the province. There were 12 systems in total that were implemented within the province. While other provinces either had no systems in place, others have only one or two in place. An estimate in the reduction of methane emissions through one system can be shown through the data obtained from Nova Scotia, which only had one system in 2005 when the data was collected that showed a 14 percent decrease (Statistics Canada, 2005). Therefore I can assume that methane emissions at Robin Hood Bay in St. John's have decreased by approximately 14 percent with the implementation of a methane capturer, assuming that the system is similar to the original in Nova Scotia. Through the data it was also shown that the number of systems in place did not necessarily have an impact on the percent difference in emissions as some landfill gas capture systems are more effective than others. This can be shown by Ontario only having a 27 percent decrease in methane emissions with 19 systems in place versus the 30 percent decrease in emissions in Quebec with only 12 systems in place. The effectiveness can depend on the type of system that is implemented and the waste composition of a landfill.

The main limitation to a landfill gas capture system is that they are not 100 percent efficient so there will always be methane released from landfills despite improvements in recovery technology emissions still remaining relatively high (Sanscartier *et al.,* 2012). Due to this limitation, waste diversion is imperative to controlling the amount of methane that is released into the atmosphere from landfills.

The Central Waste Facility opened in 2014 so there is no need for a methane capturer to be implemented at the present time as no methane is generated in such a short time span. In the future, the option of implementing a methane capture system will be considered (Evans, personal communication, February 27th, 2015).

II. Waste-to-Energy

Landfill gas recovery systems can also be used to capture greenhouse gases to be transformed into energy that can be used to heat or provide power for other buildings on site, with excess power being sold back to the grid. The biogas produced from organic waste can also be converted into fuels which has the potential to power vehicles and machinery. Waste is converted to energy through anaerobic digestion. Once biogas is released, carbon dioxide and other trace gases are removed that can be used to produce low-carbon electricity in a generator. The digestate that remains is dewatered and treated in an anaerobic composter. Upon drying, the remaining bio char can be used as a high quality fertilizer and remaining residues are landfilled (Pagnotta, 2012). Nuss et al., (2012) discussed the need to move away from the acquisition of raw materials and towards using waste as a means to produce materials. They discuss that waste containing carbon should have all of its energy recovered as well as carbon to be recycled. The use of waste to provide polymers and chemical feedstock will lower our dependence on fossil fuel in the future, which in return would be mitigating the effects of climate change. The management of methane can also decrease the rate of climate change in the near future due to its short atmospheric life of 10 years compared to carbon dioxides atmospheric life, which can last for several centuries (Environment Canada, 2013). These methods can be implemented worldwide through different technologies such as biochemical or thermochemical converters. The reduction in greenhouse gases is not the only benefit to converting waste to energy but once the system is implemented it can generate additional revenue for the facility while also saving on costs in relation to energy needed for operations (Environment Canada, 2013). The construction of biogas plants worldwide have been drastically increasing with an estimated 20 to 30 percent increase each year. Leading countries include Austria, Germany and Denmark, with Germany having 3700 plants in 2007. Other areas of the world have also began to convert waste to energy but not to the extent of Germany due to the high costs associated with the construction of a biogas power plant (Curry *et al.,* 2011).

It is important to note that different types of organic material will produce biogas of differing quality known as the biogas yield. For example, biogas that is produced from high cellulose materials (e.g. leaves, paper, grass, etc.) tend to be of lower quality than biogas produced from food waste (Environment Canada, 2013). Another factor to consider is the type of bioreactor design that would be used at your local waste management facility. There are three popular designs that are normally used, which are batch reactors, a one stage continuously fed system and also a two stage continuously fed system. Batch reactors are the simplest design in which the bioreactor is filled with feedstock and is left there for a long period of time, known as the hydraulic retention time and then emptied. This type of bioreactor has a low cost compared to others but also produces a lower quality biogas. The one stage continuously fed design is similar and also has these same limitations. The two stage continuously fed system would be the best option. Within this system there are numerous biochemical processes occurring such as acidification, hydrolysis, acetogenesis and methanogenesis that all occur in separate areas. This type of system produces a higher quality biogas and also has higher yields. Through this system the organic molecules are degraded to allow the metabolization of methane to occur easily. Also, there is an increase in stabilization compared to other systems through the process of acidification as it aids in the prevention of toxic buildup and overloading. The main concern with the two stage continuously fed system is the high cost associated with the system (Anjum *et al.,* 2011). Also, it is imperative that you monitor the pH of the system as there is a possibility of the pH dropping near the beginning of the anaerobic process, which can limit the amount of methane produced. If the concentration of ammonia is high within the system then it has the potential to be of harm to the microbes and may increase bacteria growth (Zhang *et al.*, 2014). It has been shown in the past that co-digestion may be the solution to this particular problem as the co-digestion of carbohydrate rich waste with other types of waste in the two stage system can prove to be effective in reducing the chance of ammonia being produced (Li *et al.*, 2011).

