Golder Associates Ltd.

500 - 4260 Still Creek Drive
Burnaby, British Columbia V5C 6C6
Telephone 604-296-4200
Fax 604-298-5253

REPORT ON

INVENTORY OF GREENHOUSE GAS GENERATION FROM LANDFILLS IN BRITISH COLUMBIA

Submitted to:

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PO Box 9341, Stn. Prov. Govt.
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V8W 9M1

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1.0 INTRODUCTION

Golder Associates Ltd. (Golder) has been retained by the Ministry of Environment (MOE) under General Service Agreement Contract EQB-08-100 dated December 13, 2007 (Contract) to carry out an inventory of greenhouse gas (GHG) generation from landfills in British Columbia (BC). The objectives of this assessment are to:

- Develop first-order kinetic methane generation model parameters for selected landfills based on precipitation and Golder's experience in British Columbia;
- Estimate methane generation for the years 2008, 2012, 2016 and 2020 from all operating municipal solid waste (MSW) landfills under Provincial jurisdiction that have a disposal rate greater than 10,000 tonnes/year in 2006. The Provincial definition of MSW includes demolition, land clearing and construction waste (DLC) materials and associated landfills; and
- Model methane generation for the scenarios of a woodwaste landfill in a wet and dry climate, and compare this with that of a municipal solid waste landfill.

This report summarizes the information and methodology used in our assessment, and presents the results of our inventory. A draft report was submitted on January 14, 2008 as required by our Contract.

Golder appreciates the input provided by the Province, Regional District and municipal personnel, many of whom, due to Christmas vacations, had limited time to provide the information.

2.0 APPROACH

Landfill gas (LFG) that is produced by the anaerobic decomposition of municipal solid waste generally contains 55 to 65 % methane and 35 % to 45 % carbon dioxide by volume. These proportions can change due to different waste types or if there is oxygen intrusion into the waste. At this time, only the methane in LFG is considered to be a GHG. The carbon dioxide that is a component of LFG is considered to be a part of the natural carbon cycle and is not considered to be a GHG. Other trace gases in the LFG are currently neglected when analyzing the GHG potential of LFG.

This GHG inventory is intended to be a screening level assessment of GHG generation from municipal solid waste landfills in British Columbia that operate under Provincial jurisdiction. Landfills on lands subject to Federal jurisdiction, closed landfills, and proposed landfills are not included in the inventory. Modelling of GHG generation was carried out using a simple first-order kinetic model that has only two input parameters in addition to waste tonnage (total weight basis) for each year:

- Ultimate methane yield (L_o) – The maximum amount of methane that could be expected to be produced by a unit weight of waste, given an infinite period for it to decompose, in cubic metres of methane per tonne of waste disposed (m^3/tonne); and

- Methane generation rate constant (k) – A factor for quantifying the rate that landfilled waste decays and produces methane, in $years^{-1}$.

For both L_o and k, it has been assumed, due to the lack of information for all landfills and for simplicity, that the waste composition at all British Columbia landfills (except for the Ecowaste Landfill which only accepts DLC waste) is the same.

A relationship between the model parameters and precipitation has been developed in this report based on published data and Golder's experience in British Columbia. This relationship was used to model methane generation for most landfills. However, site-specific model parameters back-calculated by Golder (based on project experience at these landfills) have been used to model methane generation at the Vancouver Landfill, the Cache Creek Landfill, and the Foothills Boulevard Landfill.

DLC waste, where it is identified separately, is included as MSW, although its short-term and medium-term LFG generation rates are less than those of MSW landfills. This is a conservative assumption with respect to potential GHG generation.

Waste disposal information was either provided by the MOE or obtained directly from the landfill owners (i.e., Regional Districts and Municipalities). The only exception was the Cache Creek Landfill, information for which was obtained from the Operations and Closure Plan 2005 for the landfill. Most landfills did not have all of the required information, and some have very little information. For these landfills, Golder estimated waste disposal for each year based on BC Stats population statistics for the particular Regional District, assuming waste disposal to be approximately proportional to population. This was carried out by assuming that the waste tonnages were proportional to waste disposed at the landfill, with the baseline being the date of the oldest data of actual measured waste tonnage at the landfill.

Modelling was only carried out for waste that has been placed since 1977. Waste placed prior to 1977 was neglected in the analysis because:

- Experience indicates that such old waste has a low methane generation rate since all readily degradable components that generate significant quantities of methane will already have decomposed and produced methane in the past;
- Waste disposal rates were typically lower than those at present;
- For virtually all landfills, the annual waste tonnages placed prior to 1977 are highly uncertain; and
- Older waste may have been burned at the landfill, or there may have been landfill fires that affected the waste.

Modelling was only carried out for landfills having a waste disposal rate of 10,000 tonnes/year or more in 2006. This cut-off was selected because:

- GHG generation at a small landfill is considered to be less (on a per tonne of waste basis) due to opportunities for air intrusion and aerobic decomposition of the waste, for example, due to a lack of daily cover or thinner lifts of waste;
- Landfills that are this small generally lack the infrastructure and personnel to support a "best practice"[1] LFG collection project to reduce GHG emissions. Many likely do not have electrical power supply to the site or a full-time attendant;
- Compared with larger landfills, the cost of a "best practice" GHG emission reductions project would be relatively high;
- 10,000 tonnes per year of waste is about 2 % of the waste received at the Vancouver Landfill or the Cache Creek Landfill, the two largest municipal solid waste landfills in the Province. In this context, such small landfills are insignificant generators of GHG emissions compared with the largest landfills; and
- The 35 largest landfills are estimated to account for more than 90 % of all MSW disposed in 2006 at Provincially regulated landfills in British Columbia.

There are approximately 92 municipal solid waste landfills that are currently operating in British Columbia under Provincial jurisdiction. Of these, 35 have been identified as having a waste disposal rate of 10,000 tonnes/year or more in 2006.

[1] "Best practice" would typically include instruments to accurately and continuously monitor and record the flow rate of methane collected, and an enclosed flare or LFG utilization facility.

For the limited scope to complete this inventory, it was not possible to carry out more detailed analyses. Therefore, it must be recognized that the actual methane generation at each landfill may differ from the model predictions of methane generation due to the following factors:

a) Methane generation depends on the anaerobic degradability of each component of the waste, and thus, waste composition has a significant effect on methane generation. The composition of waste varies from landfill to landfill and has varied with time historically. For example, prior to the mid 1990's, yard waste was routinely landfilled. However, it is now largely banned at most landfills. Site-specific waste composition could not be included in the model due to the lack of such data at individual landfills;

b) The design of each landfill varies. Some landfills are either lined with an engineered liner or natural impermeable soil, while others are underlain by permeable soils. Some landfills have a greater thickness of waste than others, and some have leachate collection systems under the entire landfill while others do not. These are some of the factors that can affect methane generation;

c) The operation of each landfill varies, especially with regard to past practices. Historically, garbage was burned at some landfills, but this is no longer an acceptable practice. Some landfills have historically used little daily or intermediate cover, while the practice today is to apply daily and intermediate cover. Low permeability intermediate cover is applied at some landfills, while at others, the intermediate cover is relatively permeable. Some landfills are contoured to promote precipitation runoff, while at other landfills, most precipitation (that does not evaporate) infiltrates into the waste. These are some of the factors that can affect methane generation;

d) Most landfills do not have a complete record of the tonnage of waste disposed since 1977. Some landfills do not have weigh scales to measure the weight of waste disposed. Thus, there is uncertainty regarding the quantity of waste placed in the landfills;

e) Where records of waste placement do not exist, Golder assumed waste disposal rates based on available BC Stats population statistics for a limited number of years. However, the per capita waste disposal rate may have changed during these years. In addition, the Regional District boundaries on which the population statistics are reported may have been modified between reporting periods, and Regional Districts may have closed landfills and diverted the waste to the existing landfills, thus potentially inflating historical quantities at these existing operating landfills. Thus, there is uncertainty regarding waste quantities assumed based on population statistics; and

f) The assumption that LFG generation can be modelled using a single-phase first-order kinetic model may not be accurate, particularly for DLC landfills or materials. Wood can be a very large proportion of the waste in a DLC landfill. This wood is inferred to be able to generate LFG for a very long time (i.e., one hundred years or more), and a first-order kinetic model may not be the best representation of LFG generation in this case.

At a few landfills, LFG generation studies have been conducted by others. However, for consistency of treatment, the results of these studies were not included in our analysis.

3.0 INFORMATION ON LANDFILLS

Table 1 lists the 35 landfills in British Columbia under Provincial jurisdiction with a waste disposal rate of 10,000 tonnes/year or more in 2006, the tonnage landfilled in 2006, the total tonnage of waste estimated to have been landfilled at each landfill between 1977 and 2007, the estimated date the landfill was opened, and its projected closure date. These are the only landfills that have been considered in this inventory. Figure 1 shows the locations of these landfills in British Columbia. The Greater Vancouver Regional District (GVRD) is also known as Metro Vancouver. On February 15, 2008, the Comox-Strathcona Regional District (RDCS) is scheduled to be partitioned into the Comox Valley Regional District and the Strathcona Regional District.

One landfill, the "Tofino stump dump", had a reported waste disposal rate of 21,000 tonnes in 2006. However, this landfill was not included in the inventory since the waste is tree stumps and not municipal solid waste.

Table 2 provides a list of the landfills and the waste tonnages used as input to the model. The blue font data were provided to Golder. The green font data were obtained from reports by the Recycling Council of British Columbia (RCBC). The black font data are values assumed or estimated by Golder.

4.0 COMMON METHANE GENERATION MODELS

Methane generation models are simplified representations of the natural processes of methane generation in a landfill. Model parameters generally depend on the characteristics of the waste in a particular landfill, and should be selected based on site-specific information for the landfill being modelled, if available. Among the different landfill methane generation models that have been developed in the past, the more well-known ones are:

- Simple first-order model;
- Multi-phase first-order model; and
- Zero order model.

Other methane generation models have been proposed in previous studies, but many of them are variants of the simple and multi-phase first-order models. Some of these alternative models are described in USEPA (2005b).

4.1.1 Simple First-order Model

The simple first-order model is the most widely used methane generation model in North America to date, and has been adopted by the USEPA in their LandGEM model. This model assumes that methane generation follows an exponential trend and uses the following equation to model methane generation:

$$Q_{CH_4} = \sum kL_o Me^{-kt}$$

where:

- $\sum$ indicates summation;
- k is the methane generation rate constant or the first-order rate constant in year^{-1}. It is strongly influenced by moisture content, with higher values associated with higher waste moisture contents;
- L_o is the ultimate methane yield in cubic metres of methane per tonne of waste (m^3/tonne). The tonnage of waste is expressed in terms of total weight. While it is often thought of as a constant, it can vary depending on the moisture content of the waste. Water is required in the anaerobic decomposition of waste to generate methane, and thus, higher moisture content would promote methane generation, leading to higher L_o values;
- M is the tonnage of waste, on a total weight basis, disposed in a given year;
- t is the time point of interest in years after the waste is placed, and
- Q_{CH4} is the methane generation rate in cubic metres per year (or tonnes/year after conversion).

The simple first-order model requires three input parameters – M (annual tonnage), L_o (ultimate methane yield) and k (methane generation rate constant). The annual tonnage (M) can be obtained from records maintained by the operator or manager of the landfill. The parameters L_o and k depend on the waste composition, moisture content, temperature, pH, particle size, and availability of nutrients. Of these factors for municipal solid waste, the most important are waste composition and moisture content of the waste. Previous studies (SWANA 2005) demonstrated that L_o and k depend, to some extent, on the average annual precipitation that a landfill receives. Thus, it would be reasonable to select these model parameters based on the precipitation at the landfill being modelled.

The main advantage of the simple first-order model is its simplicity. This model uses a simple equation with three parameters that can be input into any spreadsheet program for methane generation modelling. However, the assumption of a single value of L_o and k to represent the waste may not be appropriate for all landfills. In such cases, the multi-phase first-order model described below could be a better option.

4.1.2 Multi-phase First-order Model

The multi-phase first-order model is a variant of the simple first-order model. The multi-phase model first divides the annual tonnages into two or more sets of tonnage with different degradability (e.g., rapid-decaying, slow-decaying and non-decaying). The simple first-order model is then run concurrently on each set of annual tonnage, and the methane generation from each set is summed to generate the annual methane generation rate.

The basic equation used in the multi-phase first-order model is the same as the one used in the simple first-order model. SWANA (2005) referenced a study indicating that multi-phase models were better than simple first-order models, but only by a narrow margin. SWANA's (1998) own study did not indicate better regression coefficient values for the multi-phase model compared with the simple first-order model. However, in landfills with waste composition that has varied significantly with time, or where the waste composition varies considerably from that of household/commercial type of municipal solid waste, the multi-phase first-order model might generate more realistic results.

The multi-phase model was not selected for the present modelling exercise because waste composition data were not available for most landfills, and there was virtually no data available for the change of waste composition with time at the 35 landfills considered in this assessment.

4.1.3 Zero Order Model

In contrast to the first-order models, the zero order model does not assume an exponential trend for methane generation. The rationale behind the zero order model is that methane generation is directly proportional to the quantity of waste available for anaerobic decomposition, but is limited by other factors within the landfill besides the quantity of waste (e.g., temperature, pH and moisture). The zero order model predicts that methane generation will be high during the initial phase of waste disposal, will reach a maximum level shortly after commencement of waste disposal, and will remain at the maximum level for some time. However, as more organics are consumed, the waste will become depleted of decomposables and the rate of methane generation will decrease to close to zero.

The zero order model uses the same parameters as the first-order models (i.e., M, L_o and k). The equation for modelling is:

$$Q_{CH_4} = \sum kL_o M$$

The L_o is the same as the one used in the first-order models. However, the k in the zero order model represents the percentage of ultimate production released per year, and is not the same constant used in the first order model.

The zero order model was not selected for the present modelling exercise because the usage of the simple first-order model in North America is more widespread than that of the zero order model.

5.0 METHANE GENERATION MODELLING FOR MSW LANDFILLS

5.1 USEPA LandGEM Model

This study uses the USEPA's LandGEM model (USEPA, 2005a) to model methane generation. This model was selected for this assessment because it is simple to use and is the most well-known and commonly used methane generation model in North America to date. The equation used in the LandGEM model is:

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} kL_o \left(\frac{M_i}{10} \right) e^{-kt_{i,j}}$$

where:

- $\sum$ indicates summation;
- i is time increment in one year;
- n is the total number of years being modelled;
- j is time increment in 0.1 years;
- k is the methane generation rate constant or the first-order rate constant in $year^{-1}$;
- L_o is the ultimate methane yield in cubic metres of methane per tonne of waste (m^3/tonne);
- M_i is the tonnage of waste, on a total weight basis, disposed in i^{th} year;
- $t_{i,j}$ is the age of the j^{th} portion of M_i disposed in the i^{th} year; and
- Q_{CH4} is the methane generation rate in cubic metres per year (or tonnes/year after conversion).

The LandGEM model is a slightly modified version of the simple first-order model. It requires the same input parameters as the simple first-order model (i.e., M, L_o and k) and assumes that L_o and k are the same throughout the entire modelling period. However, the LandGEM model divides the tonnage in a particular year into ten equal portions, and calculates the methane generation between the end of each portion and the end of that particular year using the simple first-order equation. The model then sums the methane generation from each of the ten portions to generate the methane generation rate for that year.

Similar to the simple first-order model, the main advantage of the LandGEM model is its simplicity, and the main disadvantage of the model is its lack of flexibility in assessing the effects of varying waste composition on methane generation. However, since the waste composition in the BC landfills considered in this study has been assumed to be the same for all landfills as explained below, the use of the LandGEM model in this assessment is considered to be adequate.

5.2 Model Parameter Variations with Precipitation

As mentioned in section 4.1.1, the parameters L_o (ultimate methane yield) and k (methane generation rate constant) depend largely on waste composition and moisture content of the waste. The effects of waste composition on L_o and k for a mixed waste (e.g., municipal solid waste) are not easily quantifiable since the waste composition can change, but waste composition studies have not been conducted on an annual basis at any landfills in BC to track such change. Thus, for simplicity, it has been assumed that different waste composition at different landfills does not affect the L_o and k values used in our analysis. The exception is the waste at the Ecowaste Landfill, which is of a much different composition (i.e., DLC) than that at the other landfills. Specific parameters were selected for the waste at this landfill.

Moisture content is a factor known to affect k and L_o, and thus, a relationship involving waste moisture content was sought. Since there is very little waste moisture content data for the 35 BC landfills, L_o and k have been correlated with average annual precipitation.

