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Final Draft Report

PROVINCE OF NEWFOUNDLAND AND LABRADOR SOLID WASTE MANAGEMENT PLAN: LIFE CYCLE ANALYSIS OF POTENTIAL PLAN OPTIONS

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505846

Submitted to:

Western Newfoundland Waste Management Committee
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SNC•LAVALIN Environment

EXECUTIVE SUMMARY

A carbon life cycle assessment (LCA) was undertaken by SNC-Lavalin Inc., Environment Division (SLE) for two potential waste management options associated with the Province of Newfoundland and Labrador (Province) Solid Waste Management Strategy (Strategy). The LCA was designed to identify the expected climate change impacts of the two Strategy options and to aid in the decision making process alongside other features of interest such as construction and operation costs. The LCA found no substantial difference between the two options in terms of effective carbon emissions when the implications of landfill emissions (common to both options) are considered.

The Province developed the Strategy for Newfoundland with a goal of 50% diversion of the waste stream by 2016. BAE Newplan Group Limited (BNG), a division of SNC-Lavalin Inc., was retained by the Province to prepare the Central Newfoundland Waste Management Plan (Plan). Key to the Plan is a comprehensive system that meets the needs of Newfoundland both presently and in the future.

In each waste management region, a central Regional Waste Management Facility (RWMF) is expected to handle waste transported to the facility from transfer stations servicing outlying areas. Figure E-1 shows the Central and Western Newfoundland Waste Management Zones as they currently exist in the Provincial plans.

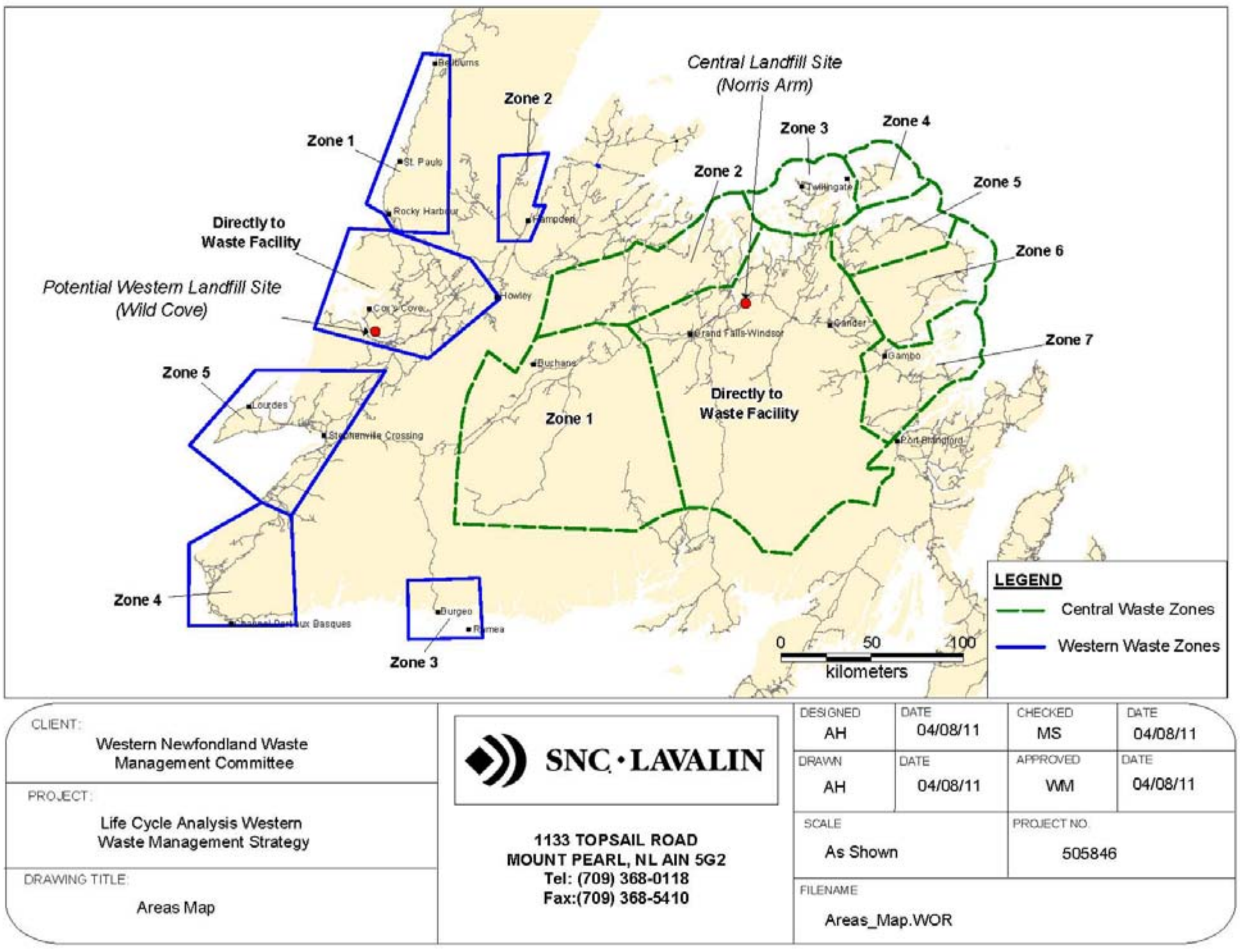
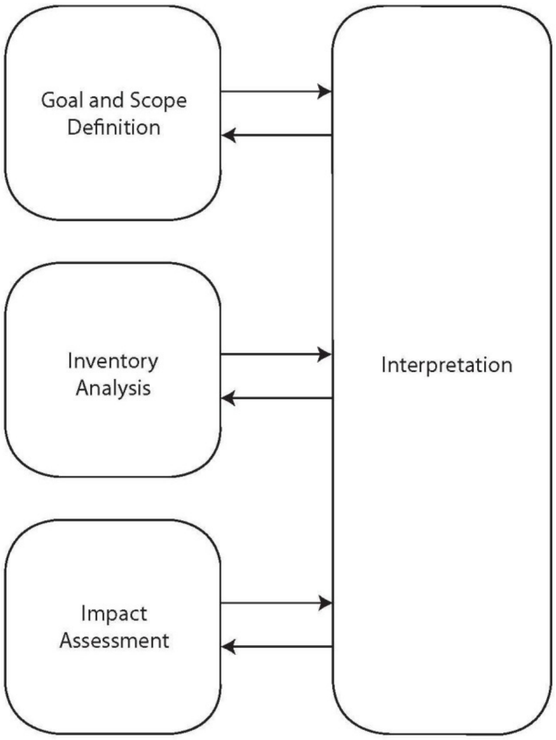


Figure E-1: Map of Western and Central Newfoundland Waste Management Zones

The two Plan options evaluated through life cycle analysis are Scenario 1: construction and operation of an expanded Central RWMF that would additionally encompass the Western region, and Scenario 2: construction and operation of both the Central and Western RWMFs according to the initial Plan.

The LCA process can be envisioned within a framework identified in Figure E-2. The goal of the LCA, the calculated effects and their significance are evaluated in a cyclical way to ensure that the analysis addresses the key questions and sensitivities of importance. The goal of the LCA is to establish the expected climate change impacts of the two scenarios, as measured by the equivalent carbon dioxide (eCO_2) emissions through the construction, operation and decommissioning of the waste management systems.



* Reproduced from CSA Standard CAN/CSA-ISO 14040:06, p. 8.

Figure E-2: Life Cycle Assessment

The eCO_2 emissions for each of the two scenarios were estimated through a conceptual model that incorporates the design criteria of the waste systems as well as the geographical context of the waste management zones. The model characterises the activities and associated emissions directly related with the waste management systems, including:

- procurement of materials (and the embedded carbon in these materials);
- construction (transfer stations, regional waste handling facilities);
- operations (all related activities over a 50 year life span, including transportation of waste); and
- decommissioning (following 50 years of operation).

An uncertainty framework was used to determine the expected error range in the waste management system emissions for the two scenarios. Although the uncertainty for some of the LCA source categories such as Decommissioning was high, the aggregate scenario uncertainties were reasonably low due to a high level of detail available for the significant Plan components. As shown in Table E-1, a 49,000 tonne eCO_2 benefit was found to be associated with Scenario 2 and this difference is higher than the aggregate uncertainties estimated for the emission calculations. For this reason, Scenario 2 is considered to have a better “carbon performance” than Scenario 1.

Table E-1: Summary of GHG Emissions for Different Phases of LCA

LCA Phases	Scenario 1 GHG Emissions (t eCO_2)	Scenario 2 GHG Emissions (t eCO_2)
Procurement of Materials	118,669	117,848
Construction - Transfer Stations	2,512	2,333
Construction - RWMFs	2,121	4,241
Operation - Collection	92,768	92,768
Operation - Transportation	96,691	31,032
Operation - Transfer Stations	21,363	19,837
Operation - RWMFs	41,776	58,659
Decommissioning - Transfer Stations	44	41
Decommissioning - RWMFs	57	114
Total	**376,001**	**326,872**

The major difference between the two scenarios was related to greater transportation emissions for waste shipped from the Western Zone to the Central Zone RWMF in Scenario 1.

The initial LCA Impact Assessment showed that gas emissions (carbon dioxide and methane) from the landfills at the RWMFs as well as emissions from the compost facilities had the potential to influence the significance of the analysis outcome noted in Table E-1. For this reason these emission sources were brought into the comparison even though they were considered equivalent in magnitude for both scenarios. Additionally, emissions due to the private transportation of waste to and from the RWMFs (Urban IC&I Collection and Recyclables Transportation), although not under the direct management of RWMF operations, were included as associated sources.

Landfill gas has been of interest to Canadian governments for a number of years, primarily due to the relatively high global warming potential (GWP) of the methane that is released over time. As part of the BNG Plan, wet waste will be processed and cured at the RWMF Compost Facility, which has a dual benefit of reducing methane emissions that would otherwise be released at the landfill, and producing valuable compost. Decomposition at the Compost Facility produces carbon dioxide rather than methane. Although a reasonable estimate can be made for the landfill emissions over time, the estimated effect (benefit) of diverting the organic matter from the landfill to the Compost Facility is uncertain. A detailed evaluation of the RWMF landfill emissions was beyond the scope of this investigation; as such, the landfill gas emissions were evaluated within a “nominal-case” and “best-case” setting for comparative purposes.

Figure E-3 provides a graphical summary of the emissions estimated for the two scenarios including the emissions from the “nominal-case” landfill as well as emissions associated with compost gas and private transportation of waste (Urban IC&I Collection and Recyclables Transportation). Figure E-4 provides the same comparison using ”best-case” landfill assumptions.

In terms of carbon performance, Figures E-3 and E-4 imply that Scenario 2 achieves a level of 653 kg (350 kg) eCO_2 per tonne of waste handled and Scenario 1 achieves a level of 643 kg (340 kg) eCO_2 per tonne of waste handled, for the “nominal-case” and “best-case” landfill assumptions, respectively. This comparison of the two Plan scenarios implies that the difference in transportation related emissions is not large in terms of the total greenhouse gas emissions that could be attributed to the operation of the waste management systems.

To put the magnitude of these emissions into perspective, it is estimated that the difference between the scenario emissions amounts to approximately 5.5 kg eCO_2 per person per year for the residents within the Western and Central Zones. This relates to an average total residential emission level of approximately 2,400 kg per person per year according to a GHG emissions assessment completed for St. John’s in 2006 or the idealized “one tonne challenge” (1,000 kg) level the Canadian federal government previously aspired to for a national average. Residential emissions in this context include home space heating as well as personal vehicle use.

Based on these results, it is recommended that further investigation be completed to evaluate the potential of landfill gas capture within the Plan.

