The Biosolids Emissions Assessment Model (BEAM): A Method for Determining Greenhouse Gas Emissions from Canadian Biosolids Management Practices

Executive Summary

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EXECUTIVE SUMMARY

Biosolids management practices are evaluated based on environmental, economic and social impacts. A consideration of increasing importance is the impact of greenhouse gas (GHG) emissions from biosolids (treated sludge). The Canadian Council of Ministers of the Environment (CCME) retained the services of SYLVIS Environmental, and their project team, composed of Ned Beecher (Northeast Biosolids and Residuals Association), Dr. Sally Brown (University of Washington, College of Forest Resources), and Andrew Carpenter (Northern Tilth) undertook a review of literature and leading GHG accounting and verification protocols, and developed a model for calculating GHG emissions from biosolids management. Using the model, GHG emissions estimates were calculated for nine biosolids management scenarios across Canada.

The literature review was completed to verify potential GHG sources and emission factors for biosolids and sludge management processes in the model development. Where possible, values, emission factors and assumptions were corroborated by multiple sources to ensure the use of the most current and accurate information possible.

A review of existing GHG accounting and verification protocols was completed to ensure the terminology and reporting methods adopted in the model were consistent with these protocols. Development of the model was based on leading protocols to facilitate the use of the model as a tool that is widely accepted as a verifiable method of determining carbon credits which can be sold or traded to offset the cost of biosolids management.

The model, termed the “Biosolids Emissions Assessment Model”, (BEAM) consists of 12 unit process calculator modules and an aggregating spreadsheet that calculates net GHG emissions based on the values determined within each applicable module.

The BEAM was developed to be flexible and user friendly and to facilitate use throughout Canada. The BEAM accomplishes this by:

- allowing the user to select only the unit process calculator modules that apply to their management practices;
- clearly highlighting within each calculator module the data required to generate a GHG emission value for each unit process;
- having the option to use default values that are used in the absence of user-provided data;
- locked calculator modules that are not input cells, thereby reducing calculation errors; and

- having the flexibility to be easily revised based on new information gained through scientific research in the fields of GHG emissions and biosolids management.

The BEAM returns a net and per dry megagram (Mg) biosolids GHG emissions value based on user inputs and the use of default values as required. The BEAM, in following conventional GHG reporting and protocols, delineates emissions by Scope 1, 2 and 3 emissions; descriptions and examples of these emission scopes are provided within the final report.

A user guide was developed to assist jurisdictions using the BEAM. The user guide provides a step-by-step description of how to use the BEAM and includes captioned figures that show specific elements of the model. The user guide provides an explanation of how to review and interpret results. The appendices within the final report provide further explanation on the calculations and assumptions used in each BEAM unit process module.

The start and endpoints (boundaries) for the BEAM are from solids thickening at the wastewater treatment plant through to biosolids end/use disposal. Calculator tools were developed to determine GHG emissions from commonly used technologies within this segment of the process train (unit processes). Table 1 provides a summary of factors considered within each unit process module in the BEAM. The extensive lists of considerations for each unit process module demonstrate the level of detail involved in the development of the BEAM.

Table 1: Summary of considerations for unit process calculations.

Unit Process	Considerations
Storage	• mass of BOD in storage (kg/day) • aeration and electricity use (kWh/day) • depth of storage lagoon (m)
Solids Conditioning / Thickening	• volume of sludge thickened (m^3/day) • sludge solids content (%) • thickening process • polymer use (kg/day) • electricity use (kWh/day)
Aerobic Digestion	• volume of sludge to digestion (m^3/day) • sludge solids content (%) • volatile solids content (%) • volatile solids destruction (%) • electricity use (kWh/day) • fuel use, if needed (m^3/day)