Golder has been involved on projects at the Vancouver Landfill, the Cache Creek Landfill, and the Foothills Boulevard Landfill that involved the back-calculation of methane generation parameters from methane collection flow measurements. The Vancouver Landfill parameters were derived from measured LFG collection from two cells of different waste ages, while the parameters for the other two landfills were based on only a single year of flow measurements. In addition, the City of Toronto provided more than 8 years of methane collection data for the Keele Valley Landfill that were used to back-calculate parameters. However, none of these four landfills are completely enveloped with geomembrane liner and cover systems, and thus, there is uncertainty regarding the efficiency of methane collection with respect to methane generation. For all of these landfills, a methane collection efficiency has been assumed, and, based on Golder's opinion, this efficiency ranges from 65 % to 90 %. Others (SWANA 2005) also recognized the need to account for collection efficiency. Thus, the back-calculated parameters are associated with some uncertainty since the actual methane collection efficiency is unknown.

Another approach adopted by others (e.g., SWANA 2005) for a different purpose is to only model LFG collection and not attempt to extrapolate what LFG generation might be. However, the present study requires estimation of methane generation, and thus, this approach was not adopted.

The available data in SWANA (2005) include plots of L_o and k with precipitation for 13 landfills in the United States. The data were of actual LFG recovery. For the present modelling study, the L_o values provided in the SWANA study were increased by one-third based on the assumption of 75% methane collection efficiency. However, the actual collection efficiency at these landfills is unknown. Only the data for 12 of the 13 landfills were used. The SWANA (2005) data point for the landfill with about 47 inches of precipitation was neglected because it appears to have an anomalous L_o value compared with the other data.

Notwithstanding the fact that such back-calculations have their limitations, these analysis results have been combined with the available data for 12 landfills in SWANA (2005) to develop relationships between L_o and precipitation, and k and precipitation. These data and the resulting relationships developed by Golder are shown on Figures 2 and 3. The relationships are as follows:

$$L_o \text{ (m}^3\text{ methane/tonne of waste)} = 0.031 \times \text{Precipitation} + 100$$

$$k \text{ (/year)} = 0.00013 \times \text{Precipitation} - 0.019$$

where “Precipitation” is the average annual precipitation at the landfill in millimetres.

It should be noted that Golder’s back-calculated parameters for the Vancouver Landfill are within the range of parameters derived by the USEPA (2005) for wet multiple placement landfills (correcting for the fact that the parameters in the USEPA study were correlated with gas flow rate, not methane generation, and assuming 75% collection efficiency).

5.3 Modelling of Methane Generation for Each Landfill

For each landfill, the average annual precipitation for the nearest Environment Canada weather station was obtained from the available 1971-2000 Climate Normals posted on their website (http://www.climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html), or was obtained by interpolation between the two nearest stations. The only exception was for the Sechelt Landfill. Precipitation at this location is understood to be significantly different from that reported at the nearest Environment Canada weather station with climate normals (Gibsons), and thus, an average annual precipitation of 1,100 mm was used for this landfill based on MOE (1993). Table 3 summarizes the inferred precipitation at each landfill and the calculated L_o and k values for each landfill.

All landfills except the following four used the above relationship between model parameters and precipitation:

- Vancouver Landfill – Model parameters were from Golder project files, and values were derived from back-calculation of available LFG collection data. These values were used to predict LFG generation from Phase 1 (Cell F), and were determined to be a reasonably good predictor of LFG collection from this phase. DLC waste was neglected as input to the tonnage of waste landfilled in this particular case (this is the only landfill in the analysis where DLC is excluded from the waste tonnage input to the model) because the back-calculation analysis neglected DLC waste. For those years that the DLC waste tonnage was not identified separately, Golder assumed that 25% of the total waste was DLC;

- Cache Creek Landfill – Model parameters were from Golder (2004) and were based on back-calculation;

- Ecowaste Landfill – Model parameters (L_o = 75 m^3/tonne and k = 0.019) were assumed considering that DLC has a lower short and medium term LFG generation rate than the household and commercial waste that predominates at other MSW landfills. The k value was selected based on Laquidara (1986) for hard to degrade material, and the L_o was selected considering available LFG collection data for the Ecowaste Landfill (GNH 2006). LFG generation by DLC waste is characterized by a limited quantity of rapid to moderately decomposable waste, with the large majority of waste being slowly decomposable wood. Thus, a single-phase first-order LFG generation model may not represent the LFG generation process very well; and

- Foothills Boulevard Landfill – Model parameters were from Golder's project files, and the model parameter values were derived from back-calculation of LFG collection data.

The results of the modelling are discussed below.

Plots of methane generation as tonnes CO_2e with time for each landfill are provided in Appendix I. Plots of average methane and landfill gas generation rates in cubic feet per minute (cfm), assuming landfill gas is 55% methane and 45% carbon dioxide by volume, with time for each landfill are provided in Appendix II.

Table 4 summarizes the predicted methane generation for each landfill in tonnes of methane per year, tonnes CO_2e per year, and equivalent automobile tonnes CO_2e emissions per year for each of 2008, 2012, 2016, and 2020. Appendix III provides the supporting calculations for assuming that the average automobile in Canada produces 3 tonnes CO_2e per year. Tables 5, 6, 7 and 8 list the landfills in the order of CO_2e production (from highest to lowest) for each of years 2008, 2012, 2016 and 2020.

The 35 landfills are estimated to generate, in total, the following total amounts of methane per year:

Year	Tonnes of Methane	Equivalent Tonnes of CO_2 (CO_2e)	Equivalent Number of Automobiles
2008	118,000	2,474,000	825,000
2012	137,000	2,872,000	957,000
2016	147,000	3,079,000	1,026,000
2020	153,000	3,204,000	1,068,000

5.4 Accuracy of Model

Golder carried out analysis of the R^2 value for L_o and k using the associated feature in Microsoft Excel. The R^2 value can be interpreted as a statistical measure of how well a regression line approximates the actual data points. An R^2 value of 1.0 indicates a perfect fit, and a value of zero indicates no correlation. The R^2 values for L_o and k with respect to the best-fit relationship with precipitation provided in Section 5.2 are summarized below, with p = precipitation (mm) and "x" is the multiplication symbol.

Parameter	Relationship	R^2
L_o	L_o = 0.031 x p + 100	0.41
k	k = 0.00013 x p - 0.019	0.79

The best estimate of the methane generation rate would be the model's predicted value. We are confident that for about 80 % of predictions using this model, the actual value of methane generation for a given precipitation level will be within about 45 % of the predicted value.

6.0 WOODWASTE LANDFILLS

The decomposition of wood in anaerobic landfills is very slow, and hence, landfill gas production from wood in anaerobic landfills is very slow. However, the anaerobic decomposition rate for wood is anticipated to vary with moisture content of the waste and particle size. There is very little technical literature that discusses the rate of anaerobic decomposition and/or methane generation from wood in landfills. Reported decomposition rates for wood in landfills range from 0 to 3 % (Micales & Skog, 1997) to 2.5 % to 4 % after 19 to 29 years (Gardner et. al, 2002). Gardner et. al (2002) reported that the wood samples that were collected from the landfill and tested in a laboratory had an average moisture content of 44% to 59 % on a wet weight basis, which is considered to represent the water content of wood in a moist landfill.

Assuming a 3 % carbon loss due to anaerobic decomposition in 25 years for moist wood in a landfill, a methane generation rate on the order of 0.3 m^3 per year per tonne of wood is calculated (see Appendix IV). By comparison, MSW landfills in wet climates with waste that is less than 10 years old generate on the order of 1 to 20 m^3 methane per tonne of MSW. Thus, the methane generation rate from moist woodwaste landfills is considered to be on the order of 2 % to 30 % of that from a MSW landfill, located in a wet climate, with relatively recent waste.

There is currently insufficient information to derive a relationship between moisture content and the rate of anaerobic decomposition of wood. However, woodwaste in a relatively dry climate is anticipated to have a methane generation rate that is significantly less than 0.3 m^3 per year per tonne of wood.

Based on the above and at this time, we do not recommend that the methane generated by woodwaste landfills be included in the present inventory of methane emissions from landfills in British Columbia for the following reasons:

- On a per tonne basis, methane generation at woodwaste landfills is considered to be much less than that from municipal solid waste landfills;

- Woodwaste landfills that are largely logs or stumps are even more susceptible to air intrusion (due to the coarse particles) than municipal solid waste landfills, and thus, a significant portion of such waste may not be anaerobic and generating methane;

- Many woodwaste landfills are small, thus increasing the potential for air intrusion into the waste such that conditions are not favourable for anaerobic decomposition and the production of methane;

- Woodwaste landfills generally have even less data available from which to estimate the quantity of landfilled wastes than municipal solid waste landfills. The vast majority of wastes deposited in such landfills are not weighed and few even have a topographic plan. Particle size can significantly influence methane generation, with logs and stumps being relatively low generators of methane compared with sawdust or hogfuel. Considerable effort, including site visits, would be required to obtain data needed for a proper inventory; and

- Log yard waste landfills can consist of significant quantities of soil mixed with the waste. The soil does not degrade and produce methane.

7.0 QA/QC

The input data received from the MOE and others were checked for reasonableness, and corrections were made if we were aware of any errors in the data. It was necessary to make corrections to only a few data either due to discrepancies with landfill annual report data or unrealistic waste growth projections (e.g., due to misplaced decimal point).

The spreadsheet model used for the modelling had been developed and checked prior to this project. The spreadsheet was modified for this project and compared with the output generated by LandGEM. For the quality assurance scenarios modelled, the spreadsheet replicated the LandGEM output for methane generation.

Data that were input to the model and the calculations shown in Appendices I and II were checked by the other team member. The report was reviewed and checked by both members of Golder who have signed this report.

8.0 CLOSING COMMENTS

As explained in Section 2 of this report, actual methane generation at each landfill may differ from the model predictions of methane generation due to numerous factors. Site-specific studies are required to better quantify LFG generation at any particular landfill.

Table 9 provides the additional information that was collected for the landfills, but was not required for the purposes of this report.

Golder Associates Ltd. (Golder) has prepared this report in a manner consistent with that level of care and skill ordinarily exercized by members of the landfill gas engineering profession currently practicing under similar conditions in British Columbia, subject to the time limits and physical constraints of the scope of work for this project. No warranty, express or implied, is made.

We trust that the information presented in this report is sufficient for your immediate needs. Should you have any questions or require clarification of any issues addressed herein, please do not hesitate to contact the undersigned.

GOLDER ASSOCIATES LTD.

ORIGINAL SIGNED BY

Keith C. K. Lam, E.I.T.
Project Engineer

ORIGINAL SIGNED BY

Colin L. Y. Wong, P.Eng.
Principal

KCKL/CLYW/nnv
07-1411-0243
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TABLE 1
LIST OF LANDFILLS

Regional District	Acronym	Landfill	No.	2006 Disposal (Tonnes)[2,3]	Total Quantity of Waste Landfilled between 1977 and 2007 (Tonnes)[3]	Year Open	Closure Year
Alberni-Clayoquot	ACRD	Alberni Valley	L1	*22,000*	549,000	1974	2096
Bulkley-Nechako	RDBN	Knockholt	L2	12,500	119,000	1995	2035
Capital	CRD	Hartland	L3	160,260	4,793,000	1950's	2045
Cariboo	CaribooRD	Gibraltar	L4	15,162	63,000	2003	2042
Central Kootenay	RDCK	Central	L5	11,000	387,000	1981	2047
		Ootischenia	L6	11,000	519,000	1970's	2040
Central Okanagan	RDCO	Glenmore	L7	116,218	2,324,000	1966	2050
		Westside	L8	*28,000*	473,000	N/A[4]	2012
Columbia Shuswap	CSRD	Salmon Arm	L9	17,751	302,000	1970's	2081
Comox-Strathcona	RDCS	Comox Valley	L10	*30,000*	744,000	1964	2032
		Campbell River	L11	*25,000*	661,000	1960's	2015
East Kootenay	RDEK	Central Subregion	L12	32,203	231,216	2000	2030
		Columbia Regional	L13	15,294	336,000	1972	2032
Fraser-Fort George	RDFFG	Foothills	L14	85,950	2,328,000	1974	2040
Fraser Valley	FVRD	Bailey	L15	31,584	715,000	1950's	2034
		Mini's Pit	L16	17,854	427,000	1973	2050
Greater Vancouver	GVRD[5]	Vancouver[1]	L17	759,598	14,884,626	1966	2037
		Cache Creek	L18	481,313	7,701,936	1989	2010
		Ecowaste	L19	193,380	4,408,000	1979	2020
Kitimat-Stikine	RDKS	Thornhill	L20	*10,000*	205,000	1970's	2010
		Terrace	L21	*10,000*	290,000	1962	2009
Kootenay Boundary	RDKB	McKelvey Creek	L22	*11,000*	284,000	1980	2030
Nanaimo	RDN	Nanaimo	L23	75,000	1,565,934	1940's	2024
North Okanagan	NORD	Vernon	L24	37,937	774,000	1980	2050
		Armstrong	L25	12,857	231,000	1910	2019
Northern Rockies	NRRD	Ft. Nelson	L26	12,069	81,000	2000	2050
Okanagan-Similkameen	RDOS	Campbell Mtn	L27	49,758	1,251,000	1972	2040
Peace River	PRRD	Ft. St. John	L28	*34,000*	680,000	1975	2009
		Bessborough	L29	18,736	87,148	2002	2050
Sunshine Coast	SCRD	Sechelt	L30	12,515	358,000	1973	2030
Squamish-Lillooet	SLRD	Squamish	L31	15,037	284,000	1978	2008
Skeena-Queen	SQCRD	Prince Rupert	L32	11,027	202,000	1991	2066
Thompson-Nicola	TNRD	Mission Flats	L33	49,806	1,266,000	1975	2057
		Lower Nicola	L34	13,410	141,000	1972	2015
		Heffley Creek	L35	11,726	120,000	1970	2018

Notes: [1] Disposal includes DLC, but DLC was neglected in LFG generation modelling.
[2] Italics indicates Golder's estimate of waste disposal in 2006.
[3] Quantities include MSW and DLC; tonnages with estimates have been rounded to the nearest thousand.
[4] "N/A" means that the information was not provided.
[5] Also known as Metro Vancouver.