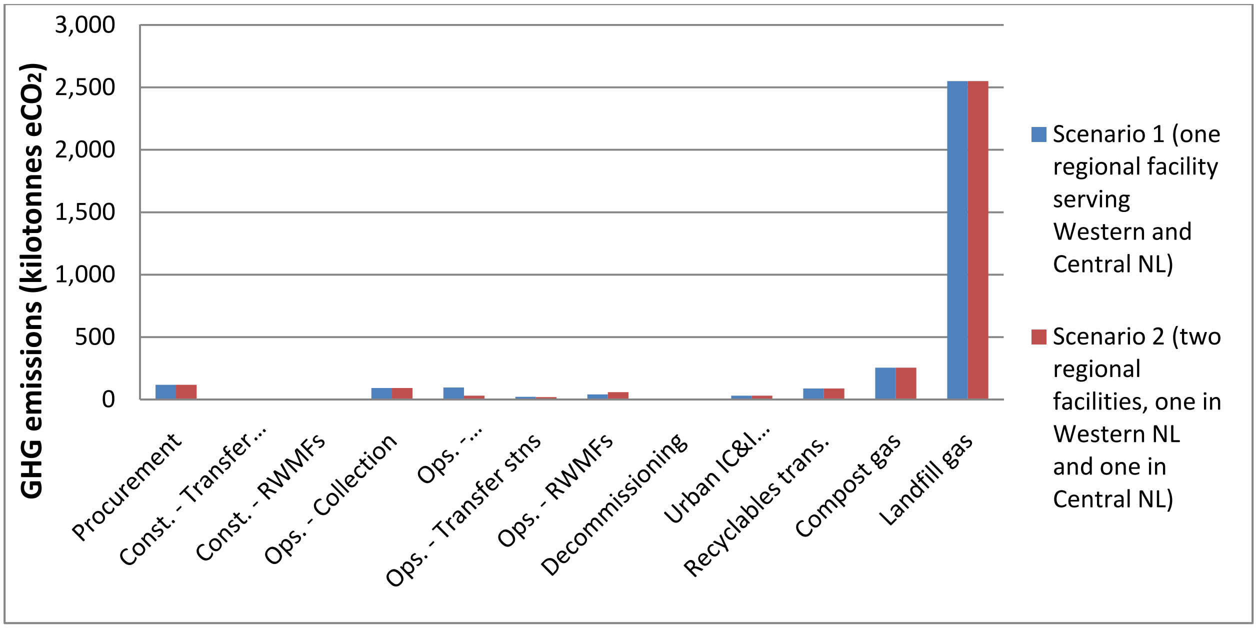


Figure E-3: Lifetime GHG Emissions for Procurement, Construction, Operation, and Decommissioning of Two Plan Scenarios, with "Nominal-Case" Landfill Assumptions

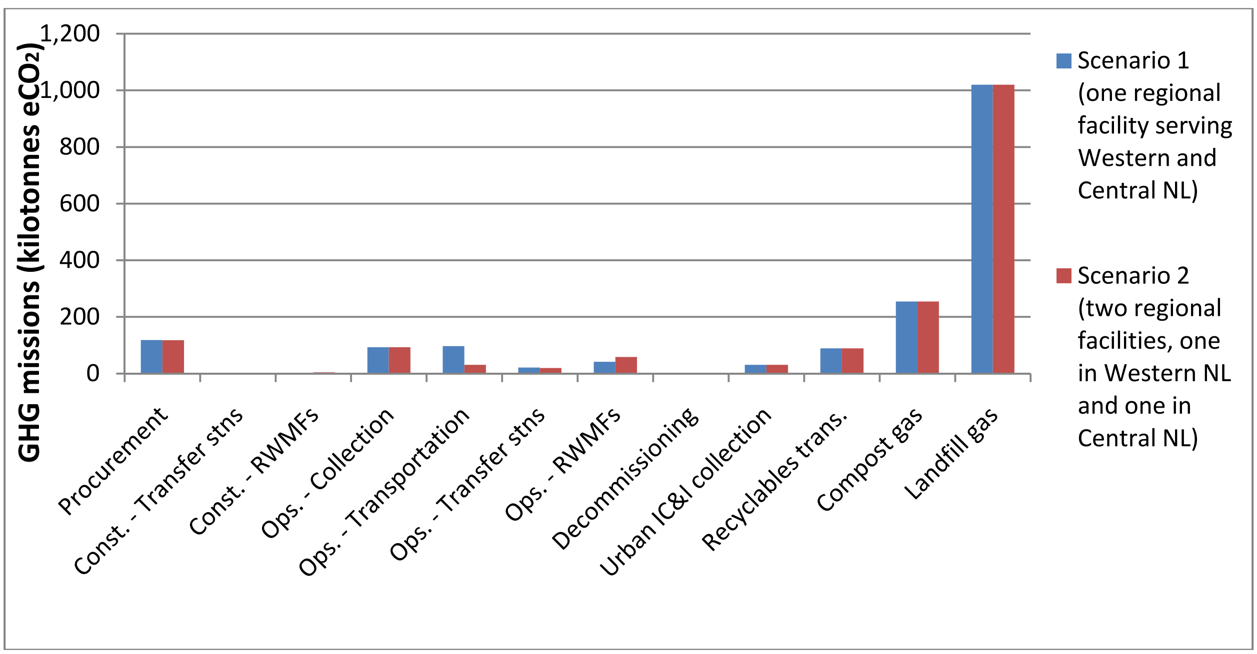


Figure E-4: Lifetime GHG Emissions for Procurement, Construction, Operation and Decommissioning of Two Plan Scenarios, with "Best-Case" Landfill Assumptions

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1.0 INTRODUCTION

1.1 Provincial Solid Waste Management Strategy

The Province of Newfoundland and Labrador (Province) has developed a Solid Waste Management Strategy (Strategy) for Newfoundland that has a goal of reduced materials to landfill (50% diversion of the waste stream by 2016) and a reduction in the number of disposal sites. Key to the Strategy is a comprehensive system that meets the needs of the Newfoundland Region both presently and in the future, and serves as an example of innovative, strategic environmental management.

BAE-Newplan Group Limited (BNG), a division of SNC-Lavalin Inc., was retained by the Central Newfoundland Waste Management Committee (CNWMC) in 2002 to assist with the development of the Central Newfoundland Waste Management Plan (Plan). A Phase I and a Phase II study and report have been developed that identify the key features and options of the Plan, including characterisation of the area to be served, population and waste generation forecasts, waste management systems and associated operations, cost implications of development, and other significant issues.

Under the Strategy, Newfoundland will be divided into three regional waste management zones: the Eastern Newfoundland Waste Management Zone (ENWMZ), Central Newfoundland Waste Management Zone (CNWMZ) and the Western Newfoundland Waste Management Zone (WNWMZ). The boundaries of the Western and Central Zones, with a total population of roughly 180,000, are outlined in Figure 1. Each zone may serve remote areas beyond its defined boundaries.

1.2 Study Rationale for a Life Cycle Analysis

Presently, the Western Newfoundland Waste Management Committee (WNWMC) wishes to consider the possibility that waste generated in the Western Zone could be transported and handled in the Central Zone. SNC-Lavalin Inc., Environment Division (SLE), has been commissioned to complete a Life Cycle Analysis (LCA) for the two potential Plan options: (1) development and operation of an expanded Central waste facility that would additionally encompass the Western Zone and (2) development and operation of both the Central and Western waste facilities (i.e., following the initial Plan).

An LCA evaluation provides a comprehensive environmental impact assessment of the two proposed waste systems. This analysis typically includes evaluation of a particular system or product over its entire lifetime, from the extraction of raw materials to processing/operations on to decommissioning. In the context of the Plan, this time period spans approximately 50 years, the expected lifetime of the waste management facilities.

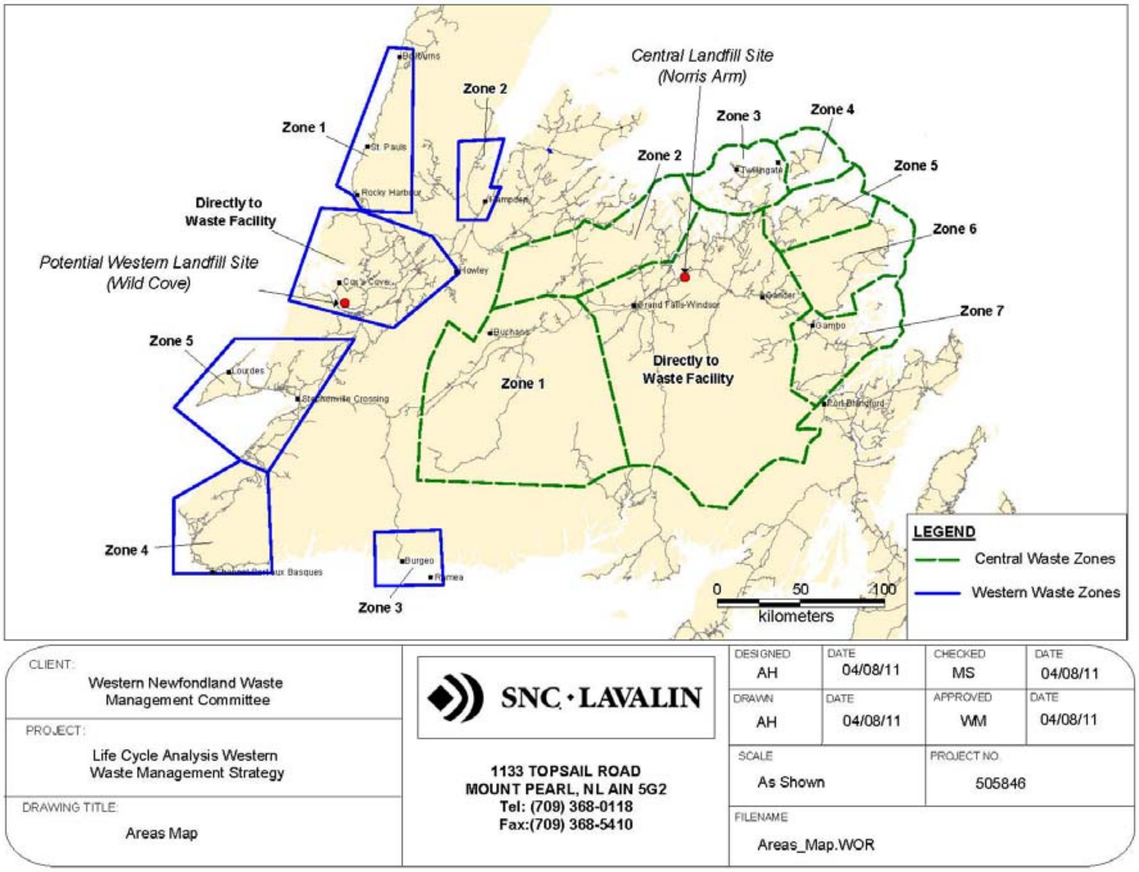


Figure 1: Map of Western and Central Newfoundland Waste Management Zones

Under the 2002 Plan, the Central Zone would utilize seven transfer stations with a Regional Waste Management Facility (RWMF) to be constructed outside Norris Arm. Based on information provided by BNG, the Western Zone will have five transfer stations with a regional facility planned for Wild Cove outside of Corner Brook. Under Scenario 1, with waste being transported to the Norris Arm RWMF, the Wild Cove RWMF would be downgraded to a transfer station.

At present, the Great Northern Peninsula is not included in the catchment area of either the WNWMZ or the CNWMZ. However, at BNG's request, the Great Northern Peninsula was included in the assessment, to gauge its effect. Given the total population and population density of this peninsula, BNG believes several transfer stations may be necessary to service this area. For the purpose of the LCA, only a single transfer station was modelled, in Eddie's Cove. Table 1 summarizes the locations of the transfer stations and RWMFs. Note that the Baie Verte Peninsula is not part of either the Central or Western Zones and so was not included in the assessment.