Anaerobic Digestion	• volume of sludge to digestion (m^3/day) • sludge solids content (%) • volatile solids content (%) • volatile solids destruction (%) • biogas and methane yield (m^3/day) • net electricity use/gain (kWh/day) • net fuel use/gain (m^3/day) • flaring and fugitive emissions of methane (%)
Dewatering	• volume of sludge thickened (m^3/day) • sludge solids content (%) • thickening process • polymer use (kg/day) • electricity use (kWh/day)
Thermal Drying	• mass of sludge to be dried (Mg/day) • sludge solids content before and after drying (%) • electricity use (kWh/day) • fuel use (m^3/day)
Alkaline Stabilization	• mass of sludge to be stabilized (Mg/day) • sludge solids content (%) • degree of stabilization • amount of alkaline material added (Mg/day) • lime is a by-product (yes/no) • electricity use (kWh/day) • fuel use (m^3/day)
Composting	• mass of sludge to be composted (Mg/day) • sludge solids content (%) • sludge density (kg/m^3) • processing prior to composting • nutrient content of sludge • fertilizer replacement (yes/no) • amount of amendment used (volumetric ratio) • amendment grinding (yes/no) • density of amendment (kg/m^3) • type of composting equipment • biofilter (yes/no) • fuel use (L-diesel/day) • electricity (kWh/day)

Landfill Disposal	• mass of sludge to be landfilled (Mg/day) • sludge solids content (%) • sludge density (kg/m^3) • processing prior to landfilling • nutrient content of sludge • methane correction factor • quality of daily cover • methane captured (%) • methane used for generating electricity (%) • Degradable organic carbon that will decompose in a landfill (DOC_f) (%) • Degradable organic carbon that will degrade prior to methane capture (%)
Combustion	• mass of sludge to be incinerated (Mg/day) • sludge solids content (%) • processing prior to incineration • nitrogen/nutrient content of sludge • type of incinerator • energy recovered as electricity and/or heat (%) • disposition/recycling of ash • urea-based selective noncatalytic reduction emissions system (yes/no) • temperature of combustion • net fuel use/gain, including afterburner fuel requirements in multiple hearth incineration (m^3/day) • net electricity use/gain (kWh/day)
Land Application	• mass of biosolids to be land applied (Mg/day) • biosolids solids content (%) • biosolids density (kg/m^3) • processing prior to land application • nutrient content of biosolids • calcium carbonate equivalence (%) • fertilizer replacement (yes/no) • lime replacement (yes/no) • lime is a by-product (yes/no) • biosolids storage time prior to land application (days) • texture of soils, fine, coarse (%) • fuel use (L-diesel/day)
Transportation	• fuel use for transportation of biosolids or sludge • biodiesel use (% of total fuel)

The BEAM does not include calculations for emissions from emerging/pilot technologies (e.g. plasma oxidation); GHG associated with infrastructure construction; and GHG emissions from upstream wastewater processes (e.g. wastewater conveyance). Emissions from septic tanks and the pumping and management of septage (including its direct land application or transportation to a wastewater treatment facility) are also not within the boundaries of the BEAM.

The BEAM was developed to be applicable to a wide variety of biosolids management scenarios. Nine Canadian jurisdictions provided “real-world” technical data from their biosolids management programs and these data were used in the development and validation of the BEAM. The nine jurisdictions were selected from an initial list of over forty Canadian cities. Selection of the participating jurisdictions was based upon a variety of biosolids management practices, regional representation, leadership in biosolids management, and their commitment to participate in model development. The scenarios cover land use, composting, incineration and landfilling, with or without energy recovery, including anaerobic digestion. While biosolids management from lagoons is not addressed in the nine scenarios, it is still covered by the model.

Table 2 summarizes the scenarios and the unit processes that were used in the BEAM GHG determinations. Net and per dry Mg (tonne) biosolids GHG emissions from these scenarios are provided in Table 3. A summary of net GHG emissions on a per dry Mg (tonne) biosolids basis is presented graphically in Figure 1.

Table 2: Biosolids management scenario unit process summary.

Scenario	Jurisdiction	Unit Processes Considered in BEAM Calculations
1	**Thunder Bay[1]**	• primary clarifier thickening • dissolved air floatation secondary thickening • anaerobic digestion • centrifuge dewatering • transportation • biosolids/soil mix to cover on landfill (final cover, see text)
2	**Incineration scenario[2]**	• primary gravity thickening • rotary press dewatering • incineration (760°C) with heat recovery • ash recycling
3	**Laval**	• primary thickening • anaerobic solids storage of liquid sludge • rotary press dewatering • landfill a portion (14%) of dewatered cake • thermal drying and pelletization • transportation • cement kiln incineration of most biosolids (1460°C)
4	**Windsor**	• primary solids gravity thickening