TABLE 2
WASTE DISPOSAL TONNAGES FOR LANDFILLS

Regional District	Acronym	Landfill	No.	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	% Increase[4]
Alberni-Clayoquot	ACRD	Alberni Valley	L1	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,761	22,813	22,440	22,000	21,780	-1
Bulkley-Nechako	RDBN	Knockholt	L2																			4,000	7,000	7,000	7,000	8,000	8,000	9,000	10,000	11,000	11,000	11,500	12,500	13,000	0
Capital	CRD	Hartland	L3	130,000	137,039	143,912	155,834	196,126	163,614	162,569	162,112	163,000	163,800	169,782	178,893	185,128	180,118	169,419	159,634	148,341	145,585	138,303	135,869	146,442	130,604	134,257	136,654	135,425	142,940	144,043	150,757	158,848	160,260	163,465	2
Cariboo	CaribooRD	Gibraltar	L4																											3,206	13,590	14,774	15,162	16,500	0
Central Kootenay	RDCK	Central	L5					15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	20,000	20,000	20,000	20,000	20,000	11,000	11,000	11,000	11,000	11,000	8,691	10,335	11,374	11,000	11,000	0
		Ootischenia	L6	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	11,000	11,000	11,000	7,051	8,125	8,680	9,947	9,738	11,000	11,000	0
Central Okanagan	RDCO	Glenmore	L7	56,000	57,000	58,000	59,000	60,000	61,000	62,000	63,000	64,000	64,000	65,000	66,000	67,000	68,000	69,000	70,000	71,000	72,000	73,000	74,000	75,000	76,000	77,345	78,892	85,000	90,000	96,772	106,483	108,597	116,218	115,000	3
		Westside	L8	9,000	9,000	10,000	10,000	11,000	11,000	11,000	11,000	11,000	11,000	11,000	11,000	11,000	11,000	12,000	12,000	13,000	14,000	15,000	16,000	16,000	16,000	16,000	17,000	17,840	24,030	20,907	30,498	28,243	28,000	28,000	0
Columbia Shuswap	CSRD	Salmon Arm	L9	7,500	7,500	7,500	7,500	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	9,000	9,000	9,000	9,000	9,000	9,000	9,500	9,510	10,216	8,184	10,404	10,894	11,899	11,991	12,342	15,765	17,751	17,929	1
Comox-Strathcona	RDCS	Comox Valley	L10	17,000	18,000	19,000	20,000	20,500	21,000	21,000	21,000	21,000	21,000	22,000	22,000	23,000	23,000	24,000	25,000	26,000	27,000	28,000	28,500	28,500	23,000	23,000	23,000	24,461	26,200	29,000	29,000	30,000	30,000	30,000	0
		Campbell River	L11	18,000	18,000	19,000	19,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	21,000	21,000	21,000	21,000	21,000	21,000	22,000	22,000	22,000	22,000	22,000	22,259	21,939	22,580	24,000	25,000	25,000	25,000	25,000	0
East Kootenay	RDEK	Central Subregion	L12																								25,000	25,071	25,071	25,269	31,184	29,347	32,203	38,071	1
		Columbia Regional	L13	9,000	9,000	9,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	15,000	15,000	15,000	15,294	18,448	1
Fraser-Fort George	RDFFG	Foothills	L14	66,123	66,784	67,452	68,126	68,808	69,496	70,191	70,893	71,602	72,318	73,041	73,771	74,509	75,254	77,551	79,848	82,145	84,442	86,739	89,035	93,084	75,808	63,501	68,760	66,200	68,381	70,073	80,478	81,735	85,950	86,000	0
Fraser Valley	FVRD	Bailey	L15	15,000	15,000	16,000	16,000	17,000	17,000	17,000	17,000	17,000	17,000	18,000	20,000	20,000	21,000	22,000	23,000	24,000	27,000	27,000	27,000	27,000	27,000	27,000	27,000	24,721	25,620	30,929	35,138	32,808	31,584	33,000	2
		Mini's Pit	L16	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,877	13,916	14,053	11,617	10,775	11,005	12,397	13,311	13,213	14,179	14,357	14,179	15,037	14,261	16,128	16,717	17,854	21,150	2
Greater Vancouver	GVRD[5]	Vancouver[6]	L17	149,250	143,250	142,500	166,500	152,250	195,750	249,750	383,250	445,500	501,750	574,500	443,250	346,500	360,000	362,250	353,250	462,000	327,750	429,800	408,500	361,600	380,100	368,118	312,546	390,197	389,855	449,311	475,278	525,074	608,979	750,000	0
		Cache Creek	L18													198,812	278,735	275,527	283,971	297,856	297,180	320,751	315,145	385,293	480,366	498,755	520,258	479,775	492,759	497,030	499,404	499,006	481,313	600,000	0
		Ecowaste	L19							174,000	174,000	174,000	174,000	174,000	174,000	174,000	174,000	174,000	174,000	174,000	174,000	174,000	174,000	138,747	109,993	116,156	172,121	123,386	164,416	220,653	246,051	293,270	193,380	193,380	0
Kitimat-Stikine	RDKS	Thornhill	L20										6,000	6,000	6,000	8,000	9,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	0
		Terrace	L21	8,500	8,500	8,500	8,500	8,500	8,500	8,500	8,500	8,500	8,500	9,000	9,000	9,250	9,250	9,500	9,500	9,500	9,500	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	0
Kootenay Boundary	RDKB	McKelvey Creek	L22				10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	9,632	10,906	10,041	11,065	10,513	11,000	11,000	0
Nanaimo	RDN	Nanaimo	L23	32,409	33,751	35,094	36,437	37,779	38,277	38,775	39,273	39,770	40,268	42,188	44,108	46,028	47,947	55,559	60,354	67,438	65,564	64,372	66,706	70,568	51,041	50,382	48,995	52,154	51,778	54,901	49,018	55,000	75,000	75,000	0
North Okanagan	NORD	Vernon	L24				22,000	22,000	22,000	22,000	22,000	22,000	22,000	22,000	22,000	23,000	23,000	24,000	24,000	25,000	26,000	27,000	28,000	31,082	32,041	31,371	32,692	31,953	31,909	33,131	35,992	37,750	37,937	40,231	4
		Armstrong	L25	4,500	5,000	5,000	5,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,500	6,500	6,500	6,500	6,500	7,000	7,000	9,351	9,688	9,072	8,607	8,081	10,817	10,376	12,894	12,857	13,000	2
Northern Rockies	NRRD	Ft. Nelson	L26																								7,188	7,689	8,459	10,230	11,885	11,198	12,069	12,310	2
Okanagan-Similkameen	RDOS	Campbell Mtn	L27	32,000	34,000	35,000	36,000	36,000	36,000	36,000	36,000	36,000	37,000	38,000	38,000	39,000	39,000	40,000	40,000	41,000	41,000	42,000	43,000	43,000	43,000	43,000	43,000	43,000	43,000	43,000	43,529	51,427	49,758	50,753	2
Peace River	PRRD	Ft. St. John	L28	14,000	15,000	17,000	18,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	22,000	24,000	25,000	26,000	28,000	30,000	32,000	34,000	35,000	3
		Bessborough	L29																											14,653	16,807	17,654	18,736	19,298	3
Sunshine Coast	SCRD	Sechelt	L30	10,000	10,000	10,000	10,000	11,000	11,000	11,000	11,000	11,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	17,062	11,684	10,833	11,576	11,453	10,658	10,692	10,514	10,651	11,121	11,710	12,627	12,815	12,515	12,765	2
Squamish-Lillooet	SLRD	Squamish	L31		7,000	7,000	7,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,470	9,797	13,486	14,731	13,455	15,037	18,020	1
Skeena-Queen	SQCRD	Prince Rupert	L32															14,484	13,863	13,769	14,039	14,546	13,707	13,386	11,533	10,425	10,781	10,978	9,644	9,838	9,083	9,910	11,027	10,508	0
Thompson-Nicola	TNRD	Mission Flats	L33	25,000	26,000	27,000	28,000	29,000	30,000	31,000	32,000	33,907	33,056	32,918	31,080	35,015	36,523	40,284	45,732	48,505	58,565	48,897	44,293	47,500	42,162	55,605	46,263	45,843	59,712	57,697	43,612	50,555	49,806	50,000	2
		Lower Nicola	L34	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,340	3,645	4,230	4,400	4,760	5,320	5,900	6,620	6,547	7,409	7,972	13,410	13,500	1.5
		Heffley Creek	L35	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,600	2,700	4,420	4,800	4,750	5,400	5,500	5,970	6,350	7,505	9,136	11,726	13,000	1.5

Notes: [1] Blue font data were provided to Golder.
[2] Green font data were obtained from reports by the Recycling Council of British Columbia.
[3] Black font data are values assumed or estimated by Golder.
[4] "% Increase" is future compounded percentage increase (or decrease) in waste tonnage from 2007 until landfill closure.
[5] Also known as Metro Vancouver.
[6] Tonnage excludes DLC waste.

TABLE 3
INFERRED PRECIPITATION AND MODEL PARAMETERS

Regional District	Acronym	Landfill	No.	Precipitation (mm/yr)	L_o (m^3 CH_4/tonne)	k ($year^{-1}$)
Alberni-Clayoquot	ACRD	Alberni Valley	L1	1,911	159	0.229
Bulkley-Nechako	RDBN	Knockholt	L2	500	116	0.046
Capital	CRD	Hartland	L3	1,003	131	0.111
Cariboo	CaribooRD	Gibraltar	L4	510	116	0.047
Central Kootenay	RDCK	Central	L5	755	123	0.079
		Ootischenia	L6	755	123	0.079
Central Okanagan	RDCO	Glenmore	L7	381	112	0.031
		Westside	L8	381	112	0.031
Columbia Shuswap	CSRD	Salmon Arm	L9	669	121	0.068
Comox-Strathcona	RDCS	Comox Valley	L10	1,179	137	0.134
		Campbell River	L11	1,452	145	0.170
East Kootenay	RDEK	Central Subregion	L12	383	112	0.031
		Columbia Regional	L13	430	113	0.037
Fraser-Fort George	RDFFG	Foothills	L14	644	112	0.050
Fraser Valley	FVRD	Bailey	L15	1,501	147	0.176
		Mini's Pit	L16	1,765	155	0.210
Greater Vancouver	GVRD[1]	Vancouver	L17	1,008	150	0.160
		Cache Creek	L18	236	100	0.020
		Ecowaste	L19	1,277	75	0.019
Kitimat-Stikine	RDKS	Thornhill	L20	1,322	141	0.153
		Terrace	L21	1,322	141	0.153
Kootenay Boundary	RDKB	McKelvey Creek	L22	775	124	0.082
Nanaimo	RDN	Nanaimo	L23	1,163	136	0.132
North Okanagan	NORD	Vernon	L24	410	113	0.034
		Armstrong	L25	488	115	0.044
Northern Rockies	NRRD	Ft. Nelson	L26	452	114	0.040
Okanagan-Similkameen	RDOS	Campbell Mtn	L27	332	110	0.024
Peace River	PRRD	Ft. St. John	L28	466	114	0.042
		Bessborough	L29	482	115	0.044
Sunshine Coast	SCRD	Sechelt	L30	1,100	134	0.124
Squamish-Lillooet	SLRD	Squamish	L31	2,367	173	0.289
Skeena-Queen	SQCRD	Prince Rupert	L32	2,594	180	0.318
Thompson-Nicola	TNRD	Mission Flats	L33	279	109	0.017
		Lower Nicola	L34	322	110	0.023
		Heffley Creek	L35	409	113	0.034

Note: [1] Also known as Metro Vancouver.

TABLE 4
PREDICTED METHANE GENERATION

Regional District	Acronym	Landfill	No.	2008			2012			2016			2020		
				CH_4/year (tonnes)	CO_2e/year (tonnes)	Equivalent Emissions (No. of Automobiles)	CH_4/year (tonnes)	CO_2e/year (tonnes)	Equivalent Emissions (No. of Automobiles)	CH_4/year (tonnes)	CO_2e/year (tonnes)	Equivalent Emissions (No. of Automobiles)	CH_4/year (tonnes)	CO_2e/year (tonnes)	Equivalent Emissions (No. of Automobiles)
Alberni-Clayoquot	ACRD	Alberni Valley	L1	2,163	45,433	15,144	2,230	46,833	15,611	2,203	46,262	15,421	2,140	44,948	14,983
Bulkley-Nechako	RDBN	Knockholt	L2	333	6,983	2,328	445	9,351	3,117	539	11,320	3,773	617	12,959	4,320
Capital	CRD	Hartland	L3	12,875	270,381	90,127	13,690	287,482	95,827	14,660	307,858	102,619	15,767	331,108	110,369
Cariboo	CaribooRD	Gibraltar	L4	210	4,418	1,473	394	8,279	2,760	546	11,475	3,825	672	14,119	4,706
Central Kootenay	RDCK	Central	L5	961	20,189	6,730	947	19,888	6,629	937	19,669	6,556	929	19,509	6,503
		Ootischenia	L6	1,053	22,117	7,372	1,014	21,293	7,098	985	20,692	6,897	965	20,255	6,752
Central Okanagan	RDCO	Glenmore	L7	3,622	76,071	25,357	4,270	89,679	29,893	4,978	104,528	34,843	5,754	120,828	40,276
		Westside	L8	767	16,106	5,369	919	19,301	6,434	871	18,287	6,096	771	16,184	5,395
Columbia Shuswap	CSRD	Salmon Arm	L9	798	16,750	5,583	961	20,190	6,730	1,101	23,114	7,705	1,222	25,655	8,552
Comox-Strathcona	RDCS	Comox Valley	L10	2,449	51,420	17,140	2,574	54,045	18,015	2,647	55,579	18,526	2,689	56,476	18,825
		Campbell River	L11	2,284	47,960	15,987	2,360	49,551	16,517	2,398	50,357	16,786	1,216	25,536	8,512
East Kootenay	RDEK	Central Subregion	L12	476	9,996	3,332	759	15,935	5,312	1,023	21,474	7,158	1,270	26,672	8,891
		Columbia Regional	L13	587	12,326	4,109	703	14,762	4,921	811	17,032	5,677	913	19,164	6,388
Fraser-Fort George	RDFFG	Foothills	L14	4,515	94,822	31,607	4,864	102,139	34,046	5,149	108,129	36,043	5,383	113,034	37,678
Fraser Valley	FVRD	Bailey	L15	2,905	61,005	20,335	3,172	66,610	22,203	3,447	72,386	24,129	3,738	78,494	26,165
		Mini's Pit	L16	1,710	35,908	11,969	2,062	43,305	14,435	2,323	48,788	16,263	2,554	53,633	17,878
Greater Vancouver	GVRD[2]	Vancouver	L17	49,222	1,033,660	344,553	61,692	1,295,537	431,846	68,268	1,433,622	477,874	71,735	1,506,433	502,144
		Cache Creek	L18	8,791	184,614	61,538	10,401	218,417	72,806	9,601	201,625	67,208	8,863	186,123	62,041
		Ecowaste	L19	3,365	70,656	23,552	3,827	80,359	26,786	4,255	89,352	29,784	4,652	97,687	32,562
Kitimat-Stikine	RDKS	Thornhill	L20	904	18,983	6,328	789	16,578	5,526	428	8,995	2,998	232	4,880	1,627
		Terrace	L21	929	19,500	6,500	688	14,439	4,813	373	7,834	2,611	202	4,251	1,417
Kootenay Boundary	RDKB	McKelvey Creek	L22	770	16,160	5,387	810	17,002	5,667	839	17,609	5,870	859	18,046	6,015
Nanaimo	RDN	Nanaimo	L23	5,268	110,622	36,874	5,917	124,249	41,416	6,299	132,279	44,093	6,524	137,012	45,671
North Okanagan	NORD	Vernon	L24	1,357	28,487	9,496	1,612	33,852	11,284	1,908	40,060	13,353	2,251	47,263	15,754
		Armstrong	L25	478	10,044	3,348	572	12,006	4,002	664	13,946	4,649	757	15,891	5,297
Northern Rockies	NRRD	Ft. Nelson	L26	214	4,486	1,495	327	6,872	2,291	436	9,158	3,053	542	11,380	3,793
Okanagan-Similkameen	RDOS	Campbell Mtn	L27	1,603	33,673	11,224	1,818	38,172	12,724	2,042	42,884	14,295	2,278	47,839	15,946
Peace River	PRRD	Ft. St. John	L28	1,305	27,413	9,138	1,311	27,528	9,176	1,110	23,310	7,770	940	19,738	6,579
		Bessborough	L29	264	5,543	1,848	478	10,036	3,345	690	14,485	4,828	904	18,980	6,327
Sunshine Coast	SCRD	Sechelt	L30	1,049	22,019	7,340	1,112	23,350	7,783	1,190	24,980	8,327	1,279	26,859	8,953
Squamish-Lillooet	SLRD	Squamish	L31	1,646	34,571	11,524	744	15,620	5,207	234	4,922	1,641	74	1,551	517
Skeena-Queen	SQCRD	Prince Rupert	L32	1,270	26,672	8,891	1,280	26,884	8,961	1,283	26,943	8,981	1,284	26,959	8,986
Thompson-Nicola	TNRD	Mission Flats	L33	1,268	26,623	8,874	1,438	30,188	10,063	1,617	33,956	11,319	1,807	37,949	12,650
		Lower Nicola	L34	186	3,911	1,304	260	5,457	1,819	333	6,985	2,328	304	6,375	2,125
		Heffley Creek	L35	228	4,796	1,599	329	6,909	2,303	425	8,920	2,973	477	10,026	3,342

Notes: [1] To obtain the approximate average annual methane flow rate in cubic feet per minute (cfm), divide CH_4/year (tonnes) by 10.
[2] Also known as Metro Vancouver.