Table 1: Locations of Transfer Stations and RWMFs in the Western and Central Newfoundland Waste Management Zones

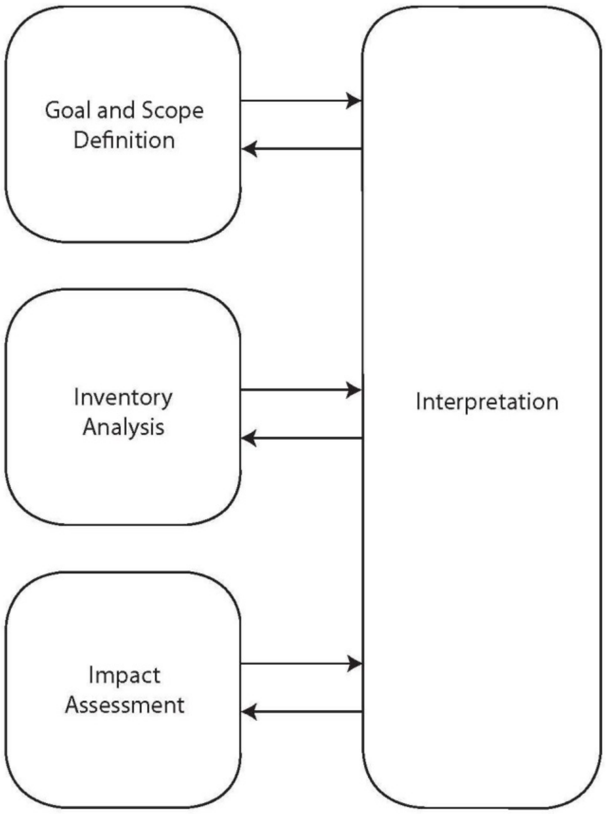
Transfer Zones	Central	Western
1	Buchan's Junction	Rocky Harbour
2	Point Leamington	Hampden
3	New World Island (Virgin Arm-Carter's Cove)	Burgeo
4	Fogo Island	Port aux Basques
5	Gander Bay (Main Point-Davisville)	Bay St. George
6	Indian Bay	Eddie's Cove
7	Terra Nova	-
RWMF	Norris Arm	Wild Cove

1.3 Evaluation Framework

This study follows the formalized LCA framework described in the CSA-ISO 14040 document *Life Cycle Assessment – Principles and Framework* (2006). This framework incorporates a decision making process accounting for the assessment goals, associated steps and features of interest for the study. The LCA framework has four stages:

- goal and scope definition;
- inventory analysis (Life Cycle Inventory – LCI);
- impact assessment (Life Cycle Impact Assessment – LCIA); and
- interpretation.

This framework is represented in Figure 2. An LCA is meant to be a transparent process suitable for stakeholder engagement and public education purposes.



* Reproduced from CSA Standard CAN/CSA-ISO 14040:06, p. 8.

Figure 2: Life Cycle Assessment Framework

An LCA requires definition of an "impact category" against which the estimated environmental consequences are evaluated. The impact category for this study was identified as climate change potential, often referred to as "the carbon footprint".

An impact category (climate change) requires an evaluation metric – a quantifiable measure that is meaningful for comparison purposes. The measure used for this study is equivalent carbon dioxide (eCO_2), which is commonly used to express greenhouse gas (GHG) emissions in Canada and internationally. The eCO_2 emissions for the waste management facilities are expected to result from the following sources and activities:

- embedded carbon in construction materials (e.g., concrete, steel);
- embedded carbon in operations equipment (e.g., trucks, loaders);
- transportation of construction materials and operations equipment to Newfoundland;
- construction activities over an expected four year period;
- operations activities over an expected 50 years (e.g., waste transportation, landfill compactor); and
- decommissioning activities.

As implied by the list above, the LCA accounts for both *direct* emissions associated with fuel combustion or landfill gas generation, as well as *indirect* emissions associated with the manufacture of goods and materials. Indirect emissions encompass what are often referred to as the "embedded" (or "embodied") emissions of a product.

In order to assist with the interpretation of the inventory results, an uncertainty scheme was used to provide an estimate of the error associated with the scenario assumptions and related estimates. The individual source uncertainty estimates were aggregated to provide a total uncertainty for the two Plan scenarios.

2.0 GOAL AND SCOPE DEFINITION

The goal of this LCA is as follows:

> *"to provide a thorough and comprehensible evaluation of the climate change implications of two potential waste management scenarios through life cycle analysis."*

Based on discussions with the Province and BNG, SLE adopted a "cradle to grave" approach to the LCA. The "cradle to grave" approach requires both facility operations (over 50 years) and decommissioning to be evaluated in addition to procurement of materials and construction of facilities. This decision was largely based upon data availability and understanding of the physical system.

In many cases, comparative assertions are included as part of an LCA and this was expected for assessment of the two potential Plan options. In general, a simplification of an LCA can be achieved by identifying key system attributes that would be common to both potential Plan scenarios (and therefore would not require detailed evaluation). However, the Province expressed an interest in the relative magnitude of the waste management facility emissions with commonly understood activities such as community (or individual) carbon emissions over a typical year. For this reason, SLE attempted to include all of the reasonable (quantifiable) emission sources of significance, even those common to both Plan scenarios.

The two potential Plan scenarios are defined as follows:

- Transport and handling of waste from both the Western Zone and the Central Zone through one central RWMF in Central Newfoundland.
- Transport and handling of waste at two separate RWMFs; one in the Western Zone and one in the Central Zone.

As indicated in the previous section, climate change (global warming) is the primary impact category assessed and eCO_2 is the metric by which the assessment was completed.

The primary reason for the LCA is to fill the key environmental consideration that will accompany the capital costs and operations costs as part of the Plan scenario evaluation. The intended audience of the assessment includes the Central Newfoundland Waste Management Committee, the Western Newfoundland Waste Management Committee, the Province (particularly the Department of Municipal Affairs), and the general public.

3.0 LIFE CYCLE INVENTORY

A key task of LCI development involves defining the system boundary. The system boundary encompasses the life cycle phases to evaluate and the processes to be included in each phase. The LCI development identified the following system boundaries:

- raw materials necessary for each phase (including production of fuels);
- transportation of input and output materials for each phase (which may include intermediate materials as well as raw materials);
- inputs and outputs of the facility operation (e.g., waste handling and processing);
- use of energies and fuels;
- use and maintenance of capital equipment;
- disposal of process wastes and products; and
- recovery of materials (recycling and composting).

The activities and related emissions were estimated from a conceptual model that linked with the development plans of the RWMFs and existing infrastructure. A detailed characterisation of every process within each LCI phase was not possible since some of planned activities have yet to be elaborated (i.e., contracted). Due to these data availability limitations, it was necessary to generalize certain components of the LCI model. These simplifications are noted in the report where applicable.

To provide a measure of equivalent carbon dioxide, emitted greenhouse gases are converted using their global warming potential (GWP), which indicates how many tonnes of carbon dioxide would produce the same warming effect over the same time period as 1 tonne of another GHG such as methane (CH_4) or nitrous oxide (N_2O). The GWP values used for this study were from the Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)[1], as shown in Table 2.

Although other GHGs have been identified as significant in terms of potential climate change, only the three noted in Table 2 are released in appreciable quantities by the activities of interest to this study.

Table 2: Global Warming Potential of Different

Greenhouse Gas	GWP
CO_2	1
CH_4	21
N_2O	310

[1] http://www.ipcc.ch/pdf/climate-changes-1995/ipcc-2nd-assessment/2nd-assessment-en.pdf

To determine the eCO_2 emissions associated with a specific activity, SLE used the following general equation:

$$E = EF \ x \ AD \qquad \textbf{\{Equation 1\}}$$

Where:

E = Emissions (in tonnes of eCO_2);

EF = Emission factor in tonnes of eCO_2 per activity measure (e.g., tonnes eCO_2 / km); and

AD = Activity data (e.g., kms travelled).

The interpretation component of an LCA benefits from an understanding of the uncertainty in the LCI emission estimates. For this reason, an uncertainty scheme identified by the IPCC and supported by groups such as the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) was used to estimate the uncertainty in each emission estimate as well as the aggregate uncertainty in the total scenario emissions. This scheme is described in Appendix II.

It should be noted that uncertainty estimates tended to be higher for activity data (e.g., tonnes of cement or steel used) rather than emission factors, since in many cases the activity data were estimates of a specific system operation. The uncertainty measures estimated for the emission rates as well as activity levels are identified in the following sections.

The LCI focused on elements under the direct management of the waste management committees (CNWMC and WNWMC). However, additional sources of emissions related to the waste management system but outside of the committee's control were also modelled for consideration during the interpretation stage of the LCA (Chapter 4). These sources generally had higher levels of uncertainty due to a lack of specific information.

3.1 Combustion Emission Factors

A significant component of the GHG emissions within each modelled phase of the LCI was due to combustion of fuel in vehicles and equipment. Combustion emission factors were sourced from the following data models:

- US Environmental Protection Agency (EPA) MOBILE[2]. In particular, MOBILE 6.2C which was modified from MOBILE by Environment Canada to incorporate Canadian fleet testing data. The model produces g/km emission factors of CO_2, CH_4, and N_2O (as well as other air contaminants)

[2] http://www.epa.gov/mobile

under various driving cycle conditions. The model can provide forecast emission estimates, as it accounts for planned government emission regulations in effect in future years.

- EPA NONROAD[3]: This model predicts emission rates for all non-road equipment categories with the exception of commercial marine, locomotive and aircraft. The model handles all commonly-used fuels, including gasoline, diesel, compressed natural gas (CNG), and liquefied petroleum gas (LPG). Consistent with MOBILE, NONROAD can project emissions through 2050.

The MOBILE model was used to determine the emissions associated with the heavy trucks (e.g., compactors, tractors, etc.) and pickup trucks, while the NONROAD model was used to determine the emissions of the waste handling equipment (e.g., loaders, dozers) and the construction equipment (e.g., cranes). Table 3 lists the combustion emission factors used for the LCI. The eCO_2 values listed in the table were calculated using the GWP factors from Table 2.

Table 3: Vehicle and Machinery Operating Emission Factors

Equipment Type	Emission Factors				Units	Uncertainty (%)
	CO_2	CH_4	N_2O	eCO_2		
Heavy Truck - Driving	1.0	3.0E-05	8.5E-06	1.0	kg / km	20%
Heavy Truck - Idle	4.5	1.3E-04	3.7E-05	4.5	kg / hr	20%
Pickup Truck - Driving	0.2	2.0E-06	1.4E-06	0.2	kg / km	20%
Landfill Compactor – Duty Cycle	126.9	4.8E-03	1.0E-03	127.3	kg / hr	20%
Dozer – Duty Cycle	19.7	2.9E-03	1.6E-04	19.8	kg / hr	20%
Medium Excavator – Duty Cycle	46.8	3.6E-03	3.9E-04	47.0	kg / hr	20%
Medium Wheeled Loader – Duty Cycle	56.9	4.0E-03	4.7E-04	57.1	kg / hr	20%
Small Wheeled Loader – Duty Cycle	47.1	3.6E-03	3.9E-04	47.3	kg / hr	20%
Backhoe Loader – Duty Cycle	16.3	2.4E-03	1.3E-04	16.3	kg / hr	20%

The emission rates for NONROAD equipment are based on average engine duty cycles. Emissions for heavy trucks are presented for an average driving cycle as well as for simple idling (since a significant amount of idling time would be expected in normal operations of a trash compactor).

[3] http://www.epa.gov/nonroad/

The emission factors were chosen based on information provided by BNG on the vehicles and equipment to be used at the facilities[4]. For example, a Caterpillar 938H loader with a 180 hp engine was categorized as a medium wheeled loader in Tables 3 and 4. All emission factors were determined for a single year, 2005, and were assumed to remain unchanged for the life of the facilities, even though some of the emission rates may improve as equipment gets replaced with age (heavy trucks for waste transport in particular). The heavy truck classification was applied for trash compactors, tractors, roll-on/roll-off trucks, and tandem dump trucks.

In addition to the GHG emission factors, the fuel consumption of each piece of equipment was characterised based on the MOBILE and NONROAD models. The fuel economy was employed to determine the quantity of fuel combusted (assumed to be diesel) so that the embedded GHG emissions of diesel extraction/refining could be included and modelled (see Section 3.2). Table 4 lists the fuel economy factors for the vehicles and machinery.