		• high speed centrifuge dewatering • thermal drying and pelletizing • agricultural land application
5	**Moncton**	• primary clarifier thickening • centrifuge dewatering / polymer addition • alkaline stabilization • composting • compost use
6	**Vancouver**	• primary gravity thickening • dissolved air floatation secondary thickening • anaerobic digestion • digester gas utilization (electricity production) • centrifuge dewatering • transportation • mine site applications
7	**Halifax**	• primary clarifier thickening • anaerobic digestion • digester gas utilization (heat production) • Fournier press dewatering • stabilization using recycled alkaline sources (e.g. cement kiln dust) • transportation • agricultural land application
8	**Nanaimo**	• primary and secondary gravity thickening • aerobic digestion • centrifuge dewatering • transportation • silvicultural land application
9	**Halton**	• dissolved air floatation thickening and polymer addition • anaerobic digestion • liquid biosolids storage • belt filter press dewatering • transportation • liquid and dewatered biosolids agricultural applications

1. Landfilling of sludge/biosolids is only covered partially in Scenario 3 where Laval landfills a part (14%) of the primary sludge. In Scenario 1, Thunder Bay sends anaerobically digested biosolids at a landfill, where it is used as a blended soil product applied on the surface of the landfill for final cover. Hence it is more related to land application scenarios.

2. This scenario corresponds to one of the seven Canadian cities that operate sludge incinerators.

Table 3: Summary of GHG emissions from the biosolids management scenarios.

Biosolids Management Scenario[1]	Jurisdiction	WWTP Name	Population Served	Wastewater Treated (MLD)	Net GHG Emissions (Mg CO_2 equivalents / year)	GHG Emissions Mg CO_2eq/ Mg dry solids
1	Thunder Bay	Atlantic Avenue	100,000	70	1,462	0.09
2	Incineration Scenario	-	-	295	19,608	1.63
3	Laval	La Pinière	271,633	254	10,277	1.02
4	Windsor	Lou Romano	181,348	161	2,427	0.22
5	Moncton	GMSC	125,000	79	1,123	0.18
6	Vancouver	Annacis Island	980,000	436	–1,868	–0.16
7	Halifax	Mill Cove	54,000	27	–875	–0.15
8	Nanaimo	French Creek	25,000	10	177	0.11
9	Halton	Burlington Skyway	165,000	96	–531	–0.18

1 See Table 2 for scenario description.

A summary of net GHG emissions on a per dry Mg biosolids basis are presented graphically in Figure 1.