TABLE 5
PREDICTED GHG GENERATION IN 2008

Rank	Landfill	Regional District	CO_2e/year (tonnes)	Equivalent Emissions (No. of Automobiles)
1	Vancouver	Greater Vancouver	1,033,660	344,553
2	Hartland	Capital	270,381	90,127
3	Cache Creek	Greater Vancouver	184,614	61,538
4	Nanaimo	Nanaimo	110,622	36,874
5	Foothills	Fraser-Fort George	94,822	31,607
6	Glenmore	Central Okanagan	76,071	25,357
7	Ecowaste	Greater Vancouver	70,656	23,552
8	Bailey	Fraser Valley	61,005	20,335
9	Comox Valley	Comox-Strathcona	51,420	17,140
10	Campbell River	Comox-Strathcona	47,960	15,987
11	Alberni Valley	Alberni-Clayoquot	45,433	15,144
12	Mini's Pit	Fraser Valley	35,908	11,969
13	Squamish	Squamish-Lillooet	34,571	11,524
14	Campbell Mtn	Okanagan-Similkameen	33,673	11,224
15	Vernon	North Okanagan	28,487	9,496
16	Ft. St. John	Peace River	27,413	9,138
17	Prince Rupert	Skeena-Queen	26,672	8,891
18	Mission Flats	Thompson-Nicola	26,623	8,874
19	Ootischenia	Central Kootenay	22,117	7,372
20	Sechelt	Sunshine Coast	22,019	7,340
21	Central	Central Kootenay	20,189	6,730
22	Terrace	Kitimat-Stikine	19,500	6,500
23	Thornhill	Kitimat-Stikine	18,983	6,328
24	Salmon Arm	Columbia Shuswap	16,750	5,583
25	McKelvey Creek	Kootenay Boundary	16,160	5,387
26	Westside	Central Okanagan	16,106	5,369
27	Columbia Regional	East Kootenay	12,326	4,109
28	Armstrong	North Okanagan	10,044	3,348
29	Central Subregion	East Kootenay	9,996	3,332
30	Knockholt	Bulkley-Nechako	6,983	2,328
31	Bessborough	Peace River	5,543	1,848
32	Heffley Creek	Thompson-Nicola	4,796	1,599
33	Ft. Nelson	Northern Rockies	4,486	1,495
34	Gibraltar	Cariboo	4,418	1,473
35	Lower Nicola	Thompson-Nicola	3,911	1,304

TABLE 6
PREDICTED GHG GENERATION IN 2012

Rank	Landfill	Regional District	CO_2e/year (tonnes)	Equivalent Emissions (No. of Automobiles)
1	Vancouver	Greater Vancouver	1,295,537	431,846
2	Hartland	Capital	287,482	95,827
3	Cache Creek	Greater Vancouver	218,417	72,806
4	Nanaimo	Nanaimo	124,249	41,416
5	Foothills	Fraser-Fort George	102,139	34,046
6	Glenmore	Central Okanagan	89,679	29,893
7	Ecowaste	Greater Vancouver	80,359	26,786
8	Bailey	Fraser Valley	66,610	22,203
9	Comox Valley	Comox-Strathcona	54,045	18,015
10	Campbell River	Comox-Strathcona	49,551	16,517
11	Alberni Valley	Alberni-Clayoquot	46,833	15,611
12	Mini's Pit	Fraser Valley	43,305	14,435
13	Campbell Mtn	Okanagan-Similkameen	38,172	12,724
14	Vernon	North Okanagan	33,852	11,284
15	Mission Flats	Thompson-Nicola	30,188	10,063
16	Ft. St. John	Peace River	27,528	9,176
17	Prince Rupert	Skeena-Queen	26,884	8,961
18	Sechelt	Sunshine Coast	23,350	7,783
19	Ootischenia	Central Kootenay	21,293	7,098
20	Salmon Arm	Columbia Shuswap	20,190	6,730
21	Central	Central Kootenay	19,888	6,629
22	Westside	Central Okanagan	19,301	6,434
23	McKelvey Creek	Kootenay Boundary	17,002	5,667
24	Thornhill	Kitimat-Stikine	16,578	5,526
25	Central Subregion	East Kootenay	15,935	5,312
26	Squamish	Squamish-Lillooet	15,620	5,207
27	Columbia Regional	East Kootenay	14,762	4,921
28	Terrace	Kitimat-Stikine	14,439	4,813
29	Armstrong	North Okanagan	12,006	4,002
30	Bessborough	Peace River	10,036	3,345
31	Knockholt	Bulkley-Nechako	9,351	3,117
32	Gibraltar	Cariboo	8,279	2,760
33	Heffley Creek	Thompson-Nicola	6,909	2,303
34	Ft. Nelson	Northern Rockies	6,872	2,291
35	Lower Nicola	Thompson-Nicola	5,457	1,819

TABLE 7
PREDICTED GHG GENERATION IN 2016

Rank	Landfill	Regional District	CO_2e/year (tonnes)	Equivalent Emissions (No. of Automobiles)
1	Vancouver	Greater Vancouver	1,433,622	477,874
2	Hartland	Capital	307,858	102,619
3	Cache Creek	Greater Vancouver	201,625	67,208
4	Nanaimo	Nanaimo	132,279	44,093
5	Foothills	Fraser-Fort George	108,129	36,043
6	Glenmore	Central Okanagan	104,528	34,843
7	Ecowaste	Greater Vancouver	89,352	29,784
8	Bailey	Fraser Valley	72,386	24,129
9	Comox Valley	Comox-Strathcona	55,579	18,526
10	Campbell River	Comox-Strathcona	50,357	16,786
11	Mini's Pit	Fraser Valley	48,788	16,263
12	Alberni Valley	Alberni-Clayoquot	46,262	15,421
13	Campbell Mtn	Okanagan-Similkameen	42,884	14,295
14	Vernon	North Okanagan	40,060	13,353
15	Mission Flats	Thompson-Nicola	33,956	11,319
16	Prince Rupert	Skeena-Queen	26,943	8,981
17	Sechelt	Sunshine Coast	24,980	8,327
18	Ft. St. John	Peace River	23,310	7,770
19	Salmon Arm	Columbia Shuswap	23,114	7,705
20	Central Subregion	East Kootenay	21,474	7,158
21	Ootischenia	Central Kootenay	20,692	6,897
22	Central	Central Kootenay	19,669	6,556
23	Westside	Central Okanagan	18,287	6,096
24	McKelvey Creek	Kootenay Boundary	17,609	5,870
25	Columbia Regional	East Kootenay	17,032	5,677
26	Bessborough	Peace River	14,485	4,828
27	Armstrong	North Okanagan	13,946	4,649
28	Gibraltar	Cariboo	11,475	3,825
29	Knockholt	Bulkley-Nechako	11,320	3,773
30	Ft. Nelson	Northern Rockies	9,158	3,053
31	Thornhill	Kitimat-Stikine	8,995	2,998
32	Heffley Creek	Thompson-Nicola	8,920	2,973
33	Terrace	Kitimat-Stikine	7,834	2,611
34	Lower Nicola	Thompson-Nicola	6,985	2,328
35	Squamish	Squamish-Lillooet	4,922	1,641

TABLE 8
PREDICTED GHG GENERATION IN 2020

Rank	Landfill	Regional District	CO_2e/year (tonnes)	Equivalent Emissions (No. of Automobiles)
1	Vancouver	Greater Vancouver	1,506,433	502,144
2	Hartland	Capital	331,108	110,369
3	Cache Creek	Greater Vancouver	186,123	62,041
4	Nanaimo	Nanaimo	137,012	45,671
5	Glenmore	Central Okanagan	120,828	40,276
6	Foothills	Fraser-Fort George	113,034	37,678
7	Ecowaste	Greater Vancouver	97,687	32,562
8	Bailey	Fraser Valley	78,494	26,165
9	Comox Valley	Comox-Strathcona	56,476	18,825
10	Mini's Pit	Fraser Valley	53,633	17,878
11	Campbell Mtn	Okanagan-Similkameen	47,839	15,946
12	Vernon	North Okanagan	47,263	15,754
13	Alberni Valley	Alberni-Clayoquot	44,948	14,983
14	Mission Flats	Thompson-Nicola	37,949	12,650
15	Prince Rupert	Skeena-Queen	26,959	8,986
16	Sechelt	Sunshine Coast	26,859	8,953
17	Central Subregion	East Kootenay	26,672	8,891
18	Salmon Arm	Columbia Shuswap	25,655	8,552
19	Campbell River	Comox-Strathcona	25,536	8,512
20	Ootischenia	Central Kootenay	20,255	6,752
21	Ft. St. John	Peace River	19,738	6,579
22	Central	Central Kootenay	19,509	6,503
23	Columbia Regional	East Kootenay	19,164	6,388
24	Bessborough	Peace River	18,980	6,327
25	McKelvey Creek	Kootenay Boundary	18,046	6,015
26	Westside	Central Okanagan	16,184	5,395
27	Armstrong	North Okanagan	15,891	5,297
28	Gibraltar	Cariboo	14,119	4,706
29	Knockholt	Bulkley-Nechako	12,959	4,320
30	Ft. Nelson	Northern Rockies	11,380	3,793
31	Heffley Creek	Thompson-Nicola	10,026	3,342
32	Lower Nicola	Thompson-Nicola	6,375	2,125
33	Thornhill	Kitimat-Stikine	4,880	1,627
34	Terrace	Kitimat-Stikine	4,251	1,417
35	Squamish	Squamish-Lillooet	1,551	517

TABLE 9
OTHER LANDFILL INFORMATION

Regional District	Acronym	Landfill	No.	Owner If Not RD	Population Served	Existing Waste Area (ha)	Waste Area at Closure (ha)	Average 2006 LFG Flow (scfm)	Average 2006 CH_4 (% vol)
Alberni-Clayoquot	ACRD	Alberni Valley	L1		29,000	9	15	None	N/A
Bulkley-Nechako	RDBN	Knockholt	L2		20,000	N/A	N/A	None	N/A
Capital	CRD	Hartland	L3		360,000	29	43	650	52
Cariboo	CaribooRD	Gibraltar	L4		N/A	3		None	N/A
Central Kootenay	RDCK	Central	L5		N/A	5	30	None	N/A
		Ootischenia	L6		N/A	5	32	None	N/A
Central Okanagan	RDCO	Glenmore	L7	Kelowna	N/A	81	142	60	52
		Westside	L8		N/A	N/A	N/A	None	N/A
Columbia Shuswap	CSRD	Salmon Arm	L9		N/A	7	22	None	N/A
Comox-Strathcona	RDCS	Comox Valley	L10		50,000	10	10	None	N/A
		Campbell River	L11		50,000	7	7	None	N/A
East Kootenay	RDEK	Central Subregion	L12		N/A	1	40	None	N/A
		Columbia Regional	L13		N/A	6	12	None	N/A
Fraser-Fort George	RDFFG	Foothills	L14		85,000	23	80	215	45
Fraser Valley	FVRD	Bailey	L15	Chilliwack	N/A	31	35	None	N/A
		Mini's Pit	L16	Maple Ridge	N/A	8	14	None	N/A
Greater Vancouver	GVRD[1]	Vancouver	L17	Vancouver	963,000	225	225	2,800	52.6
		Cache Creek	L18	Cache Creek/Wastech	N/A	30	36	510	55
		Ecowaste	L19	Ecowaste	N/A	70	117	235	50
Kitimat-Stikine	RDKS	Thornhill	L20		N/A	7	7	None	N/A
		Terrace	L21	Terrace	N/A	8	N/A	None	N/A
Kootenay Boundary	RDKB	McKelvey Creek	L22		N/A	N/A	N/A	None	N/A
Nanaimo	RDN	Nanaimo	L23		N/A	22	22	250	51
North Okanagan	NORD	Vernon	L24		62,166	5	14	None	N/A
		Armstrong	L25		N/A	1	4	60-100	56
Northern Rockies	NRRD	Ft. Nelson	L26		4,200	2	10	None	N/A
Okanagan-Similkameen	RDOS	Campbell Mtn	L27		N/A	N/A	N/A	None	N/A
Peace River	PRRD	Ft. St. John	L28		N/A	11	15	None	N/A
		Bessborough	L29		12,000	2	140	None	N/A
Sunshine Coast	SCRD	Sechelt	L30		27,759	7	10	None	N/A
Squamish-Lillooet	SLRD	Squamish	L31	Squamish	N/A	5	5	None	N/A
Skeena-Queen	SQCRD	Prince Rupert	L32	Prince Rupert	N/A	6	15	None	N/A
Thompson-Nicola	TNRD	Mission Flats	L33	Kamloops	80,000	15	32	None	N/A
		Lower Nicola	L34		12,000	5	8	None	N/A
		Heffley Creek	L35		7,500	6	8	None	N/A

Note: [1] Also known as Metro Vancouver.

LEGEND

Approximate Location of Landfill

NOTES

1. Locations of the landfills are approximate.
2. Municipal solid waste landfills shown on this figure had an annual tonnage exceeding 10,000 tonnes in 2006.

REFERENCE

Tranportation/Populated Places provided by DMTI Spatial Inc.
Provinces/States provided by ESRI.
Datum: NAD 83 Projection: BC Albers

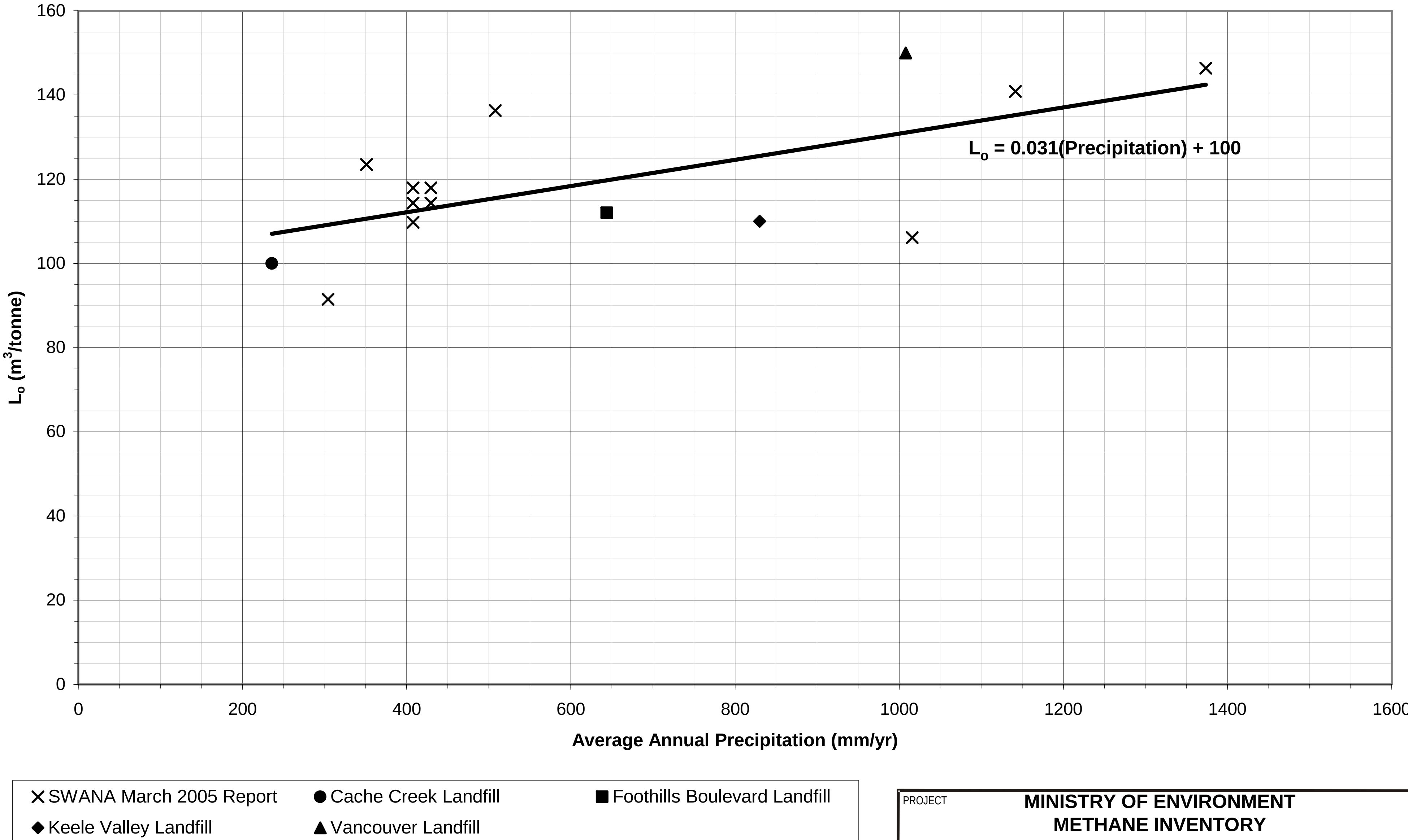
PROJECT
MINISTRY OF ENVIRONMENT
METHANE INVENTORY
BRITISH COLUMBIA

TITLE
LOCATIONS OF LANDFILLS

Golder Associates
Burnaby, B.C.

PROJECT NO. 07-1411-0243			SCALE AS SHOWN	REV. 0
DESIGN	KCKL	11 Jan. 2008	**FIGURE 1**	
GIS	AL	11 Jan. 2008		
CHECK	KCKL	11 Jan. 2008		
REVIEW	CLYW	11 Jan. 2008		

N:\Bur-Graphics\Projects\2007\1411\07-1411-0243\GIS\projects\figure-01_landfill-locations.mxd



NOTES

Correlation between L_o and precipitation is approximate.