Table 4: Vehicle and Machinery Operating Fuel Economies

Vehicle Type	Value	Units	Uncertainty (%)
Heavy Truck – Driving	0.4	L / km	20%
Heavy Truck – Idle	1.7	L / hr	20%
Pickup Truck – Driving	0.2	L / km	20%
Landfill Compactor – Duty Cycle	47.9	L / hr	20%
Dozer – Duty Cycle	7.4	L / hr	20%
Medium Excavator – Duty Cycle	17.7	L / hr	20%
Medium Wheeled Loader – Duty Cycle	21.5	L / hr	20%
Small Wheeled Loader – Duty Cycle	17.8	L / hr	20%
Backhoe Loader – Duty Cycle	6.1	L / hr	20%

The uncertainty estimates listed in Tables 3 and 4 were based on SLE judgment. Although the uncertainty in emission rates for one individual vehicle or piece of equipment may be higher than 20%, this level of uncertainty was considered a reasonable estimate for a group of vehicles/equipment of the same general type over extended periods of time.

[4] Email communication, Mike Smith, BNG, February 22, 2011.

3.2 Procurement

The embedded emissions associated with the procurement of materials needed for the construction and operation of the waste management system (including diesel fuel) were based on a number of data sources. To the degree possible, SLE sourced embedded emissions data on a “cradle to gate” basis so that transportation and decommissioning emissions were accounted for separately, acknowledging the regional realities. Within the context of an LCA, a “cradle to gate” basis covers the manufacturing stage of a product from raw material acquisition (“cradle”) to the product being shipped out of the manufacturing facility (“gate”).

Five specific data sources relevant to the LCI are identified below:

- Athena Sustainable Materials Institute[5]: Athena is a non-profit organization that provides data and tools to support calculation of the embedded energy and emissions of whole buildings and assemblies. The Athena LCI databases include characterization of commonly used building materials and products in North America. In most cases, the data are regionally sensitive, accounting for manufacturing processes, transportation and the origin of electrical power. The Athena LCI databases are continually developed and documented (since 1999).
- Greenhouse Gases, Regulated Emissions and Energy Use in Transportation Model (GREET)[6]: Sponsored by the US Department of Energy and constructed by the Argonne National Laboratory, GREET is a life cycle model for fuels and vehicles through a “wells to wheels” accounting, primarily focusing on advanced vehicle technologies and new fuel blends.
- Economic Input Output LCA (EIO-LCA) project[7]: Maintained by the Green Design Institute at Carnegie Mellon University, the EIO-LCA project estimates the materials and energy resources required for activities in the economy. The model uses information about industry transactions and direct environmental emissions of industries to estimate the total emissions throughout a product supply chain. The data set most relevant to this study was the Industry Benchmark Canada EIO model from 2002, which included supply chain emissions from 105 separate industry sectors.

[5] http://athenasmi.org/index.html
[6] http://greet.es.anl.gov/
[7] http://www.eiolca.net/

- Inventory of Carbon and Energy (ICE)[8]: ICE is a database of embodied energy and carbon developed by the Sustainable Energy Research Team at the University of Bath in England, representing a large number (approximately 170) of building materials. Although primarily developed in support of the building sector it is also considered relevant to other sectors. This database is representative of European manufacturing realities, which may or may not be relevant to North America.
- UK Department for Environment, Food and Rural Affairs (DEFRA) GHG Guidelines[9]: DEFRA has provided an aggregation of the GHG emission factors to be used for mandatory GHG company reporting. Annex 13 of the guidelines lists indirect emission data from the supply chain, which is appropriate for use in an LCA. The data presented in the guidelines were calculated from economic input/output data similar to EIO-LCA but are specific to the UK economy.

The Athena and GREET databases were the primary source for embedded emissions within the LCI. The Athena data set was used for the building materials needed for the RWMF and transfer station construction. Athena was selected because it is the most comprehensive data set currently available, the measures are regionally (and Canadian) based and relates to specific processes rather than aggregated industrial flows. The GREET data set is the only widely available process-based data set of its kind for vehicles and fuel in North America, which was the reason for its employment.

The EIO-LCA data set from Carnegie Mellon University was used for the machinery and equipment to be used in the Compost Facility because it was the only Canadian source available for that type of product. The last two data sets listed above were useful as a reference and as a point of comparison to estimate uncertainty but were not used in the LCI model. It should be noted that all the data from these sources are freely available on the internet.

Table 5 shows the embedded emission factors used in the LCI.

[8] http://people.bath.ac.uk/cj219/
[9] http://archive.defra.gov.uk/environment/business/reporting/pdf/101006-guidelines-ghg-conversion-factors.pdf

Table 5: Embedded Emission Factors

Product	Cradle-To-Gate Embedded Emissions						Gate To Site Distance (km)	Cradle-To-Site Embedded Emissions		
	CO_2	CH_4	N_2O	eCO_2	Native Units	Uncertainty (%)		Emission Factor	Final Units (eCO_2)	Uncertainty (%)
Steel - Galvanized Studs	1,757.6	0.1		1,759.3	kg / t	25%	2150	1,969.3	kg / t	22.6%
Steel - Rebar, Rod, Light Sections	2,111.3	0.1		2,113.4	kg / t	25%	2150	2,323.4	kg / t	22.9%
Concrete - 20 mpa	214.1	7.8E-03		214.2	kg / m^3	25%	400	307.1	kg / m^3	19.5%
Concrete - 30 mpa	301.7	8.6E-03		301.9	kg / m^3	25%	400	394.7	kg / m^3	20.3%
Road Asphalt				355.0	t / km	25%	400	50.4	kg / m^2	19.1%
Diesel	16,314.0	107.3	0.2	18,641.4	g / mmBTU	25%	400	0.7	kg / L	24.0%
Heavy Trucks	46,701.4	85.3	0.5	48,655.0	kg / vehicle	25%	3800	56,448.3	kg / vehicle	21.9%
Waste-Handling Equipment	46,701.4	85.3	0.5	48,655.0	kg / vehicle	60%	3800	56,448.3	kg / vehicle	51.9%
Pickup Trucks	11,450.7	20.3	0.1	11,917.9	kg / vehicle	25%	3000	13,148.4	kg / vehicle	22.8%
Machinery Manufacturing	560.0	0.1	2.2E-02	568.2	kg / $1000	60%	2000	609.3	kg / $1000	56.0%

The “cradle-to-gate” emission factors of CO_2, CH_4 and N_2O were converted into eCO_2 values using the GWP values quoted in Table 2. As can been seen in the table, the reported values do not always include all three greenhouse gases of interest. In the case of the “Road asphalt”, the Athena report only lists an aggregate eCO_2 value of 355 tonnes per kilometre of roadway. Furthermore, the report used the GWP factors from the Third IPCC Assessment Report so the 355-tonne value would be slightly different had the Second Assessment Report GWP factors been used. Since the individual GHG contributions were not available the listed eCO_2 value was retained. In all cases, the estimated uncertainty percentages account for the issues noted above.

For simplicity, the heavy truck embedded “cradle-to-gate” emission factor was employed for all heavy machinery, including trash compactors, tractors and waste-handling equipment. While it is likely that the actual factors would scale with the weight of the equipment (generally, heavier machines require more raw materials and more assembly) the heavy truck value was employed without adjustment, due to a lack of alternative data sources.

For the “cradle-to-gate” emission factors, a generic 25% uncertainty was applied to account for potential regional differences in manufacturing and energy sources. The two exceptions were for the heavy machinery for the reasons listed above, and the machinery used in the Compost Facility (which required use of the EIO-LCA data which are not process-based). The uncertainties for the heavy machinery and the compost equipment were both set to 60% to reflect their low confidence.

The transportation of products from the “gate” to the location of usage was modelled in a straightforward fashion, with the following assumptions:

- All transportation was over land by tractor/trailer only.
- The uncertainty associated with the tractor/trailer emissions was set to 50% because some of the materials may actually be transported by rail, which has different (lower) emissions per tonne of material moved.
- The expected carrying capacity of a tractor/trailer was 21 tonnes.
- Tractor/trailers always travelled with a full load.
- Back-hauling of the empty tractor/trailer was included.
- The embedded emissions of the tractor/trailer were not included since the trip would represent only a small fraction of the vehicle’s lifetime.

The final destination of all items was assumed to be Norris Arm, Newfoundland (the site of the Central Zone RWMF). Specific purchasing orders have not yet been made, so therefore, reasonable assumptions were applied for each product type. The origin of the products was estimated as follows:

- Steel: Montreal, QC, 2,150 km away (currently there are no steel mills in the Maritimes);
- Concrete: St. John's, NL, 400 km away;
- Road asphalt: St. John's, NL, 400 km away;
- Diesel: St. John's, NL, 400 km away;
- Pickup trucks: Windsor, ON, 3,000 km away (centre of vehicle manufacturing in Canada);
- Heavy trucks: Peoria, IL, USA, 3,800 km away (headquarters of Caterpillar Inc., a heavy vehicle manufacturer); and
- Compost facility equipment: Boston, MA, USA, 2,000 km away (manufacturer of the IPS Composting system to be installed at the RWMFs).

The uncertainty associated with the distance travelled was set to 30% to reflect this situation. Distances listed above are aggregate values that account for the travel that various components undergo. For example, while the aggregate used in concrete and asphalt might be sourced locally, other components such as cement might be transported from much further away. For detailed information on combining uncertainties, see Appendix II.

For the three subsequent life cycle phases (construction, operation and decommissioning), the embedded emissions associated with the procurement of diesel used for each phase were calculated using the annual hours of engine use and the specific fuel economy of each vehicle or piece of equipment. The total estimated diesel use was then multiplied by the embedded emission factor for diesel following Equation 1.

For the operations phase, the embedded emissions associated with the initial purchase and eventual replacement of vehicles and equipment were also modelled, based on hours of use, distance driven or other information provided by BNG. A discussion on the quantity of vehicles and equipment purchased and replaced is provided in Appendix I.

The embedded emissions of different materials used in the other LCI phases are summarized in Table 6.

Table 6: Summary of Procurement Phase GHG Emissions for Both Scenarios

Product Type	Scenario 1 GHG Emissions ($t\ eCO_2$)	Scenario 2 GHG Emissions ($t\ eCO_2$)
Construction Materials	20,851	35,432
Compactors and Haul Trucks	25,755	20,787
Facility Waste Handling Equipment	10,167	12,149
Diesel	61,896	49,480
Procurement Total	**118,669**	**117,848**

3.3 Construction

To model the construction phase, it was first necessary to determine the quantity of building materials needed for both the RWMF and the transfer stations. To simplify the study, several assumptions were used:

- The size and construction material requirements of the RWMFs will be the same for the two facilities in Central and Western Newfoundland.
- The size and construction material requirements of the transfer stations will be the same for all transfer stations being constructed.
- All fuel consumed by construction equipment is diesel.
- Construction operations are 5 days a week, 52 weeks a year.
- The carbon implication of tree removal at the construction sites was ignored in the model but is discussed in Chapter 4.

BNG provided facility design documents for the RWMF in Norris Arm, represented in Figure 3. An expected bill of materials was not available for the buildings. To determine the construction material requirements, SLE used a software program called the Impact Estimator for Buildings, version 4.1[10], from the Athena Sustainable Materials Institute. This program provided an estimate of the building materials based on the total expected floor space (as well as the construction techniques employed).