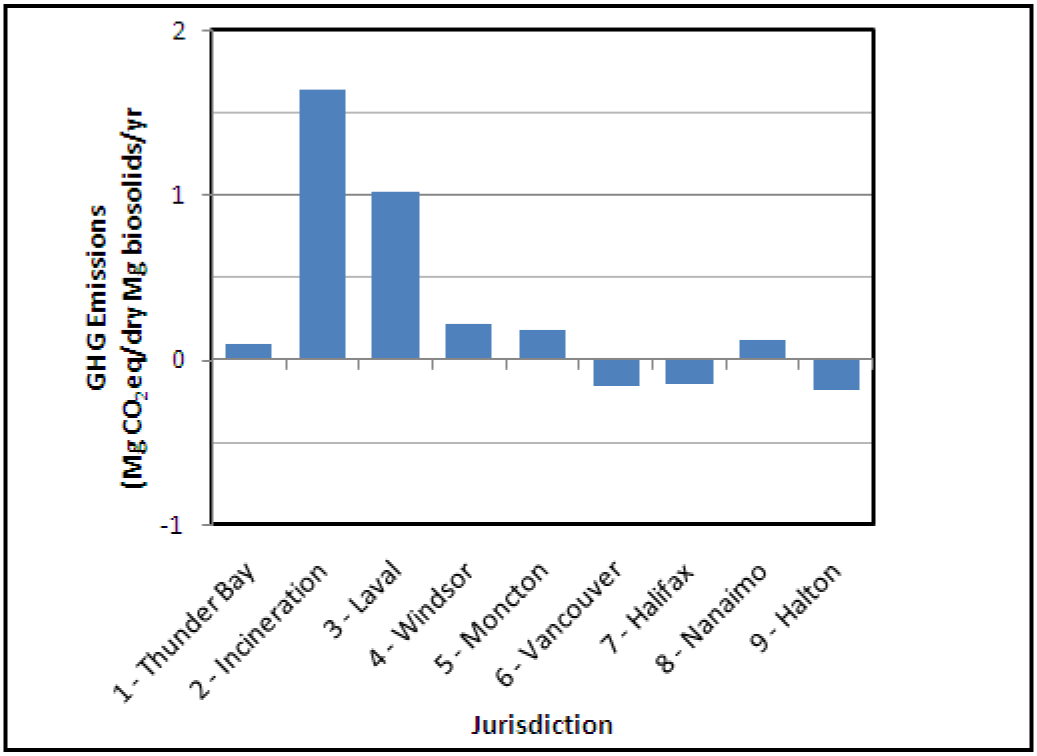

Figure 1: Summary of net GHG emissions on a per dry Mg (tonne) biosolids basis.

Refer to Table 2 for descriptions of each scenario. The BEAM outputs indicate higher emissions from two jurisdictions, the incineration scenario and Laval. In the incineration scenario, the burning of dewatered sludge at relatively low temperature (760°C) produces significant N_2O emissions, according to Japanese studies and the algorithm used in the model. For Laval, N_2O emissions remain low, due to high temperatures of combustion, while CO_2 emissions from heat drying at the WWTP are entirely offset by fuel savings at the cement kiln. Laval's emissions are mainly associated with anaerobic storage of liquid sludge and landfilling a portion (14%) of the primary sludge cake, both of which result in significant CH_4 emissions.

Conversely it appears that net GHG neutrality or offsets can be obtained through land application/surface cover. It is due to less methane and N_2O emissions and also to carbon sequestration in soil and reduced use of chemical fertilizers to promote plant growth.

Interestingly, biosolids transportation distances generally have little impact on GHG emissions from biosolids management. Although Metro Vancouver hauls their biosolids a relatively long distance to mine application sites, they have one of the lowest GHG emissions totals on a per dry tonne biosolids basis (negative value). In some jurisdictions, polymer use in thickening /

conditioning is a greater source of GHGs than transportation, due to the GHG intensive nature of their industrial production.

The results presented here are best estimates based on the current state of knowledge regarding GHG emissions from biosolids management. However, accuracy may vary according to some general factors including the use of default values as opposed to local or regional data, and assumptions made with respect to the biosolids management scenarios. In general, there is more known about sources and emissions relating to processes which release carbon dioxide (CO_2), followed be methane (CH_4) and nitrous oxide (N_2O). The understanding of these three GHGs is inversely related to the relative importance of the GHGs; N_2O and CH_4 are 310 and 21 times more potent GHGs than CO_2 respectively. Thus, as research progresses, particularly with respect to N_2O and CH_4, the model is amenable to revising default values and emission factors to improve overall model accuracy.

Identification of the incineration scenario and Laval management practices as the largest GHG emission scenarios prompted an investigation into process modifications that could decrease GHG emissions. The BEAM was used to evaluate the changes in biosolids processing and management. Modification of the incineration scenario focused on increasing the standard burn temperature of their fluidized bed incinerators from 760°C to 800°C. Areas for modifying the Laval scenario included the implementation of aerobic as opposed to anaerobic storage and composting the portion of dewatered biosolids which is currently landfilled.

Implementation of these modifications to the Laval and the incineration scenarios indicates a decrease in estimated GHG emissions from each modified management practice (Figure 2). Greenhouse gas emissions were decreased in the incineration scenario from 1.63 to 1.09 Mg CO_2eq/Mg dry biosolids, due to reduced N_2O emission from the incinerators. Increased fuel and electricity use associated with an increase in standard burn temperature were considered for the incineration scenario and found to have minimal impact on the net GHG emissions.

Greenhouse gas emissions from the Laval scenario were decreased from 1.01 to 0.22 Mg CO_2eq/Mg dry biosolids, due largely to net negative (i.e. carbon credit generating) emissions from compost used as opposed to landfilling the equivalent volume of primary sludge. Compost use results in increased carbon sequestration and the displacement of chemical fertilizers and removal of the sludge from landfilling mitigates CH_4 emissions associated with landfill disposal. Additionally, the elimination of CH_4 emissions from anaerobic storage were mitigated by changing to aerobic storage. Figure 2 illustrates the potential GHG reductions predicted by the BEAM for these process modifications.