REFERENCES

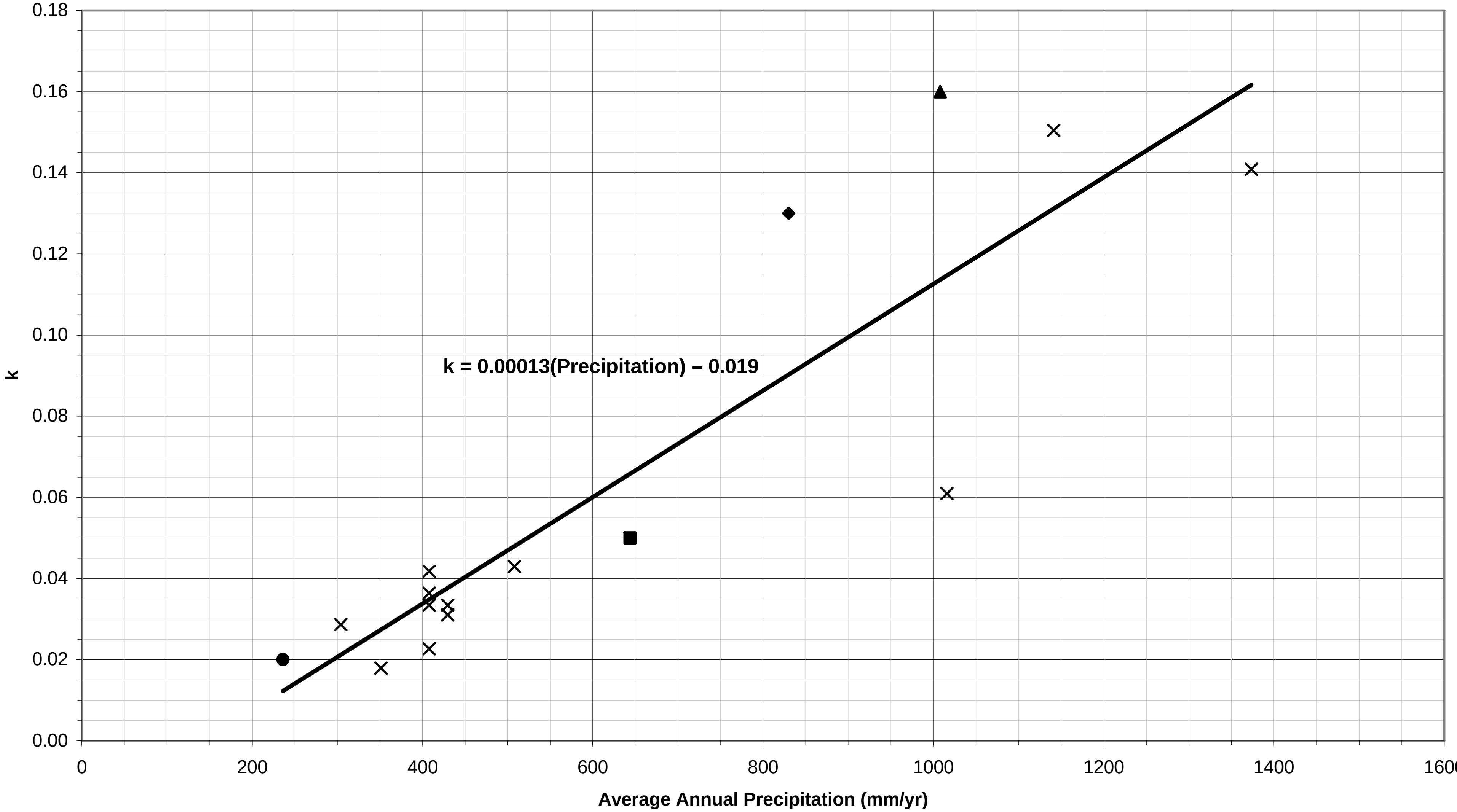
1. Solid Waste Association North America's report on "Manual of Modelling of Landfill Gas Generation" (March 2005).
2. Golder project files for Ashcroft Ranch Landfill, Foothills Boulevard Landfill and Vancouver Landfill.

PROJECT
MINISTRY OF ENVIRONMENT
METHANE INVENTORY
BRITISH COLUMBIA

TITLE
RELATIONSHIP BETWEEN L_o AND PRECIPITATION

Golder Associates

PROJECT No.	07-1411-0243		PHASE / TASK No.	6000
DESIGN	KCKL	08FEB08	SCALE NTS	REV.
CADD	KCKL	08FEB08	**FIGURE 2**	
CHECK	KCKL	08FEB08		
REVIEW				



× SWANA March 2005 Report ● Cache Creek Landfill ■ Foothills Boulevard Landfill
◆ Keele Valley Landfill ▲ Vancouver Landfill

NOTES

Correlation between k and precipitation is approximate.

REFERENCES

1. Solid Waste Association North America's report on "Manual of Modelling of Landfill Gas Generation" (March 2005).
2. Golder project files for Ashcroft Ranch Landfill, Foothills Boulevard Landfill and Vancouver Landfill.

PROJECT
**MINISTRY OF ENVIRONMENT
METHANE INVENTORY
BRITISH COLUMBIA**

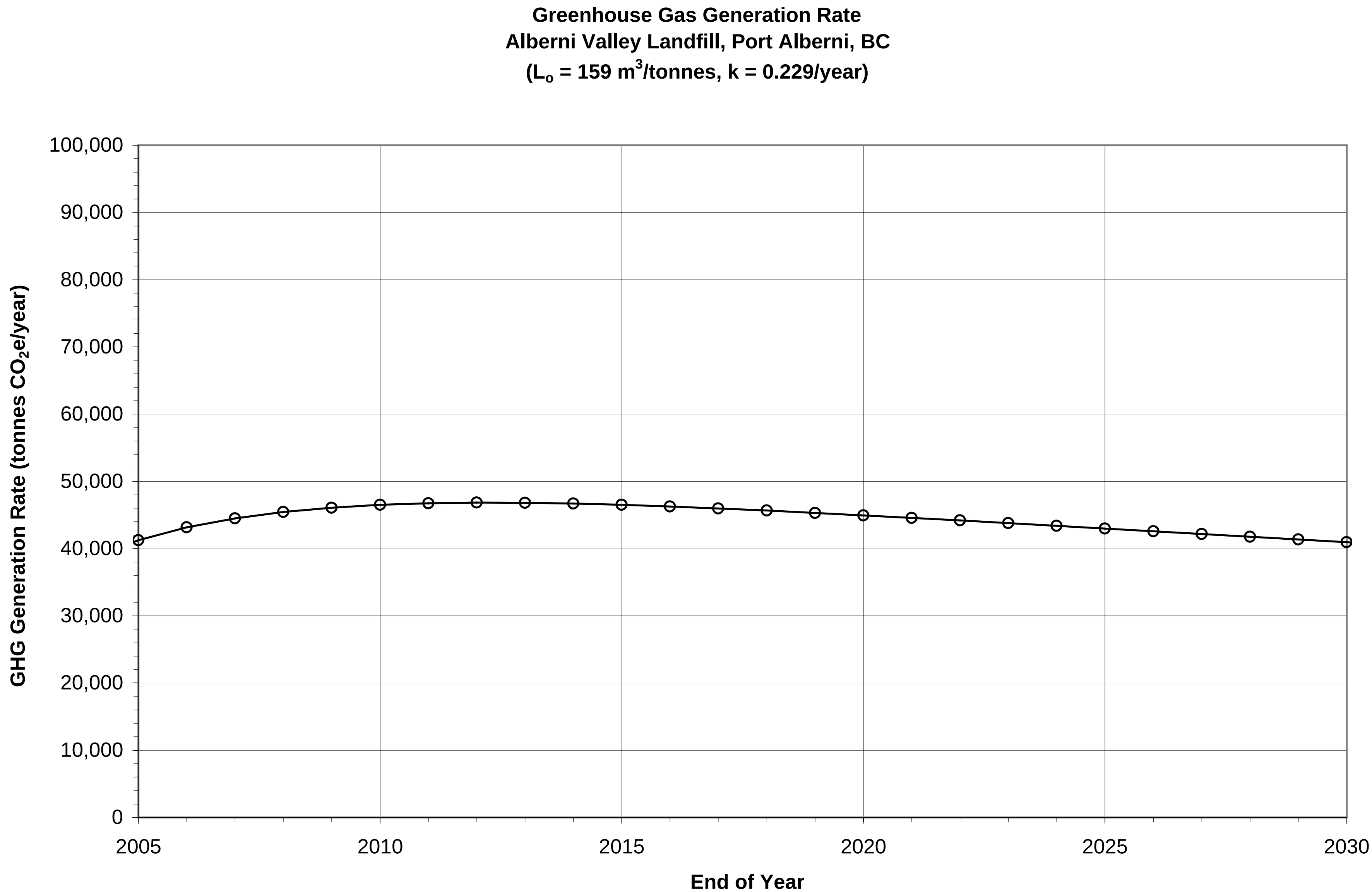
TITLE
RELATIONSHIP BETWEEN K AND PRECIPITATION

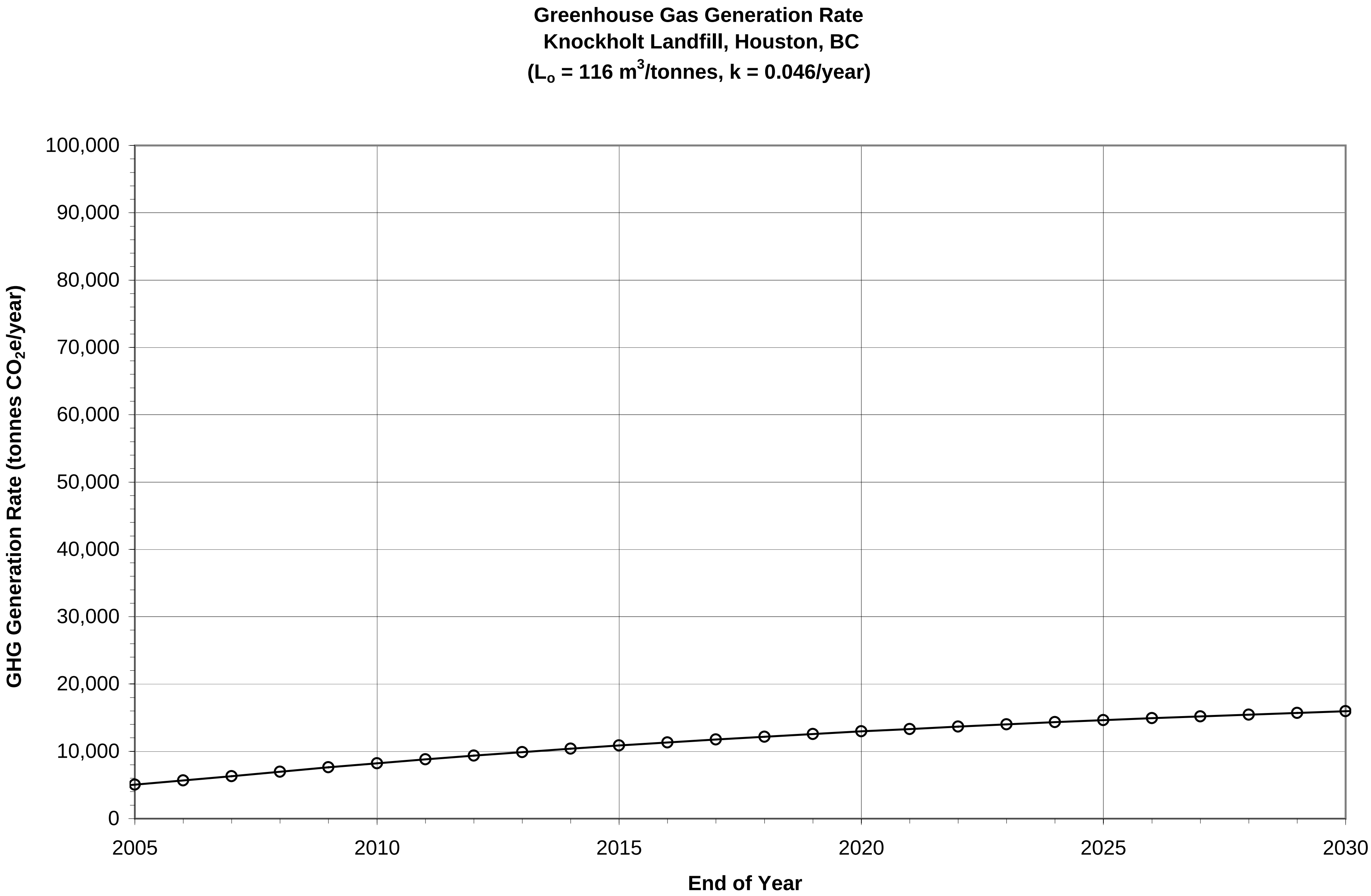
Golder Associates

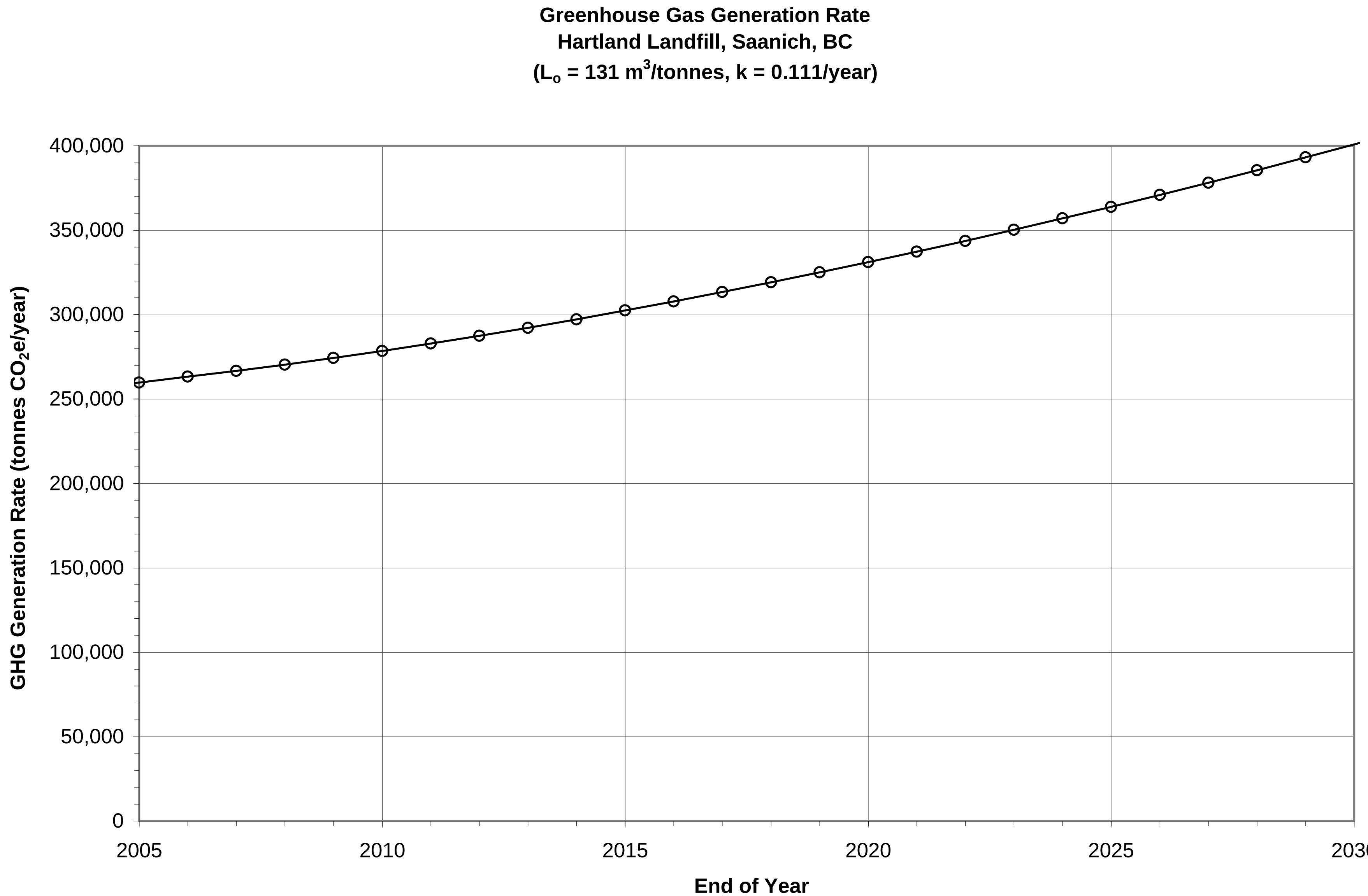
PROJECT No.	07-1411-0243		PHASE / TASK No.	6000
DESIGN	KCKL	08FEB08	SCALE NTS	REV.
CADD	KCKL	08FEB08		
CHECK	KCKL	08FEB08	**FIGURE 3**	
REVIEW				