[10] http://www.athenasmi.org/tools/impactEstimator/index.html

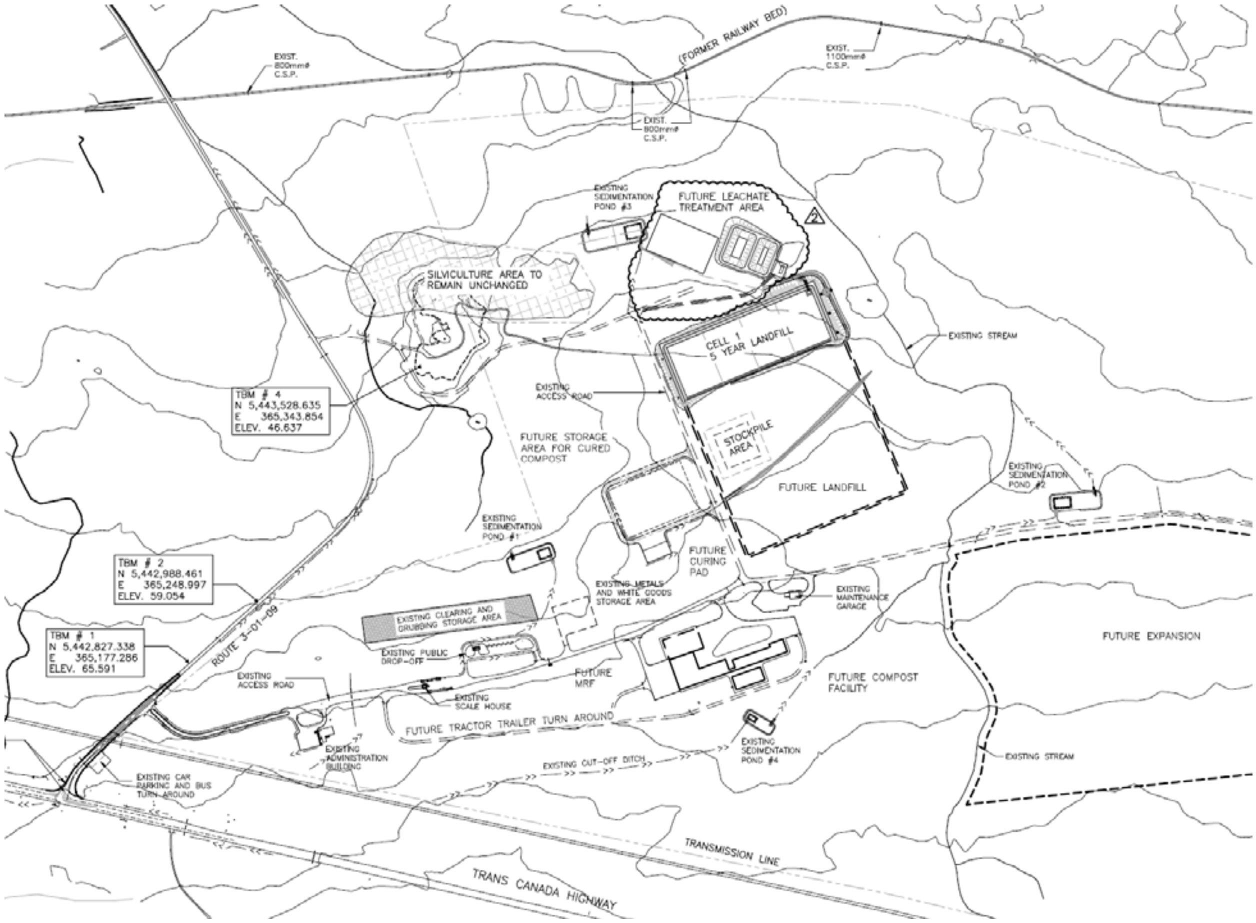


Figure 3: Planned layout of the Regional Waste Management Facility in Norris Arm, Newfoundland *(provided by BNG)*

Estimates of the total floor space of each building were determined from design drawings provided by BNG[11] and a preliminary design report for the Compost Facility by Stearns & Wheeler[12]. The buildings and their floor plans areas are identified in Table 7. For Scenario 1, BNG indicated that the compost facility would have to be roughly 20% larger than the design specifications to handle the increased waste tonnages.

[11] Personal communication, Mike Smith, BNG, February 22, 2011.

[12] Stearns & Wheeler. "Preliminary Design Report, Central Newfoundland Municipal Solid Waste Processing Facility," November 2009.

A simple single floor concrete/steel structure was assumed for all buildings. The material requirements for a single structure of 405 m^2 was determined then scaled up to cover the total area of all the building floor plans summed together. These material requirements are shown in the first four lines of Table 8.

Another major material requirement for the RWMFs was road construction. Communication from BNG indicated that the total asphalt required for one RWMF is 22,809 m^2.

Table 7: Floor Plan Areas of Buildings for one Regional Waste Management Facility

Buildings	Floor Plan Areas (m^2)	
	Scenario 1	Scenario 2
Administration	400	400
Scale House	50	50
Maintenance Garage	225	225
Material Recycling Facility	3,360	3,360
Compost Facility	15,120	12,600

The processing equipment within the Compost Facility would also have a significant embedded carbon footprint. However, no related data were available in this case, so an approximation was made based on its estimated cost of $CDN 10.82 million. The EIO-LCA model from Carnegie Mellon University included an emission factor for machinery manufacturing per million dollar cost. This factor (listed in Table 5) was combined with the estimated cost above to yield an approximate emissions value.

A summary of the material requirements for one RWMF is shown in Table 8.

Table 8: Construction Material Requirements for One Regional Waste Management Facility

Material	Scenario 1 Quantity	Scenario 2 Quantity	Unit	Uncertainty (%)
Concrete - 20 MPa	12,497	10,485	m^3	50%
Concrete - 30 MPa	6,144	5,155	m^3	50%
Galvanized studs	171	144	tonnes	50%
Rebar, Rod, Light Sections	1,630	1,368	tonnes	50%
Asphalt	22,809	22,809	m^2	50%
Compost Facility Equipment	10,800	10,800	$CDN thousand	50%

The estimated material quantities were multiplied by the relevant emission factors from Table 5 to determine the effective emissions due to procurement. As can be seen in Table 8, the uncertainty associated with the building material requirements was deemed to be large due to the lack of specific construction data. Additional materials not accounted for would include the following:

- materials associated with the maintenance of the buildings; and

- materials that may be used for lining the landfill.

It was estimated that the building period would be approximately 2.5 years (or 650 days of 5-day work weeks), based on information provided by BNG and other construction projects of a similar size. A conservative assumption of construction equipment type and use was made accordingly, as shown in Table 9. The total estimated activity hours by equipment type were used with the representative emission rates from Table 3 to produce the estimated construction emissions. An estimated equipment use of 16 hours per day implies two pieces of equipment, each used for 8 hours a day.

Table 9: Construction Operations for One Regional Waste Management Facility

Activity Description	Activity Data			
	Daily Use Per Unit (hrs)	Uncertainty (%)	Project Use (days)	Uncertainty (%)
Crane	8	50%	650	10%
Back hoe	16	50%	650	10%
Excavator	16	50%	650	10%
Medium Wheeled Loader	16	50%	650	10%
Dozer	16	50%	650	10%

To model the construction of a single transfer station, the model described above was simply scaled down based on the expected floor space. From design documents provided by BNG, one transfer station was estimated to contain 370 m^2 of floor space. The same construction equipment was used for the transfer facilities, only for a shorter period of time. BNG indicated that the construction of seven transfer stations would take 18 months.

The embedded emissions associated with manufacturing the construction equipment were not included since this would not be the only project that the equipment would be used for. Additionally, the provision of services (electricity, waste, sewage) during construction was not included in the evaluation, due to an expectation that their impact would be low relative to the construction as a whole.

A summary of the operational construction emissions (not including procurement of materials) for each scenario is provided in Table 10.

Table 10: Summary of Construction Phase GHG Emissions for Both Scenarios

LCA Phases	Scenario 1 GHG Emissions (t eCO_2)	Scenario 2 GHG Emissions (t eCO_2)
Construction – Transfer stations	2,512	2,333
Construction – RWMFs	2,121	4,241
Construction Total	**4,633**	**6,574**

3.4 Operations

Emissions due to operating the Western and Central waste management systems over 50 years were modelled based on a description of the operations supplied by BNG, as well as an assessment of waste transportation distances for the two scenarios. A visualization of waste collection, transportation and handling is provided in Figure 4.

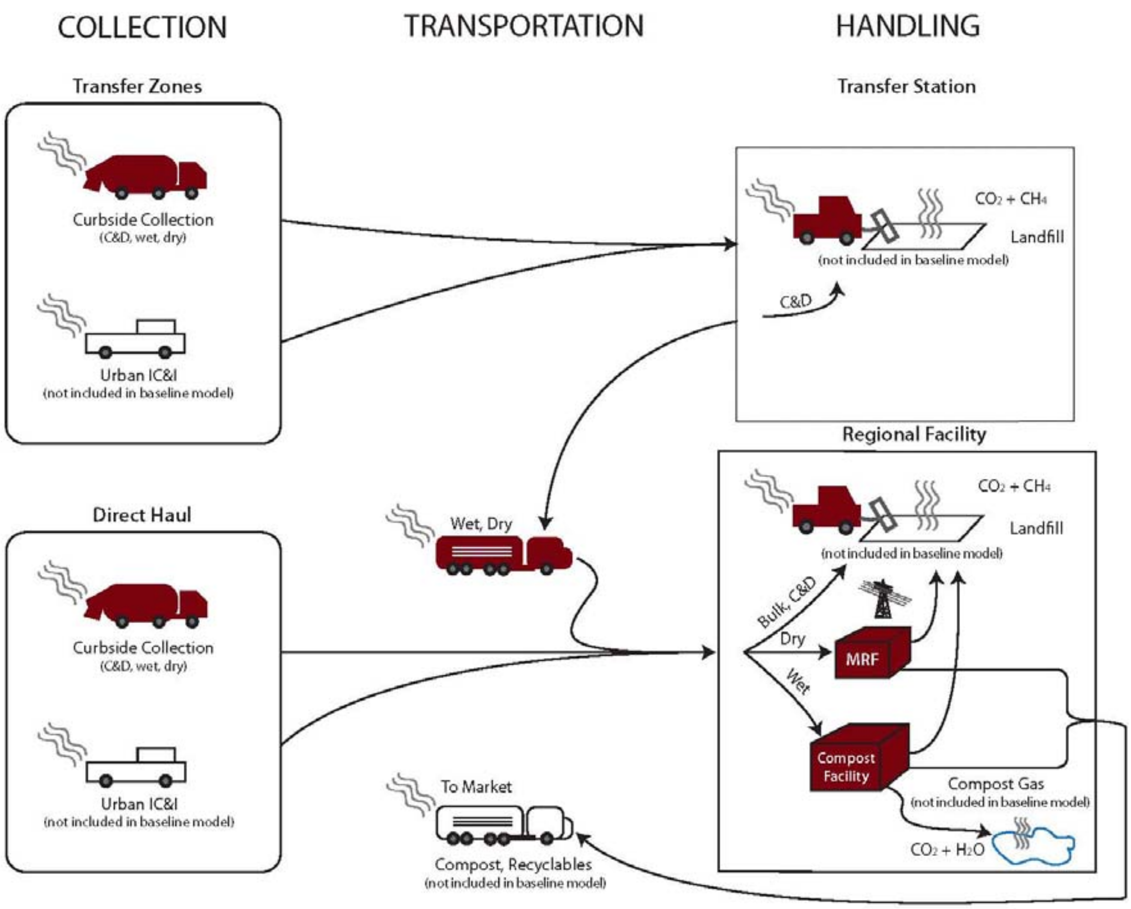


Figure 4: Schematic of Western and Central Newfoundland Waste Management System

Under the design criteria, waste is divided by source and type. The source divisions are urban or rural, and industrial, commercial, and institutional (IC&I) or residential. The types of waste are construction and demolition (C&D), wet, dry, bulk, and metal.

Bulk and metal waste is transported directly to transfer stations or RWMFs by members of the public. Presently, all metal waste will be shipped out of the facilities by a local operator. The actions of the public and the local operator were not modelled due to a lack of information; however, it is expected that this activity would be relatively low compared to the activities under the scope of the RWMF operations (since metal waste accounts for only 5% of the total waste stream).

The tonnages of bulk, dry, wet, and C&D waste handled in Western and Central Newfoundland were provided by BNG; the combined value for both regions was 101,102 tonnes per year. The expected waste composition of the waste is described in Table 11, along with the expected processing percentages (including natural processes).