III. Composting

Composting is an aerobic process in which microorganisms decompose organic material and transforms the material into a healthy soil supplement that can support plants without any phytotoxic effects. Varma & Kalamdhad (2014) studies whether composting organic waste would benefit the environment due to less waste being disposed into landfills. By composting nutrient rich organics (e.g. vegetables), the soil will become more nutrient rich, and there will be a lower amount of leachate contaminating surrounding soils in landfills while decreasing the quantity of emissions released from the waste. Composting is carefully planned, with the waste being layered in an order that increases the healthiness of the soil. Composting can be done at both large-scale (e.g., schools and communities) or small-scale (e.g., households).

Composting is an excellent method of reducing methane emissions in Newfoundland and Labrador that has numerous benefits. These include environmental, economic and social benefits. One of the main environmental benefits occurs when it is applied to soil, as it increases the productivity of the soil through improving drainage and it also allows better root penetration which makes plants more stable. Composting organic waste also minimizes the risk of soil-borne disease organisms which also allows plants to remain stable. Other benefits include the reduction in topsoil loss, controlling erosion, and it can also be combined in a methane oxidation system to aid in the treatment of landfill gas emissions. Compost can also be used to revitalize species habitats, reforestation and also to restore wetlands (Environment Canada, 2013).

Economic benefits of composting can include costs associated with methane emissions, allowing a landfill to have an increased life span, employment opportunities for not only the construction phase of the facility but also individuals to operate and to maintain the facility, and can also decrease the costs associated with the use of fertilizers as it is a natural supplement. Other employment opportunities can involve public education and training workshops. Also, revenue can be generated through the sale of compost as a fertilizer. Management costs will also be reduced associated with leachate since there will be less moisture entering a landfill (Environment Canada, 2013).

A social benefit of composting would be protecting human health through the protection of the environments health, for example through the reduction of greenhouse gas emissions released into the atmosphere thus increasing air quality. Also, safety is increased for employees at the waste facility as there is a small risk of explosion if methane accumulates underground, surrounding nearby buildings that are in close proximity to the landfill site. Landfills can also be an irritant to surrounding residents as it can generate a bad odour that can be reduced through a composting facility as the odour associated with rotting organic waste will be removed. Finally, by selling compost as fertilizer the agricultural industry can be sustained for the future (Environment Canada, 2013).

The implementation of a large-scale composting facility does have its limitations. One of the main limitations is the associated costs with constructing a composting facility and also costs associated with the transporting of organic waste. Often times it can be difficult to work these extra costs into the waste management budget. It is also difficult to choose the most efficient technology as you need to consider the specific site in which it will be located (Pagnotta, 2012). For example, if a large-scale composting facility was to be located in Newfoundland and Labrador it would likely be located at the Robin Hood Bay facility as it serves the largest proportion of the population. Therefore the technology would have to be suited to that specific location. It is also important that all regulatory requirements are met and that everything is legally and safely done. Finally, just because a composting facility is constructed does not mean that a composting program will be successful within the province. It is extremely important that the surrounding communities get on board with the idea and participate in the composting of their organic materials (Cole *et al.*, 2014). There were various reasons as to why residents did not participate in composting initiatives in Canada. Reasons included not having access to a compost program, not having the proper bins, being too time consuming, using up too much space, inconvenient, collection not occurring enough, and the risk of wildlife being attracted to compost bin. Residents also mentioned they never participated due to not being informed on what materials can and cannot be composted (Mustapha, 2013).