APPENDIX I

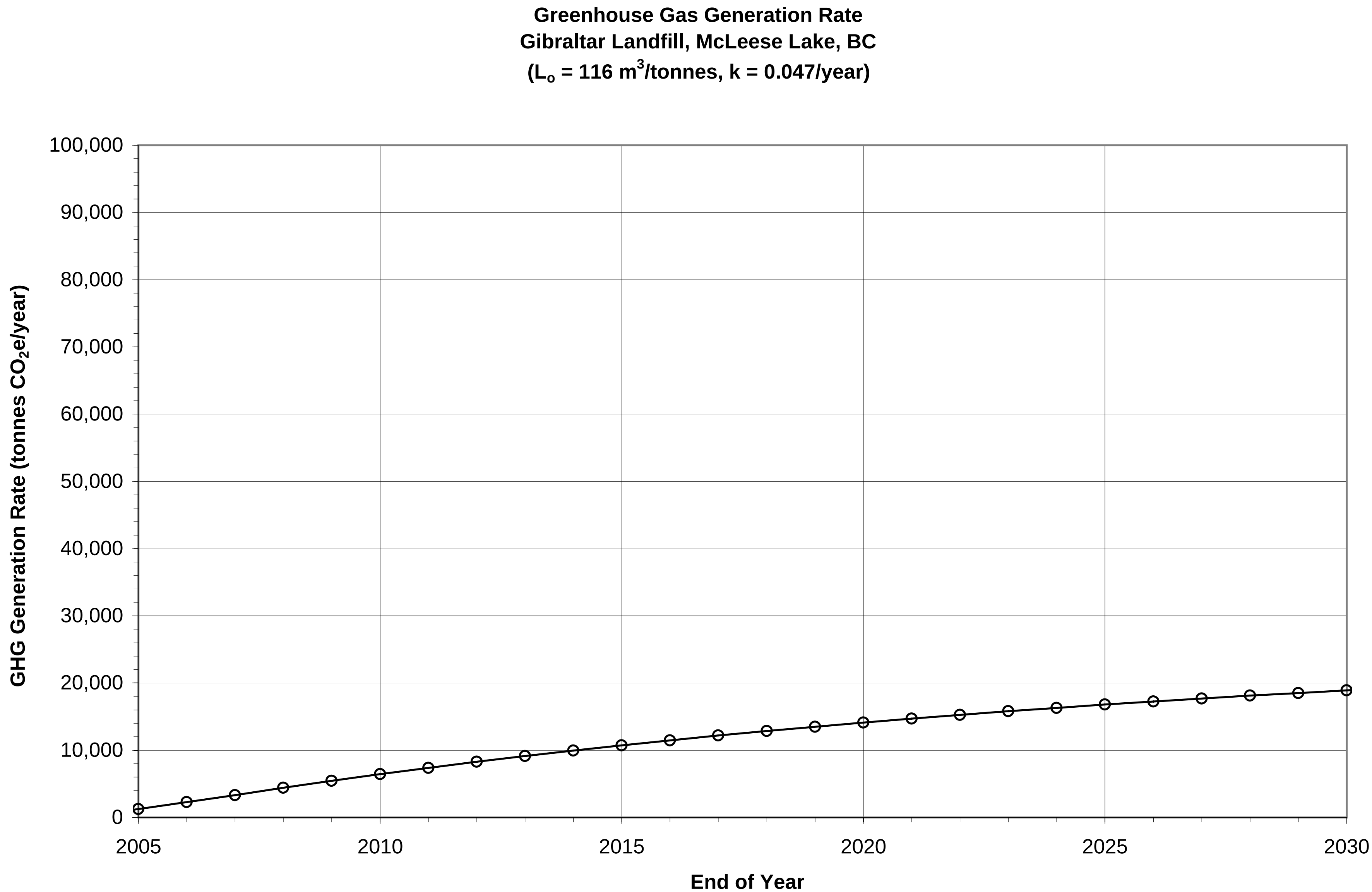
PLOTS OF METHANE GENERATION AS CO_2E WITH TIME FOR EACH LANDFILL

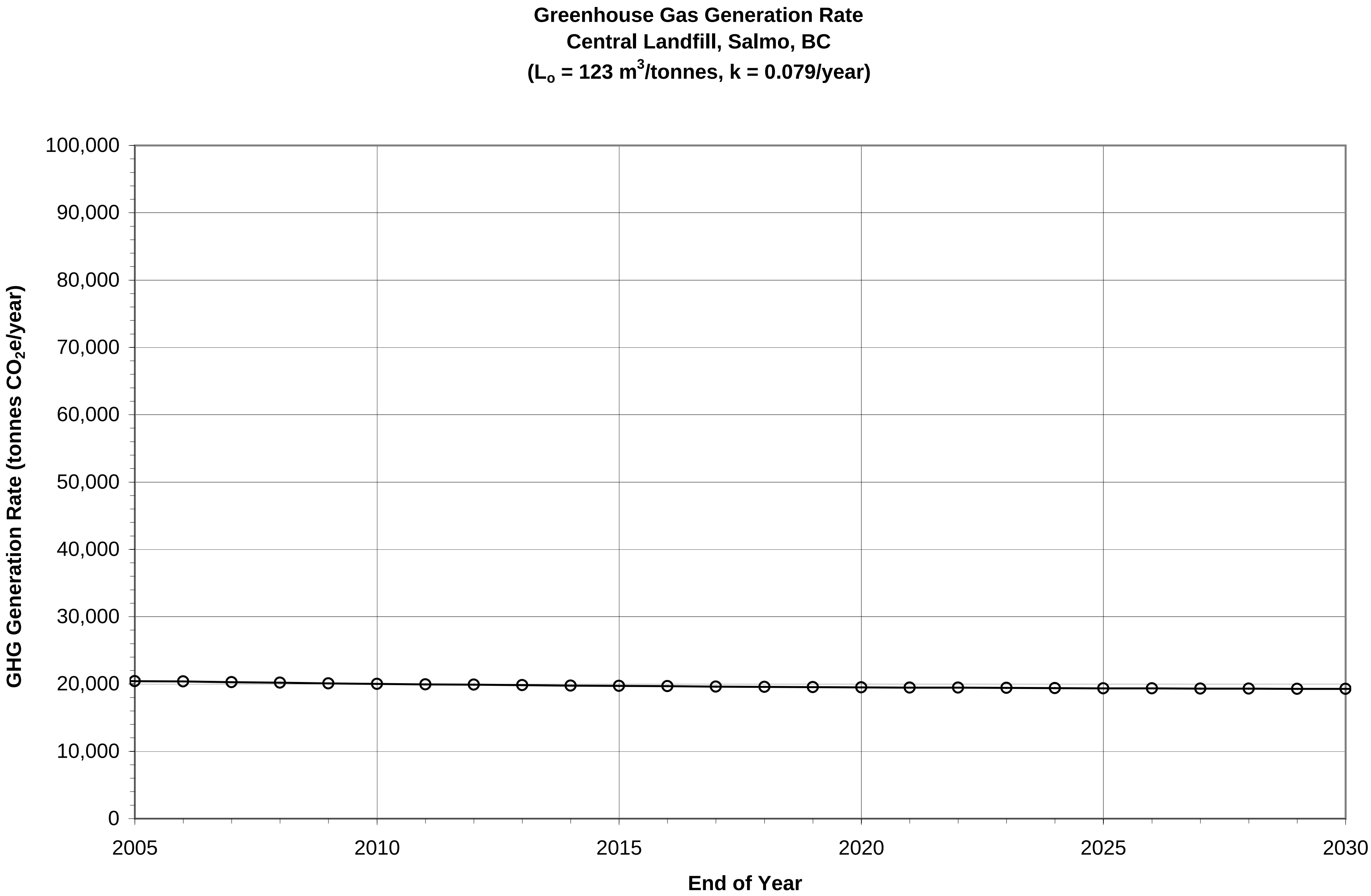

Greenhouse Gas Generation Rate
Alberni Valley Landfill, Port Alberni, BC
(L_o = 159 m^3/tonnes, k = 0.229/year)
GHG Generation Rate (tonnes CO_2e/year)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2005
2010
2015
2020
2025
2030
End of Year


Greenhouse Gas Generation Rate
Knockholt Landfill, Houston, BC
(L_o = 116 m^3/tonnes, k = 0.046/year)
GHG Generation Rate (tonnes CO_2e/year)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2005
2010
2015
2020
2025
2030
End of Year



Greenhouse Gas Generation Rate
Hartland Landfill, Saanich, BC
(Lo = 131 m3/tonnes, k = 0.111/year)
GHG Generation Rate (tonnes CO2e/year)
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
2005
2010
2015
2020
2025
2030
End of Year


Greenhouse Gas Generation Rate
Gibraltar Landfill, McLeese Lake, BC
(L_o = 116 m^3/tonnes, k = 0.047/year)
GHG Generation Rate (tonnes CO_2e/year)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2005
2010
2015
2020
2025
2030
End of Year


Greenhouse Gas Generation Rate
Central Landfill, Salmo, BC
(L_o = 123 m^3/tonnes, k = 0.079/year)
GHG Generation Rate (tonnes CO_2e/year)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2005
2010
2015
2020
2025
2030
End of Year

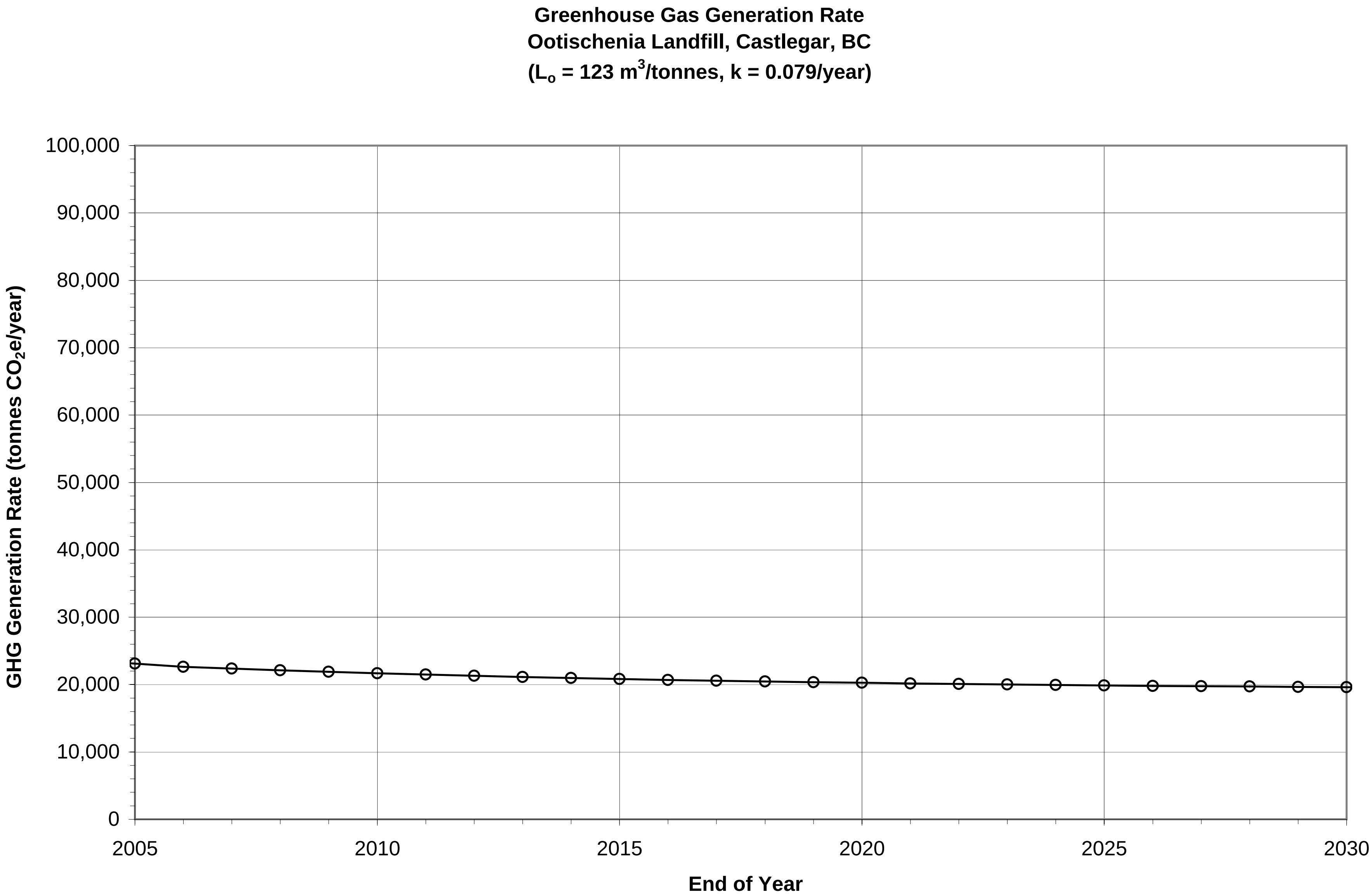
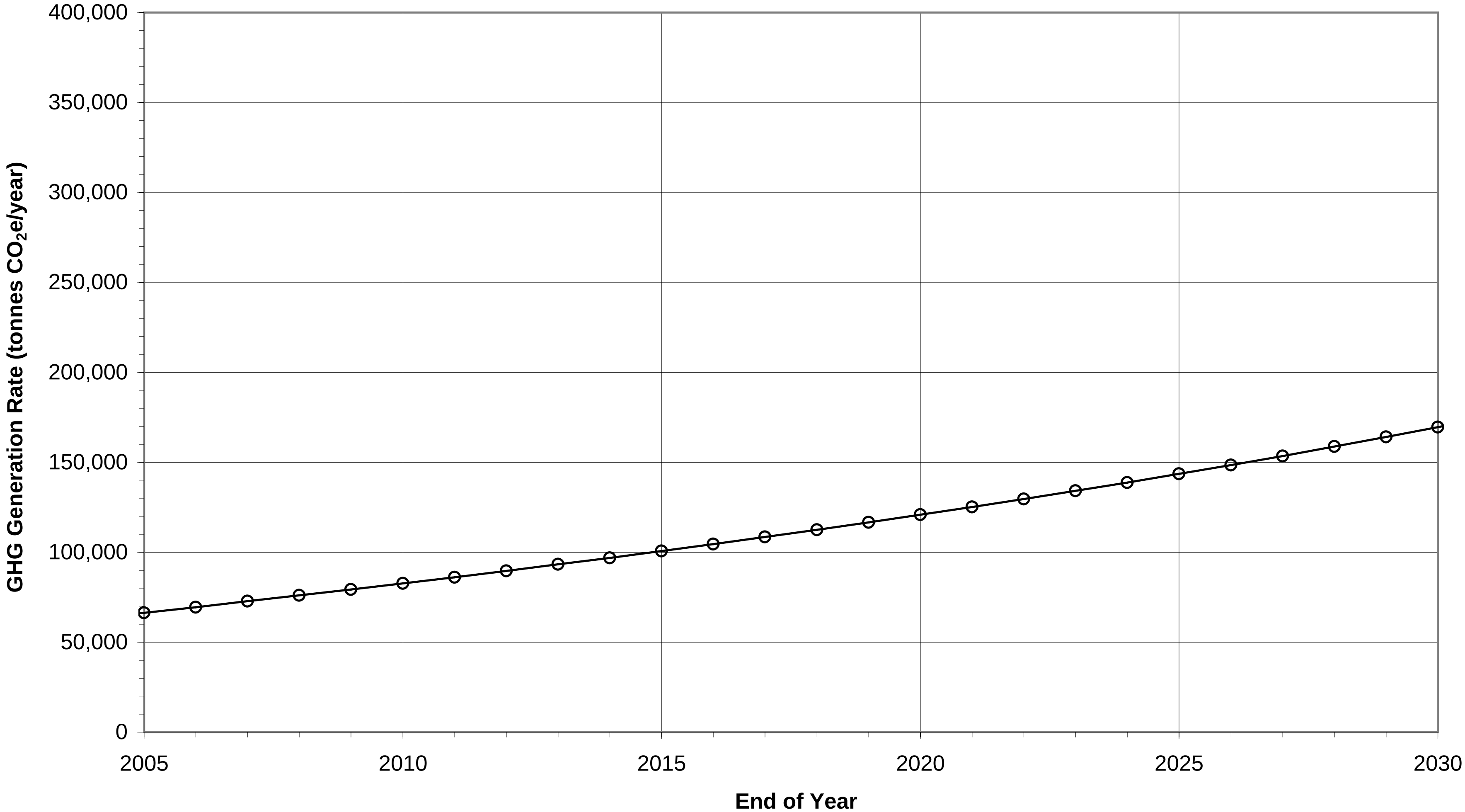
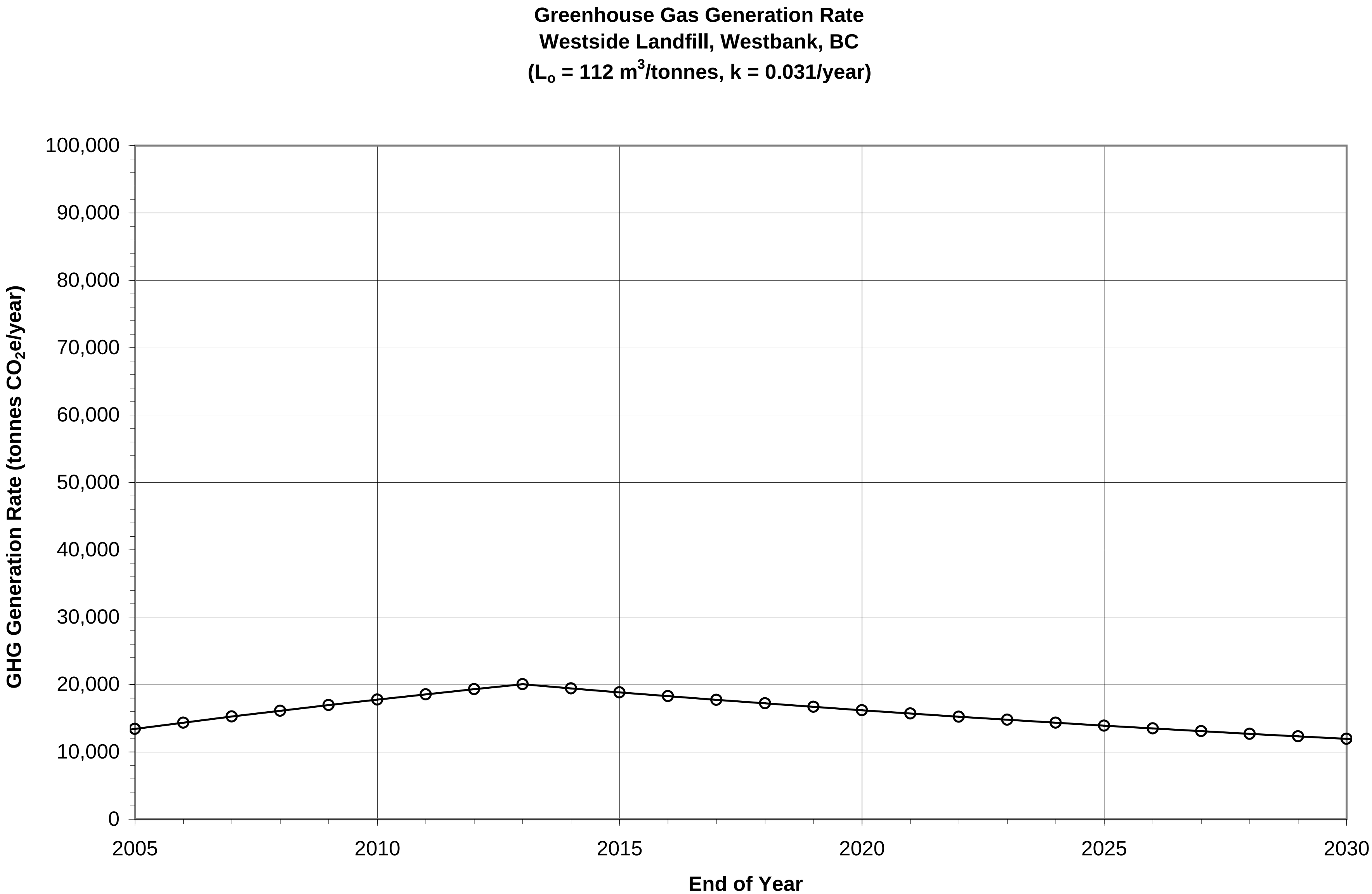
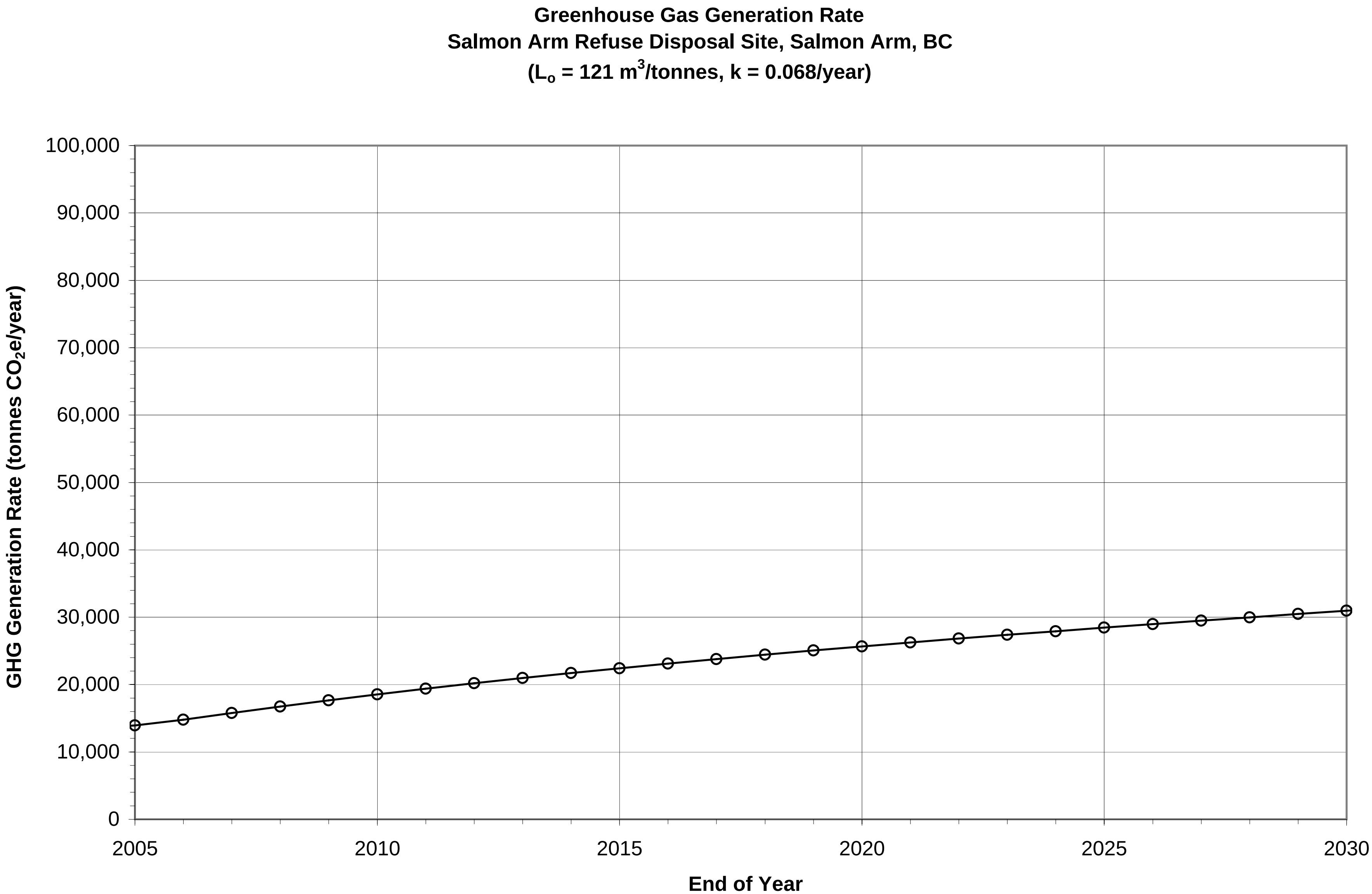