Table 11: Waste Composition and Processing

Waste Composition	Percentage
Percentage of Waste - C&D	14%
Percentage of Waste - Dry waste	48%
Percentage of Waste - Wet waste	30%
Percentage of Waste - Bulk	3%
Percentage of Waste - Metals	5%
Waste Processing	
Percentage of Dry Waste Diverted and Sent to Market	56%
Percentage of Wet Waste Diverted and Sent To Market	17.7%
Percentage of Wet Waste Lost to Water and CO_2	34.7%
Percentage of Lost Wet Waste Released as CO_2	46.0%

As shown in Figure 4, the operations of the waste management system were modelled as follows:

- Wet, dry and C&D waste from the rural division (both IC&I and residential), as well as residential urban is collected from the curb side using waste compactor trucks.
- Waste collected in a transfer zone is driven by compactor to a transfer station before being transported to the appropriated RWMF. In the region near the RWMF, waste is directly hauled to the regional facility following collection.
- Minimal operations occur at the transfer stations; SLE assumed that the major process that occurs here is the land filling of C&D waste[13].
- The other waste streams – wet, dry and bulk – are shipped by tractor/trailer from transfer stations to the RWMF. In Scenario 1, all waste is hauled to the Central RWMF in Norris Arm, whereas in Scenario 2, the waste from the Western Region is hauled a shorter distance to the Wild Cove RWMF. Although the collection of urban IC&I waste is not included in the model (as noted in the exclusions below), the transportation of this waste stream from the transfer stations to the RWMF is included.
- At the RWMF, bulk waste is land filled along with the C&D waste that is hauled directly to the regional facility.

[13] BNG has indicated that separate regional C&D handling facilities may be built in both the Western and Central Zones. However, no information was available on this option so the model assumed that all C&D waste was land filled after collection, at its first point of rest.

- The dry waste is processed at a Material Recycling Facility at each RWMF. Some of that waste is recovered and transported out of the RWMF to market. The un-recoverable dry waste is land filled.
- The wet waste is processed and cured at the Compost Facility at each RWMF. Similar to the dry waste, some of the wet waste is rejected and land filled. The cured compost is shipped out for use by local authorities. During the composting process, a substantial amount of the weight of the wet waste is lost, some to water evaporation and some to direct CO_2 emissions.

Major assumptions in the model include:

- The lifetime of the RWMFs and transfer stations in both scenarios will be 50 years.
- All facilities in the RWMFs are fully operational for the life of the facility. The construction phase described in Section 3.3 was assumed to be 100% completed before the 50 years of operations begins.
- The composition and size of the waste stream in Table 11 will remain constant for all 50 years of the system's operation.
- The efficiency of the waste processing in Table 11 will remain constant for all 50 years of the system's operations.
- Transfer stations and RWMFs operate 5 days a week, 52 weeks a year.
- All transportation activity occurs on roads. While there are some barge/boat activities expected, this will be a very small percentage of the total waste transportation in terms of fuel consumption and dedicated vehicle/vessel use.
- The equipment requirements of each RWMF are identical for both scenarios (but operational requirements will differ).
- The operational and equipment requirements for each transfer station are identical for both scenarios.
- All fuel consumed by vehicles and equipment is diesel.

A more detailed description of the waste operations is provided in Appendix I, including the specific estimates used in the emission calculations for the two scenarios. A summary of the operations emissions is provided in Table 12.

Table 12: Summary of Operations Phase GHG Emissions for Both Scenarios

LCA Phases	Scenario 1 GHG Emissions (t eCO_2)	Scenario 2 GHG Emissions (t eCO_2)
Operation - Collection	92,768	92,768
Operation - Transportation	96,691	31,032
Operation - Transfer Stations	21,363	19,837
Operation - RWMFs	41,776	58,659
Operations Total	**252,598**	**202,295**

Several significant GHG emission sources of the Operations phase were excluded from the baseline model either because they are outside the direct control of the waste management facilities or because they are not likely to vary between the two scenarios. These exclusions are as follows:

- transportation of recyclables and compost to market;
- urban IC&I waste is collected by local operators (likely with pickup trucks);
- the CO_2, CH_4 and N_2O released during composting do not vary between the two scenarios; and
- the greenhouse gases released during decomposition of the waste in the landfills are equivalent for the two scenarios.

These four emission sources are explored in more detail in Chapter 4.

3.5 Decommissioning

Decommissioning of the transfer stations and the RWMFs was modelled in a straightforward fashion, as detailed characteristics were not available. Based on discussions with BNG, the model assumed that a bull dozer would demolish the facilities and deposit all the waste in the existing landfills. At each transfer station, this process was estimated to require 20 days. For an RWMF, the time was estimated at 120 days. The embedded emissions of the dozer were not included as their use for demolition would represent only a small fraction of their useful lifetimes.

A summary of the decommissioning emissions for each scenario is provided in Table 13.

Table 13: Summary of Decommissioning Phase GHG Emissions for Both Scenarios

LCA Phases	Scenario 1 GHG Emissions ($t\ eCO_2$)	Scenario 2 GHG Emissions ($t\ eCO_2$)
Decommissioning – Transfer stations	44	41
Decommissioning – RWMFs	57	114
Decommissioning Total	**101**	**155**

3.6 Complete Inventories

The complete LCIs for the two potential Plan scenarios are shown in Table 14. Over the full lifetime of the waste management systems, Scenario 1 (operation of an expanded Central RWMF) was found to have an estimated carbon footprint of 376,001 tonnes of eCO_2, compared with a total footprint of 326,872 tonnes of eCO_2 for Scenario 2 (operation of separate regional facilities for both the CNWMZ and the WNWMZ). This is considered the baseline model outcome.

Table 14: Summary of Baseline Model GHG Emissions for Both Scenarios

LCA Phases	Scenario 1 GHG Emissions ($t\ eCO_2$)	Scenario 2 GHG Emissions ($t\ eCO_2$)
Procurement of Materials	118,669	117,848
Construction - Transfer Stations	2,512	2,333
Construction - RWMFs	2,121	4,241
Operation - Collection	92,768	92,768
Operation - Transportation	96,691	31,032
Operation - Transfer Stations	21,363	19,837
Operation - RWMFs	41,776	58,659
Decommissioning - Transfer Stations	44	41
Decommissioning - RWMFs	57	114
Baseline Model Total	**376,001**	**326,872**

The difference in scenario emissions was primarily caused by a greater amount of transportation activity for Scenario 1 over Scenario 2. Scenario 1 is expected to require less construction material – and therefore less embedded emissions – to build one regional facility instead of two. Similarly, the operation of just one RWMF instead of two facilities has a lower net carbon footprint for Scenario 1. However, these emission advantages are not sufficient to offset the extra driving distances required in Scenario 1. Further evaluation of the scenario inventories is provided in Chapter 4.

4.0 EVALUATION

This chapter provides a broader discussion of the two scenarios by evaluating the estimated uncertainty in the LCI summaries, completeness of the LCI and sensitivity analysis.

4.1 Uncertainty Analysis

As elaborated in Appendix II, an uncertainty scheme was used to track the overall uncertainty in the scenario emissions by activity type and total inventory amounts. Inherent to the uncertainty framework is an assumption that the model parameter values do not suffer from a systematic bias in either the activity estimates provided by BNG or developed by SLE, or the eCO_2 emission rates sourced from available models, i.e., the uncertainty assumptions and estimates applied do not tend to consistently over-estimate reality or vice-versa.

The aggregate uncertainty estimates are presented along with the emission estimates for each LCI phase in Table 15. The overall uncertainty in the scenario LCI estimates was found to be acceptable, since the most significant emission generating activities in the model (waste pickup and transport) could be characterised reasonably well. The activities with relatively high uncertainty, such as decommissioning, did not have a large impact on the emission totals. The difference in total emissions for the two scenarios was found to be greater than the estimated uncertainty within the conceptual model, which supports the conclusion that Scenario 2 has the lower lifetime carbon footprint.

Table 15: Summary of Baseline Model GHG Emissions for Both Scenarios, including Uncertainties

LCA Phases	Scenario 1		Scenario 2	
	GHG Emissions (t eCO_2)	Uncertainty (%)	GHG emissions (t eCO_2)	Uncertainty (%)
Procurement of Materials	118,669	12.3%	117,848	13.2%
Construction - Transfer Stations	2,512	27.1%	2,333	27.1%
Construction - RWMFs	2,121	27.1%	4,241	27.1%
Operation - Collection	92,768	10.1%	92,768	10.1%
Operation - Transportation	96,691	13.5%	31,032	12.7%
Operation - Transfer Stations	21,363	26.3%	19,837	26.3%
Operation - RWMFs	41,776	16.9%	58,659	16.3%
Decommissioning - Transfer Stations	44	60.0%	41	60.0%
Decommissioning - RWMFs	57	60.0%	114	60.0%
Baseline Model Total	**376,001**	**6.3%**	**326,872**	**6.6%**

The comparison metric for this study may be considered the amount of carbon emissions (as eCO_2) per tonne of waste handled over 50 years. The LCI results indicate that a value of 74.3 kg of eCO_2 per tonne of waste would accompany Scenario 1 whereas 64.7 kg/tonne would accompany Scenario 2. This is a difference of approximately 15%.

4.1.1 LCI Completeness

Not surprisingly, transportation of waste is the key driver of the LCI difference for the two scenarios. To put the magnitude of this difference into a broader context, additional emission sources were investigated, including:

- emissions due to the urban IC&I waste transported by local operators and accepted at the RWMFs;
- emissions due to recyclables and compost transported to market by local operators from the RWMFs; and
- emissions (both methane and carbon dioxide) that may be released from the RWMF landfill(s) as well as the RWMF Compost Facilities over time.

Estimates associated with the urban IC&I and recyclables/compost transport were completed without difficulty, whereas compost and landfill emission estimates requires characterisation of several parameters in addition to the composition of waste. The GHG emissions generated by the landfill were estimated based on the LandGEM model developed by the US Environmental Protection Agency[14]. LandGEM is an Excel-based tool used to estimate methane and carbon dioxide generated from the break-down of materials in a landfill. The quantity of gas released depends on the annual tonnage of waste, the waste composition, temperature, moisture levels, and other factors.

LandGEM was used assuming an annual landfill input of 55,763 tonnes of waste and its “inventory default” settings for waste composition and methane generation. It should be noted that a detailed investigation of the waste composition in the landfill and the soil/climate conditions of the areas could result in a substantially different estimate from the LandGEM model. However, such an investigation was beyond the scope of work for this project.

[14] http://www.epa.gov/nrmrl/pubs/600r05047/600r05047.htm

A report on the IPS Compost system[15] to be used at the RWMFs indicates that little CH_4 and N_2O would be released during the compost curing process. However, substantial amounts of CO_2 are expected to be released over a 50 year period and these estimates were available[16].

A re-expression of the scenario emissions accounting for these additional sources of interest is provided in Table 16. Although the urban IC&I and recyclables/compost transportation emissions do not substantially affect the comparison outcomes, the potential landfill and compost emissions dramatically change the implications, leaving the two scenarios with approximately the same level of carbon footprint.

Table 16: Summary of Baseline Model GHG Emissions for Both Scenarios, including Uncertainties

LCA Phases	Scenario 1		Scenario 2	
	GHG Emissions (t eCO_2)	Uncertainty (%)	GHG Emissions (t eCO_2)	Uncertainty (%)
Baseline Model Total	376,001	6.3%	326,872	6.6%
Landfill Gas (LandGEM)	2,550,100	60.0%	2,550,100	60.0%
Compost Gas	254,625	18.1%	254,625	18.1%
Recyclables/Compost Transport	89,131	14.5%	89,131	14.5%
Urban IC&I Collection	30,806	16.1%	30,806	16.1%
GHG Emissions Total	**3,300,663**	**46.4%**	**3,251,534**	**47.1%**

The implications of tree removal on carbon emissions during construction of the transfer stations and RWMFs were not considered as part of the LCI completeness evaluation. When considering the impact of land use change (i.e., forestry to waste management) there are two potential aspects to evaluate: (1) the embedded carbon within the removed forest and (2) the change in annual carbon emissions and removals due to forest removal.

15 http://www.water.siemens.com/SiteCollectionDocuments/Product_Lines/Microfloc_Products/Brochures/MerrmckC02AnalysFINALApr08.pdf

16 Stearns & Wheeler. "Preliminary Design Report, Central Newfoundland Municipal Solid Waste Processing Facility," November 2009.

Canada's forests store large amounts of carbon in the biomass above and below ground. It can be assumed that the embedded carbon above ground (trees) will not be emitted once harvested, since the trees could be used for timber, paper or biomass (in place of other biomass or fossil fuels). Soils will be disturbed during construction and some of the carbon stored below ground is likely to be emitted. However, at this time the amount of carbon stored within soil cannot be estimated to a reasonable level of assurance.