IV. <u>Education and Community Involvement</u>

To ensure that methane emissions are reduced in the future it is detrimental that the public becomes involved and participates in the implementation of various waste management programs that may occur in the future. It is imperative that the public has proper education on each type of management program so that they can learn how they can get involved and also gain knowledge on activities they can perform at a household level that can reduce methane emissions (Hird *et al.*, 2014). Residents can decrease the amount of waste that they personally send to landfills by composting food waste and yard waste. It is quite clear that Newfoundland and Labrador needs to increase educational programs as the province was ranked second last in the participation of composting activities with only Quebec having a lower percentage of participation (Statistics Canada, 2013). Providing education can aid in the change of behavior amongst residents through the encouragement of non-composters. Social marketing can also alter the behavior of residents by continuously showing the benefits of diverting or composting their organic waste through different media outlets such as television, radio, and social media (Cole *et al.*, 2014).

Through the survey on the percentage of residents who compost kitchen and yard waste in Canada, one of the main reasons as to why individuals did not participate in composting activities was due to not having the knowledge on what can and cannot be composted. These individuals would be more likely to compost kitchen and yard waste if they were more educated on the process of composting. Also, education level was related to the number of residents who composted at home. The higher the education the more likely the individual was to participate in composting activities at a household levels. Individuals who were highly educated tended to know more about the benefits of composting therefore if education was provided to individuals with lower levels of education then the number of residents who compost would be expected to increase in the future (Mustapha, 2013).

Educating youth on waste management and impacts that waste can have on the environment is detrimental for the future sustainability of the province of Newfoundland and Labrador as youth are the future of the province. MMSB are responsible for creating and implementing educational programs in Newfoundland and Labrador. Their website has a variety of educational tools that can be used to provide education on various aspects of waste management. For example, there is a section specifically for backyard composting and how it can be done. Furthermore, MMSB has a number of events available to schools across the province including “Compost Awareness

Week" and "Waste Reduction Week". The board also has a list of possible activities that schools can implement such as environmental clubs, waste audits, schoolyard composting, classroom vermicomposting and also waste reduction initiative that can be implemented in cafeterias. There are also guidelines published on their website, along with demonstrations and workshops.

MMSB also encourages schools to become sustainable through giving environmental awards to schools and also by recognizing on their website which schools across the province are participating in sustainable activities. Currently in Newfoundland and Labrador there are three schools on the website including Immaculate Heart of Mary School in Corner Brook. The school has implemented a recycling program, has an outdoor classroom and also has a composting program at the school. Other schools celebrated for their waste management initiatives are Beachy Cove Elementary in Portugual Cove, St.Phillips and Peacock Primary School in Happy-Valley Goose Bay.

Finally, there are two composting pilot projects that are funded by MMSB to promote community involvement in composting. The Town of Holyrood implemented a community composting program in 2009 which allows residents to take finished compost for free. The town also uses the finished compost to spread over green areas within the community. The second pilot project was implemented on the Burin Peninsula in which 1200 households participated in community wide composting diverting waste by 67 percent while producing Grade A compost (MMSB, 2015).

Conclusion

Overall methane is the most potent greenhouse gas and has the capacity to increase the rate of climate change in the near future. Methane emissions are common in landfills due to the process of anaerobic digestion so it is imperative that landfills be managed properly in the future to ensure the sustainability of the Earth. Newfoundland and Labrador has been progressing in waste management within the past decade but still has a lot of work to do in the near future to reduce the quantity of methane released. The initiative that Newfoundland and Labrador has already made to reduce methane emissions include implementing a landfill gas capture system at the main waste management facility in St. Johns. There is a need to take additional actions when fighting methane emissions as the landfill gas capture only converts a small amount of methane to carbon dioxide. Therefore, it is detrimental that the province increase their waste diversion initiatives and consider implementing either a large-scale composter or constructing a power plant for the waste-to-energy process. Only if additional actions are taken will there be a significant decrease in methane emissions resulting in Newfoundland and Labrador being compared to other top provinces in waste management initiatives. Also, as I mentioned the need for additional public education is dire as reducing the amount of organic waste reaching our landfills begins at the residential level. If homeowners know of ways to limit the amount of organic waste leaving their households then methane emissions will automatically be decreased. Also, public education for children is also of extreme importance as they are the individuals who will matter in the future, they are our future, and if we do not educate them now the sustainable practice of waste management will not be achievable.

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