Greenhouse Gas Generation Rate
Ootischenia Landfill, Castlegar, BC
(L$_o$ = 123 m^3/tonnes, k = 0.079/year)
GHG Generation Rate (tonnes CO$_2$e/year)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2005
2010
2015
2020
2025
2030
End of Year

FIGURE L1-7

Greenhouse Gas Generation Rate
Glenmore Landfill, Kelowna, BC
(L_o = 112 m^3/tonnes, k = 0.031/year)




Greenhouse Gas Generation Rate
Westside Landfill, Westbank, BC
(L_o = 112 m^3/tonnes, k = 0.031/year)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
GHG Generation Rate (tonnes CO_2e/year)
2005
2010
2015
2020
2025
2030
End of Year


Greenhouse Gas Generation Rate
Salmon Arm Refuse Disposal Site, Salmon Arm, BC
(L_o = 121 m^3/tonnes, k = 0.068/year)
GHG Generation Rate (tonnes CO_2e/year)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2005
2010
2015
2020
2025
2030
End of Year

Greenhouse Gas Generation Rate
Comox Valley Landfill, Cumberland, BC
(L_o = 137 m^3/tonnes, k = 0.134/year)

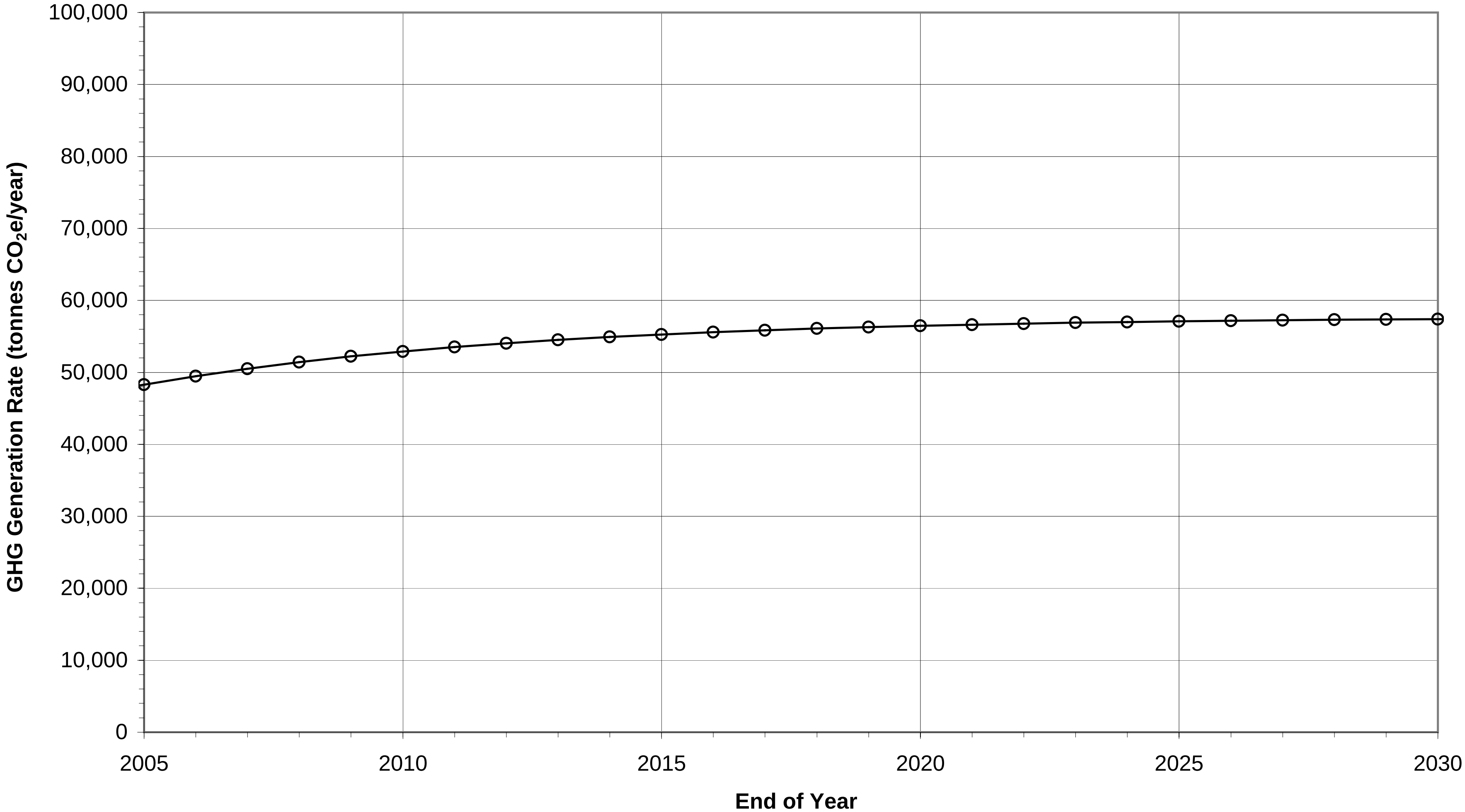
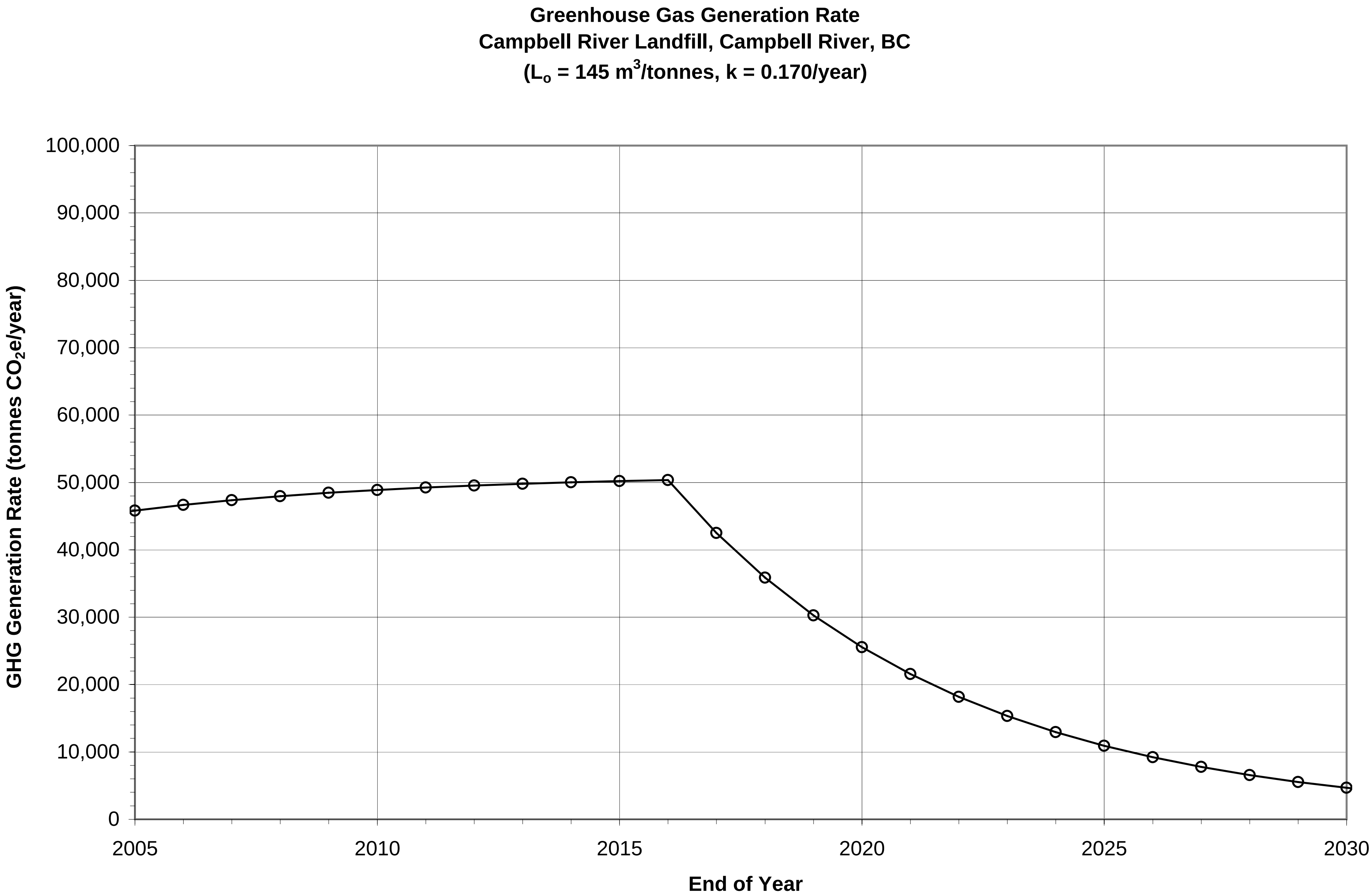
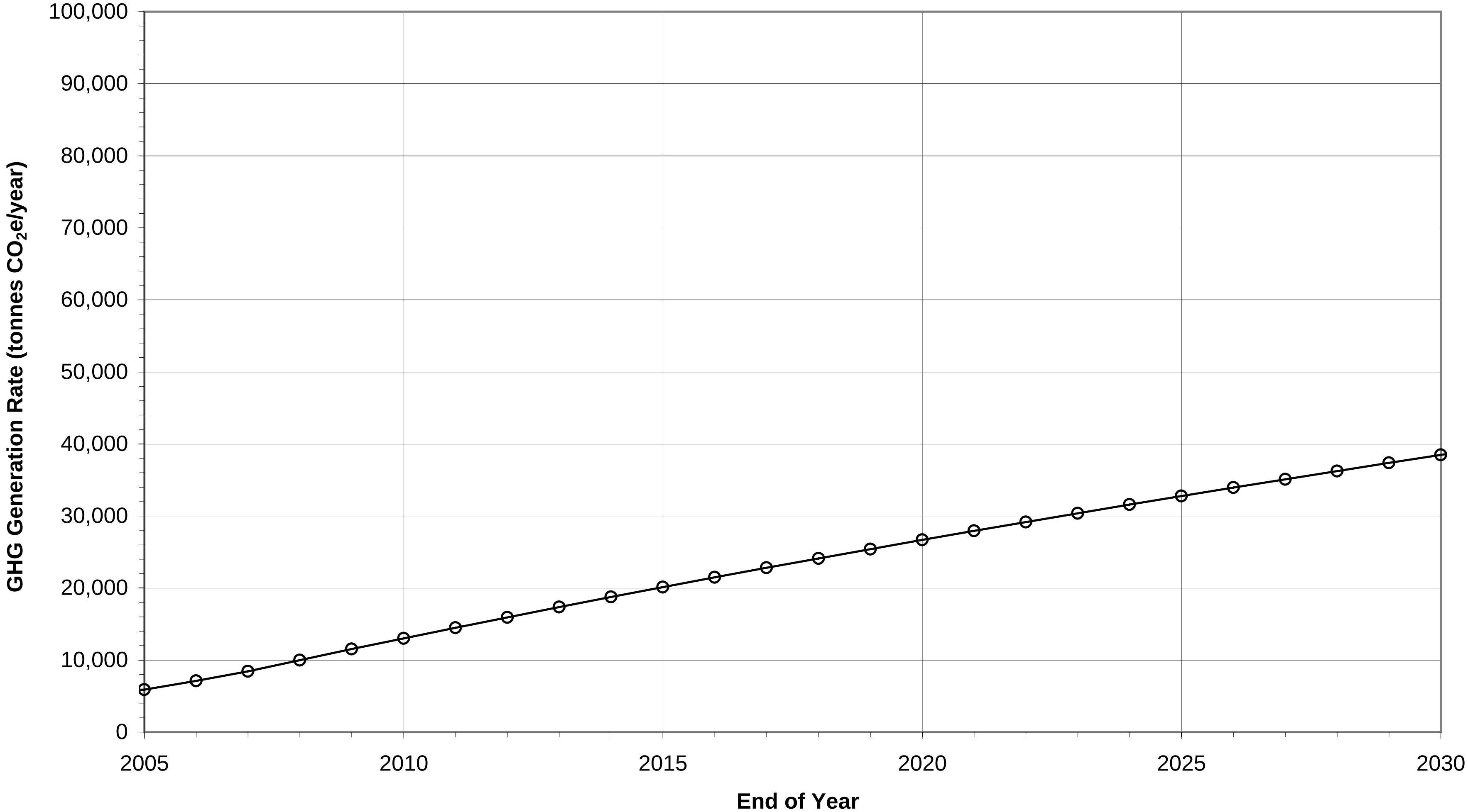
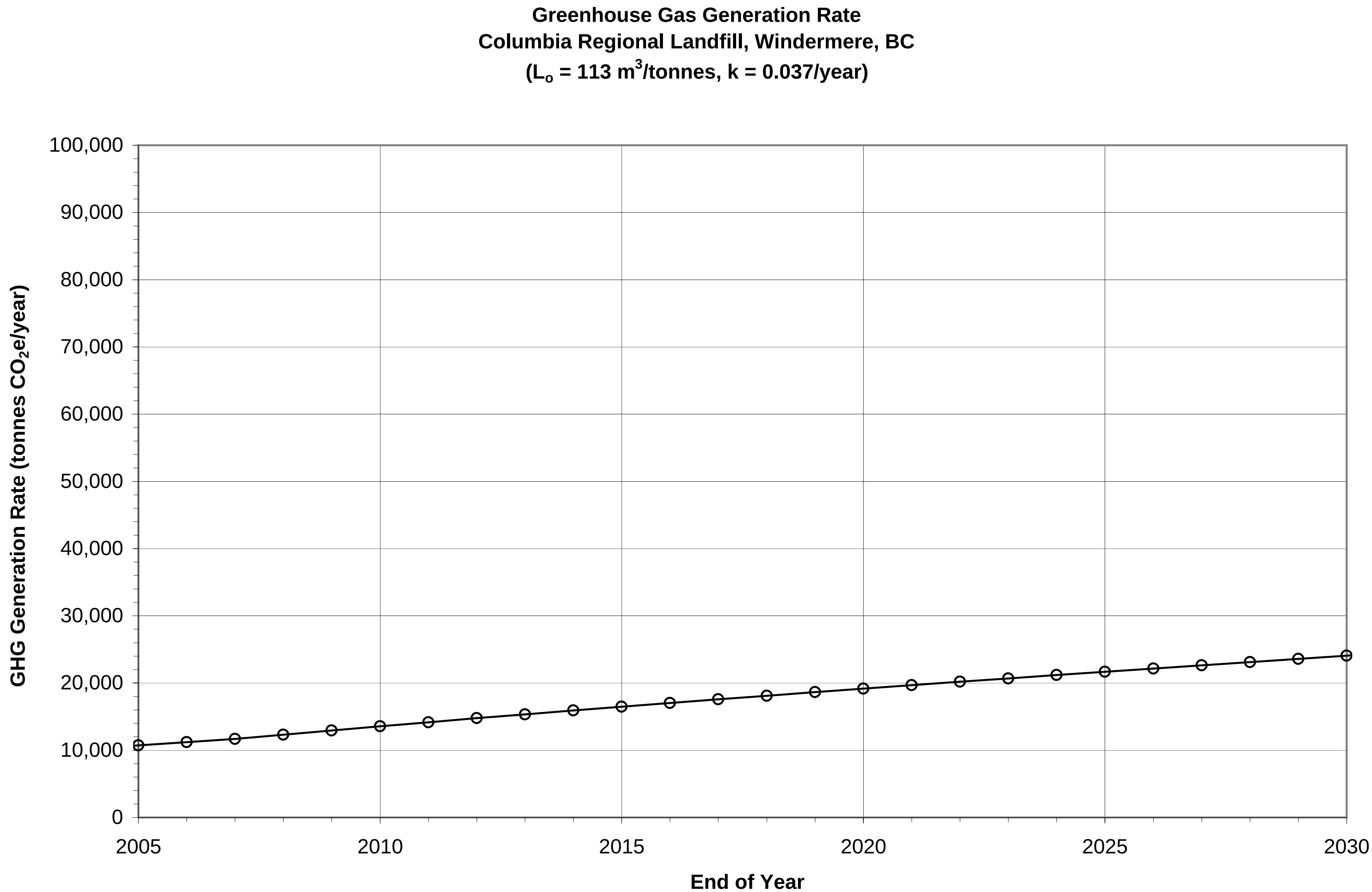