Research undertaken by Natural Resources Canada[17] showed that between 1990 and 2005, Canada's managed forests acted as an overall sink for carbon for all but five years and there is a 90% chance that the forests will act as sources in 2012. Efforts are currently underway to improve management activities such that forests behave as carbon sinks in the future.

For the reasons noted above, no effort was made to quantify the increase (or decrease) in carbon emissions due to the removal of trees at the potential RWMF or transfer station sites.

4.1.2 Sensitivity Analysis

As implied by the uncertainty estimates in Table 16, the total emission levels for the two scenarios, when including significant additional sources common to each, should not be interpreted as accurate. For example, much of the gas generating materials for the landfill (the wet waste in particular) will be diverted through processing, meaning the total landfill emissions could be half or less of the values indicated. In addition, the gas generating potential of a landfill would depend somewhat on size, potentially making the difference between two landfills (Scenario 2) and one landfill of twice the size (Scenario 1) significant.

As such, the landfill emission values of 2,550,100 tonnes eCO_2 should be considered as the "nominal-case". A "best-case" situation could yield a value 60% lower, at 1,020,040 tonnes eCO_2.

The addition of landfill and compost emissions to the scenario comparisons shows that the construction, operation and decommissioning of the RWMFs for the two scenarios have been characterised to a sufficient level of detail and accuracy to interpret the climate change implications of the two scenarios. A more important aspect of the Provincial Waste Management Strategy may be how the RWMF landfill(s) are managed in terms of GHG gas emissions.

[17] http://warehouse.pfc.forestry.ca/HQ/27501.pdf

5.0 CONCLUSION

The Life Cycle Analysis of the two Plan scenarios resulted in an estimated difference in emissions of 49,000 tonnes of eCO_2 over the 50 year lifespan of the waste facilities, or 10 kg eCO_2 per tonne of waste handled. This difference was considered large enough to be meaningful for the emission sources evaluated for construction and operation over 50 years. As displayed in Figure 5, transportation related emissions were found to be largely responsible for the better carbon performance of Scenario 2 over Scenario 1.

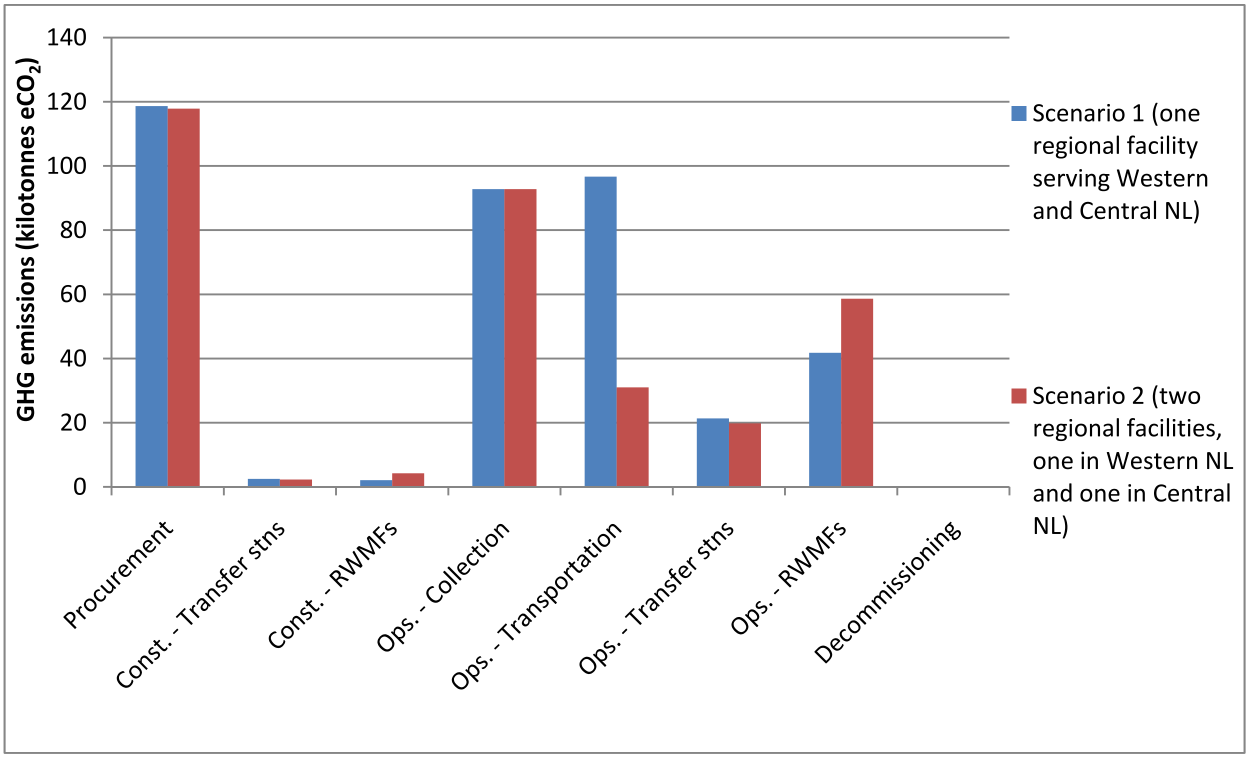


Figure 5: Summary of Baseline Model GHG Emissions for Both Scenarios

An LCA is often structured to evaluate design elements that are different between scenarios, omitting the elements that could be considered common. As shown in Figure 6, a re-evaluation of the scenario emission totals including rough estimates for the greenhouse gases that would be released from composting and land filling implies that a difference of 10 kg eCO_2/tonne of waste has far less significance when additional sources of GHGs common to both scenarios are included. When including the additional sources, the total emissions come to 653 kg eCO_2/tonne of waste handled for Scenario 1 and 643 kg/tonne for Scenario 2.

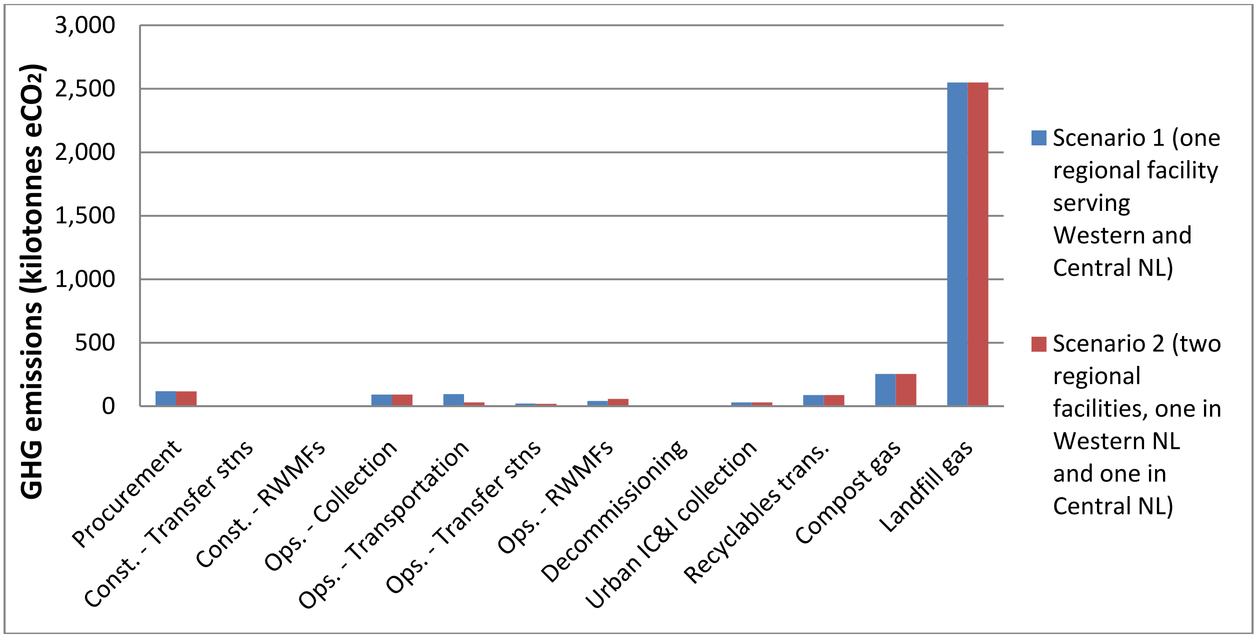


Figure 6: Summary of Scenario Emissions including "Nominal-Case" Landfill/Compost Gas and Urban IC&I and Recyclables/Compost Transport

To put the magnitude of these emissions into perspective, it is estimated that the difference between the scenario emissions amounts to approximately 5.5 kg eCO_2 per person per year for the residents within the Western and Central Zones. This relates to a total residential emission level of approximately 2,400 kg per person per year according to a GHG emissions assessment completed for St. John's in 2006, or the idealized "one tonne challenge" (1,000 kg per person per year) level the Canadian federal government previously aspired to for a national average. Residential emissions in this context include home space heating as well as personal vehicle use.

The LCA has been completed in line with the goal and scope defined at the outset of this project. The assessment has shown that Scenario 2 is preferential in terms of lifetime equivalent carbon dioxide; however, the difference between emission totals was not considered to be significant when emissions from additional sources common to both scenarios are included. As such, it is recommended that further analysis be considered for the Solid Waste Management Plan landfill design, in particular relating to the potential for landfill gas capture and increasing the diversion rate of wet waste (to reduce the landfill gas generation).

APPENDIX I: MODEL DETAILS

Section 3.4 provided an overview of the model for the operations of the waste management system. This appendix describes the operation component of the model in more detail. Operations are broken down below into three separate sections: collection, transportation and handling/processing.

Collection of Waste

Table I-1 shows the collection times and driving distances between collection for each transfer and direct haul zone, as provided by BNG. The collection time is the time spent by a trash compactor collecting waste inside a city; it includes both driving time between homes and idling periods during collection. The driving distance between collections corresponds to the inter-city driving of trash compactors. The driving circuit of trash compactors is circular, starting and ending at the transfer station (or RWMF), so back-haul distances were not included.

Table I-1: Waste Collection Times and Driving Distances

Transfer Zone	Collection Time (hrs / week)	Uncertainty (%)	Driving Distance (km / week)	Uncertainty (%)
Central				
Zone 1 - Buchan's Junction	9.20	10%	78.00	10%
Zone 2 - Point Leamington	19.37	10%	229.00	10%
Zone 3 - New Work Island (Virgin Arm-Carter's Cove)	59.77	10%	459.00	10%
Zone 4 - Fogo Island	20.50	10%	125.00	10%
Zone 5 - Gander Bay (Main Point-Davisville)	28.48	10%	310.00	10%
Zone 6 - Indian Bay	50.55	10%	407.00	10%
Zone 7 - Terra Nova	51.50	10%	363.00	10%
Direct haul to Norris Arm RWMF	221.03	10%	3,161.00	10%
Western				
Zone 1 - Rocky Harbour	23.27	10%	263.40	10%
Zone 2 - Hampden	11.43	10%	121.20	10%
Zone 3 – Burgeo	15.10	10%	178.35*	30%
Zone 4 - Port aux Basques	56.73	10%	495.60	10%
Zone 5 - Bay St. George	105.37	10%	1,447.80	10%
Zone 6 - Eddie’s Cove	81.20	10%	947.90*	30%
Direct haul to Wild Cove RWMF/transfer	207.19*	30%	2,309.51*	30%

* These values are estimated based on collection time, distance and tonnage (values were not available from BNG). The associated uncertainties were therefore set to a higher value of 30%.

The collection-related emissions do not change between the two scenarios[18]. If only the Central RWMF is built, then the Western RWMF in Wild Cove becomes a transfer station. As such, the direct haul zone would become a transfer zone. The collection time and driving distances were considered reasonably accurate so their uncertainty was set to 10%, except where noted in the table.

To calculate the emissions associated with collection, the following assumptions were applied:

- Trash compactors spend 20% of their collection time idling and 80% driving[19].
- The average speed of a trash compactor during collection in the city is 30 km/h (collection time driving would be a lot of stop/start and movement at slow speed, with some driving time on city streets at 50 km/h).
- The same collection times and driving distances apply for all 52 weeks of the year.