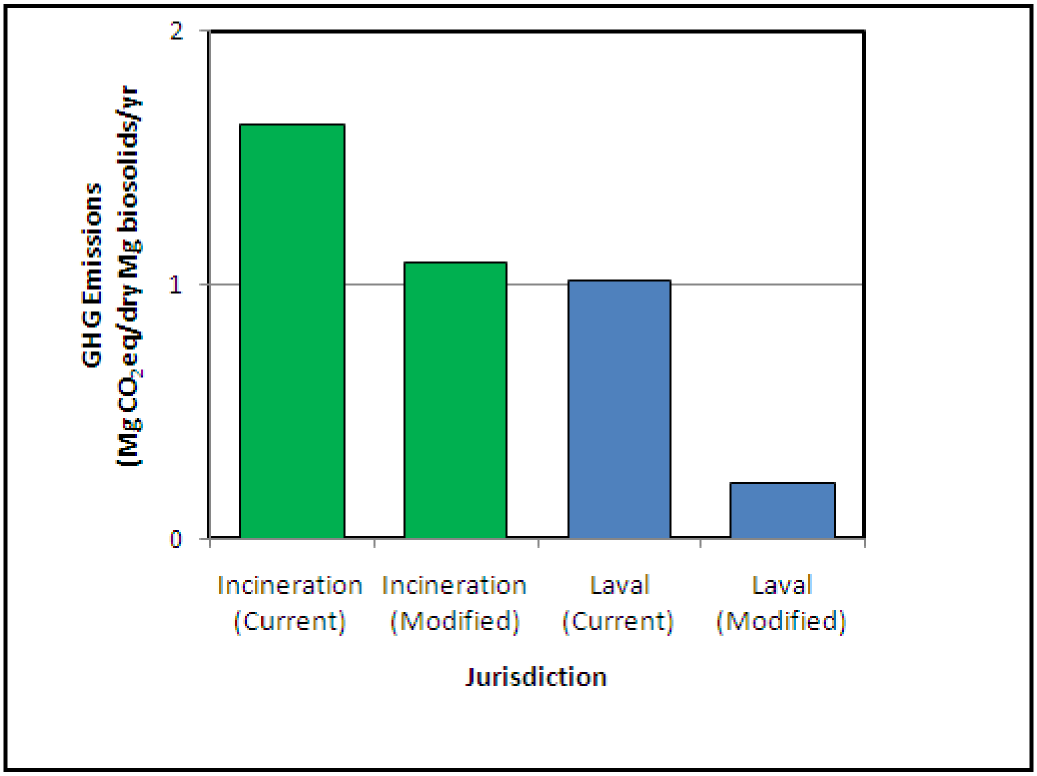

Figure 2: Potential GHG reductions through process modifications.

Results highlight the usefulness of the BEAM as a tool for biosolids generators to estimate the impacts that process modifications can have on GHG emissions. Opportunities to reduce GHG emissions from the remaining seven scenarios are discussed qualitatively in the report. Examples of these opportunities include:

- increasing energy efficiency in processes that require electricity and fossil fuels;
- digester gas capture and utilization to offset purchased energy requirements; and
- increasing land application to obtain credits through carbon sequestration and displacement of chemical fertilizers.

The BEAM will be useful to wastewater treatment plant operators and biosolids managers as it:

- is designed to enable the calculation of GHG emissions from multiple management scenarios through the use of unit process calculators;
- isolates and summarizes the net emissions from each unit process, so that the user can clearly see which processes are the largest GHG contributors;

- allows the user to evaluate other unit processes they employ or are considering, so that their impact on overall GHG emissions can be estimated;

- can be used to calculate existing or potential carbon credits, which will become marketable as carbon trading systems develop, and facilitate opportunities for cost recovery or revenue generation from biosolids management programs.

The BEAM provides estimates of emissions for the solids management train that can be added to estimates for the wastewater treatment process to establish an overall estimate for the entire operation. The BEAM could serve as an important tool in the identification of opportunities for GHG mitigation measures and offset potentials in biosolids management that could serve as a cost recovery or revenue generation mechanism in emerging carbon markets. As market incentives for GHG emissions reductions develop further, documentation using BEAM, combined with an independent verification step, could lead to the generation of marketable carbon credits.