Initial BNG estimates indicated that 15-16 (14 plus 1-2 for replacement/maintenance periods) compactor trucks would be required for curbside collection in the Central Zone. To account for the Western Zone, SLE assumed that a total of 30 trash compactors would be purchased at the beginning of operations. Based on the total compactor distance driven each year, an effective annual replacement rate was calculated based on an expected lifetime of 300,000 km.

Transportation of Waste

Table I-2 lists the driving distances between each transfer station and its respective RWMF, for both scenarios. All distances were calculated using ArcGIS Explorer[20], based on transfer station and RWMF locations provided by BNG. As indicated, within the Western Zone there was a substantial difference between Scenario 1 and Scenario 2 since all transfer station waste would be shipped a greater distance in Scenario 1, to the Central RWMF outside of Norris Arm. In Scenario 2, there was no hauling required for Wild Cove since the curbside collection would encompass transportation of the waste from the direct haul zone to the RWMF.

[18] Curbside collection was included in the Baseline Model because initially it was thought that the Wild Cove RWMF would be replaced by more than one transfer station, which would produce a different emissions profile between the two scenarios.

[19] Personal communication, Chris Bullock, SLE, March 4, 2011.

[20] http://www.esri.com/software/arcgis/explorer/index.html

Table I-2: Driving Distances between Transfer Stations and Regional Facilities

Transfer Zone	Driving Distance to RWMF			
	Scenario 1 (km)	Uncertainty (%)	Scenario 2 (km)	Uncertainty (%)
Central				
Zone 1 - Buchan's Junction	120	10%	120	10%
Zone 2 - Point Leamington	65	10%	65	10%
Zone 3 - New Work Island (Virgin Arm-Carter's Cove)	70	10%	70	10%
Zone 4 - Fogo Island	105	10%	105	10%
Zone 5 - Gander Bay (Main Point-Davisville)	100	10%	100	10%
Zone 6 - Indian Bay	150	10%	150	10%
Zone 7 - Terra Nova	120	10%	120	10%
Western				
Zone 1 - Rocky Harbour	350	10%	145	10%
Zone 2 - Hampden	250	10%	135	10%
Zone 3 - Burgeo	515	10%	220	10%
Zone 4 - Port aux Basques	450	10%	225	10%
Zone 5 - Bay St. George	380	10%	85	10%
Zone 6 - Eddie’s Cove	590	10%	390	10%
Direct Haul/Zone 7 - Wild Cove RWMF/transfer	310	10%	0	10%

As indicated in Section 3.4, all C&D waste will be land filled, either at the transfer stations or at the RWMF if direct hauled. The wet and dry waste will be shipped to the RWMF. The model also assumed that the bulk waste dropped off by the public at a transfer station would be chipped and hauled with the wet and dry waste to the RWMF.

Based on the distance between a transfer station and its RWMF and the tonnage of a tractor/trailer, the annual number of trips from each transfer station was calculated. A total annual distance is then determined and emissions calculated based on the emission factors from Table 3. To perform the calculations, the following assumptions were employed:

- the tractor/trailers always travelled with a full load;
- the capacity of a tractor/trailer was 21 tonnes; and
- back-haul (empty return trips) of tractor/trailers was included.

Based on the total annual distance, the model determined that a total of 12 tractor/trailers (working 8 hours a days, 260 days a year) would be required to haul waste to the RWMF in Scenario 1.

For Scenario 2, the shorter annual distance meant that the initial tractor/trailer requirements were only four units. Vehicle replacement was estimated based on an expected lifetime of five years per vehicle, as noted by BNG.

Handling and Processing of Waste

Waste transported to the RWMF will be handled and processed based on its type (e.g., wet, dry, C&D). The emissions associated with this stage of operations derive from several sources, primarily equipment.

BNG provided a list of the equipment requirements for an RWMF. The daily use of the equipment for each scenario was estimated based on discussions with SLE's waste expert. It was assumed that all equipment would be used every working day. Table I-3 lists the average equipment usage for Scenarios 1 and 2. The uncertainty levels (not shown) for each estimate were assumed to be 20%.

Table I-3: Activity Data for Waste Handling at One RWMF

Equipment Type	Activity Data - Scenario 1			Activity Data - Scenario 2		
	Daily Use (hrs)	Annual Use (days)	Number of Units	Daily Use (hrs)	Annual Use (days)	Number of Units
Pick Up Trucks	8	260	2	8	260	2
Landfill Compactor	6	260	1	4	260	1
Dozer	6	260	1	4	260	1
Excavator	6	260	1	4	260	1
Tandem Dump Truck	6	260	2	4	260	2
Roll-On/Roll-Off Truck	6	260	1	4	260	1
Medium Wheeled Loader	6	260	2	4	260	2
Small Wheeled Loader for MRF	6	260	1	4	260	1
Shuttle Tractor	6	260	1	4	260	1

The activity data listed for Scenario 2 are for 1 RWMF and therefore are actually twice as high since two RWMFs are operated under that scenario. As such, the total hours of use were lower for Scenario 1 compared to Scenario 2, even though the quantity of waste handled would be identical. This is because SLE assumed that equipment usage would be more efficient with one RWMF over two.

From the values in Table I-3 the annual hours of use were calculated for each type of unit. The emissions were calculated by mapping the unit type to the corresponding emission factor in Table 3. The emissions associated with diesel and vehicle manufacturing/replacement were calculated as previously described. The expected lifetime of the facility machinery listed in Table I-3 was set at 10,000 hours, as noted by BNG.

Beyond the operation of the diesel-powered equipment listed above, all other operations (e.g., conveyors in the Material Recycling Facility, aerating wet waste in the Compost Facility) will be powered by electricity. Similarly, all heating for the RWMF operations will be provided by electricity. Data provided by BNG indicated that the total electrical load for 1 RWMF is expected to be 1250kW. This value includes all electrical requirements for the leachate facility, administration building, scale house, public drop-off, metal goods and storage area, fire pump, maintenance garage, C&D drop-off, Material Recycling Facility, Compost Facility, and general area lighting.

The emission factor (effective carbon intensity) for electricity in Newfoundland was set to 26 t/GWh, the average intensity factor between 2004 and 2008[21]. Furthermore, the electrical grid mix was assumed to remain constant for the lifetime of the waste management system such that the emission factor would not change.

Waste handling and processing for a transfer station was modelled in a similar fashion with lower activity levels and equipment requirements. Consistent with BNG's expectation, only a single piece of equipment was modelled for each transfer station: a Caterpillar 450 backhoe. The electricity load at the transfer stations was assumed to be 250kW (accounting for an administration building, scale house, public and C&D drop-off, fire pump, and general lighting).

For reasons of significance, relevance, or lack of information, some elements of the regional facility operations were not modelled:

- Any fugitive emissions of chlorofluorocarbons and hydrofluorocarbons (potent greenhouse gases) from HVAC equipment would be insignificant.
- Vapours from household hazardous waste are insignificant in terms of global warming potential.
- No GHG emissions are released from the leachate facility.
- Waste system employee commuting was considered outside the scope of the analysis.
- Water usage is not included in any way. Based on information provided by BNG, the primary use of water for the RWMFs is during the composting process to maintain the adequate moisture level needed for decomposition. Approximately 20% of the weight of the wet waste will be added in the form of water (or, potentially, sewage). This water will evaporate during the curing process and so it is not necessary to include it in the mass balance estimates.

[21] Environment Canada. "National Emission Inventory, 1990-2008, Part 3".

APPENDIX II: UNCERTAINTY ANALYSIS

An uncertainty scheme was used to track the overall uncertainty in the scenario emissions by activity type and total inventory amounts. The Intergovernmental Panel on Climate Change (IPCC) supports use of an inventory uncertainty framework for greenhouse gas (GHG) emissions at the national level that has been supported for use in smaller scale inventories (e.g., corporate GHG inventories) by the World Resources Institute (WRI), the World Business Council for Sustainable Development (WBCSD), The Climate Registry (TCR), and others. The IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* outlines framework (Chapter 6 of the publication – Quantifying Uncertainties in Practice)[22].

Inherent to the uncertainty framework is an assumption that the uncertainty values do not suffer from a systematic bias in either the activity estimates provided by BNG and/or developed by SLE, or the eCO_2 emission rates sourced from outside models. In other words, the uncertainty assumptions and estimates applied do not tend to consistently over-estimate reality or vice-versa.

As noted in the IPCC guidance, the pragmatic approach for determining quantitative uncertainty measures is to use the best available estimates, which may be from measured data, published information, model outputs, or expert judgment. Uncertainty levels for the activities and emission rates used in the LCA model stemmed from available data sources and models and often simply from judgment of the report authors.

The aggregate uncertainty for terms multiplied together is calculated with Equation 2 below. Aggregation for terms added together is completed with Equation 3. These two equations comprise the uncertainty framework used in the LCA model to develop the total uncertainties expected for the two scenario life cycle inventories.

$$U_{source} = \sqrt{\left(U_{Activity}\right)^2 + \left(U_{Emission\_Factor}\right)^2} \qquad \textbf{\{Equation 2\}}$$

- U_{source} = Combined uncertainty for the individual source (percent)
- $U_{Activity}$ = Uncertainty for the activity measure (percent)
- $U_{Emission\_Factor}$ = Uncertainty for the emission factor (percent)

$$U_{total} = \frac{\sqrt{\left(U_1 * X_1\right)^2 + \left(U_2 * X_2\right)^2 + \ldots + \left(U_n * X_n\right)^2}}{\left|X_1 + X_2 + \ldots + X_n\right|} \qquad \textbf{\{Equation 3\}}$$

[22] http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

- U_{total} = Combined uncertainty (percent) for the source group (or entire inventory)
- U_1 and X_1 = Uncertainty (percent) and associated emission estimate for source 1

For completeness, Tables II-1 to II-4 list the aggregate uncertainties for each phase of the Baseline LCI Model.

Table II-1: Summary of Procurement Phase GHG Emissions for Both Scenarios, with Uncertainties

Product Type	Scenario 1		Scenario 2	
	GHG Emissions (t eCO_2)	Uncertainty (%)	GHG Emissions (t eCO_2)	Uncertainty (%)
Construction Materials	20,851	28.7%	35,432	32.0%
Compactors and Haul Trucks	25,755	27.0%	20,787	32.0%
Facility Waste Handling Equipment	10,167	28.9%	12,149	24.1%
Diesel	61,896	17.8%	49,480	15.8%
Total Procurement Emissions	**118,669**	**12.3%**	**117,848**	**13.2%**

Table II-2: Summary of Construction Phase GHG Emissions for Both Scenarios, with Uncertainties

LCA phases	Scenario 1		Scenario 2	
	GHG emissions (t eCO_2)	Uncertainty (%)	GHG emissions (t eCO_2)	Uncertainty (%)
Construction - Transfer stations	2,512	27.1%	2,333	27.1%
Construction - RWMFs	2,121	27.1%	4,241	27.1%
Total Construction	**4,633**	**19.2%**	**6,574**	**20.0%**

Table II-3: Summary of Operations Phase GHG Emissions for Both Scenarios, with Uncertainties

LCA Phases	Scenario 1		Scenario 2	
	GHG Emissions (t eCO_2)	Uncertainty (%)	GHG Emissions (t eCO_2)	Uncertainty (%)
Operation - Collection	92,768	10.1%	92,768	10.1%
Operation - Transportation	96,691	13.5%	31,032	12.7%
Operation - Transfer stations	21,363	26.3%	19,837	26.3%
Operation - RWMFs	41,776	16.9%	58,659	16.3%
Operations Total	**252,598**	**7.3%**	**202,295**	**7.4%**

Table II- 4: Summary of Decommissioning Phase GHG Emissions for Both Scenarios, with Uncertainties

LCA Phases	Scenario 1		Scenario 2	
	GHG Emissions (t eCO_2)	Uncertainty (%)	GHG Emissions (t eCO_2)	Uncertainty (%)
Decommissioning – Transfer stations	44	60.0%	41	60.0%
Decommissioning – RWMFs	57	60.0%	114	60.0%
Decommissioning Total	**101**	**42.8%**	**155**	**46.9%**