FIGURE L1-11


Greenhouse Gas Generation Rate
Campbell River Landfill, Campbell River, BC
(L_o = 145 m^3/tonnes, k = 0.170/year)
GHG Generation Rate (tonnes CO_2e/year)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2005
2010
2015
2020
2025
2030
End of Year

Greenhouse Gas Generation Rate
Central Sub-Regional Landfill, Cranbrook, BC
(L_o = 112 m^3/tonnes, k = 0.031/year)





Greenhouse Gas Generation Rate
Columbia Regional Landfill, Windermere, BC
(L_o = 113 m^3/tonnes, k = 0.037/year)
GHG Generation Rate (tonnes CO_2e/year)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2005
2010
2015
2020
2025
2030
End of Year

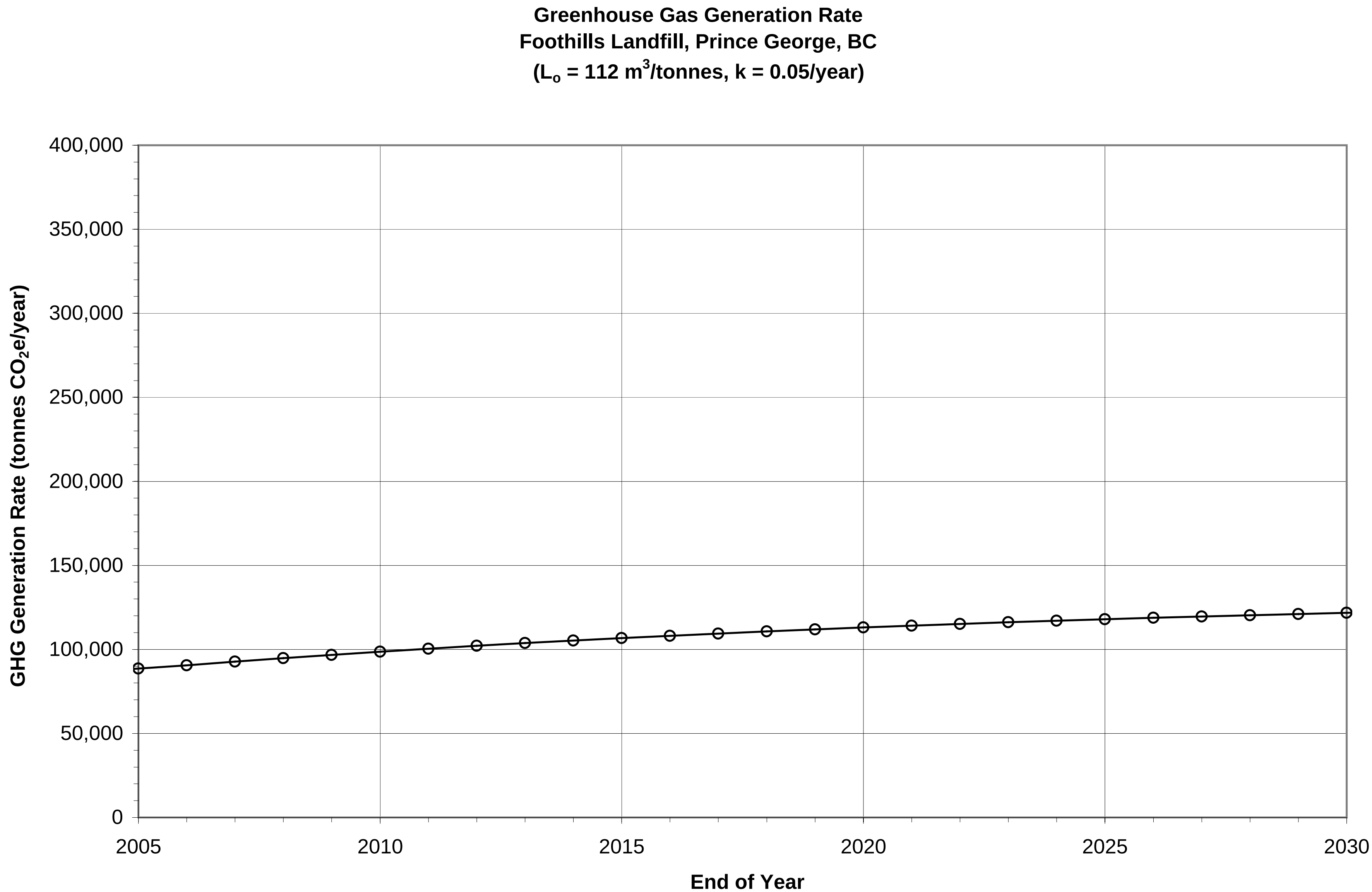
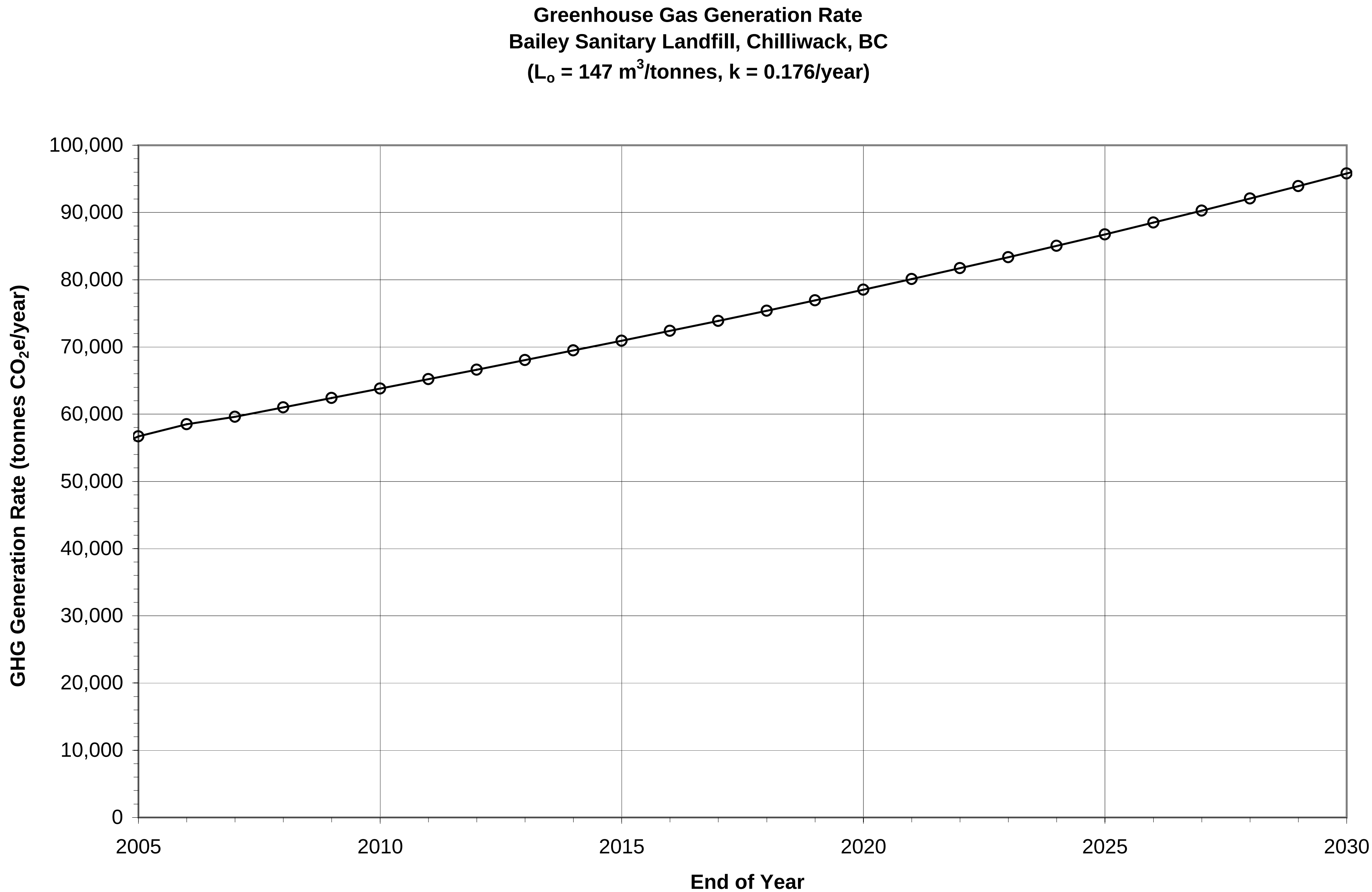
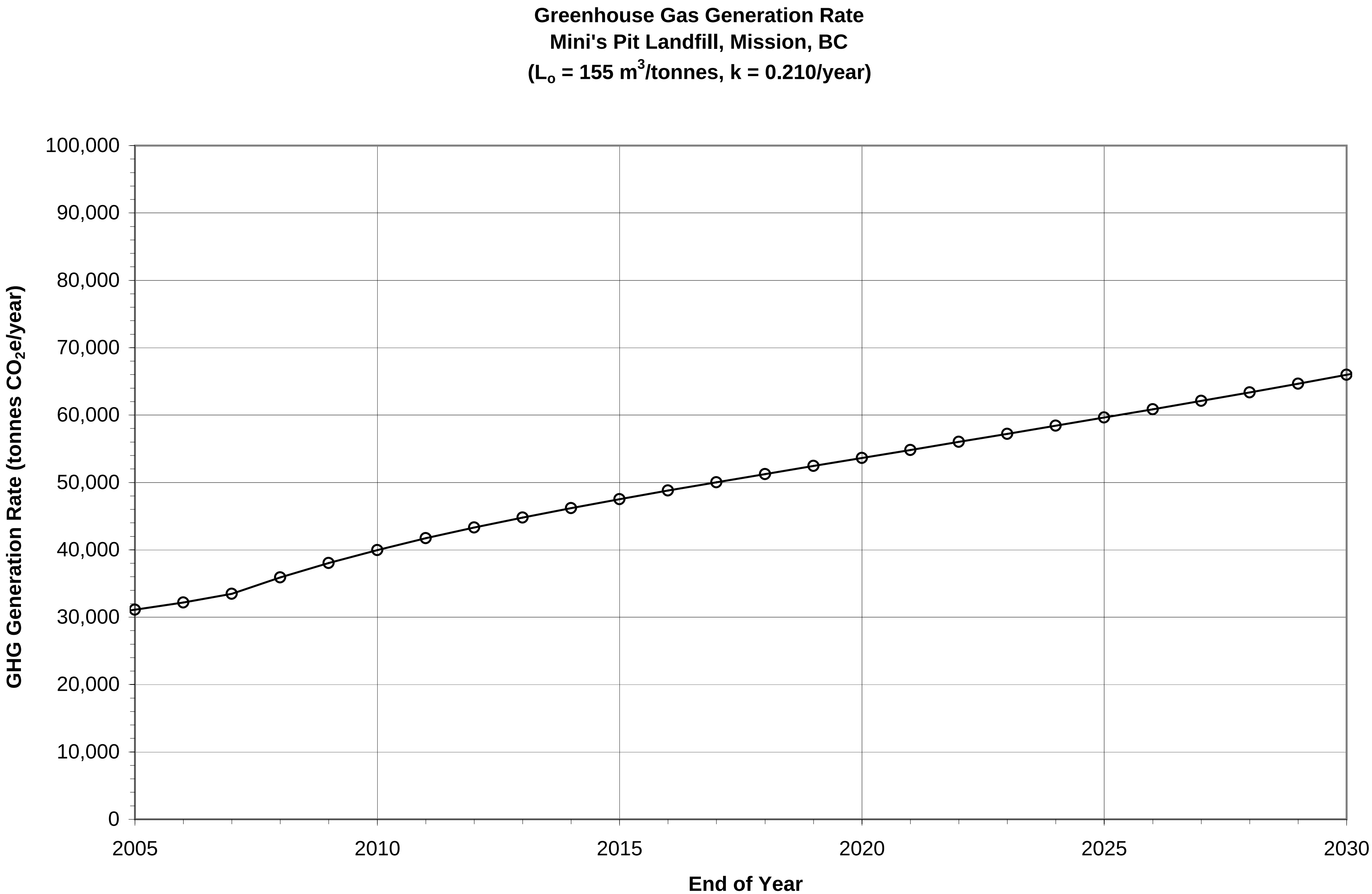
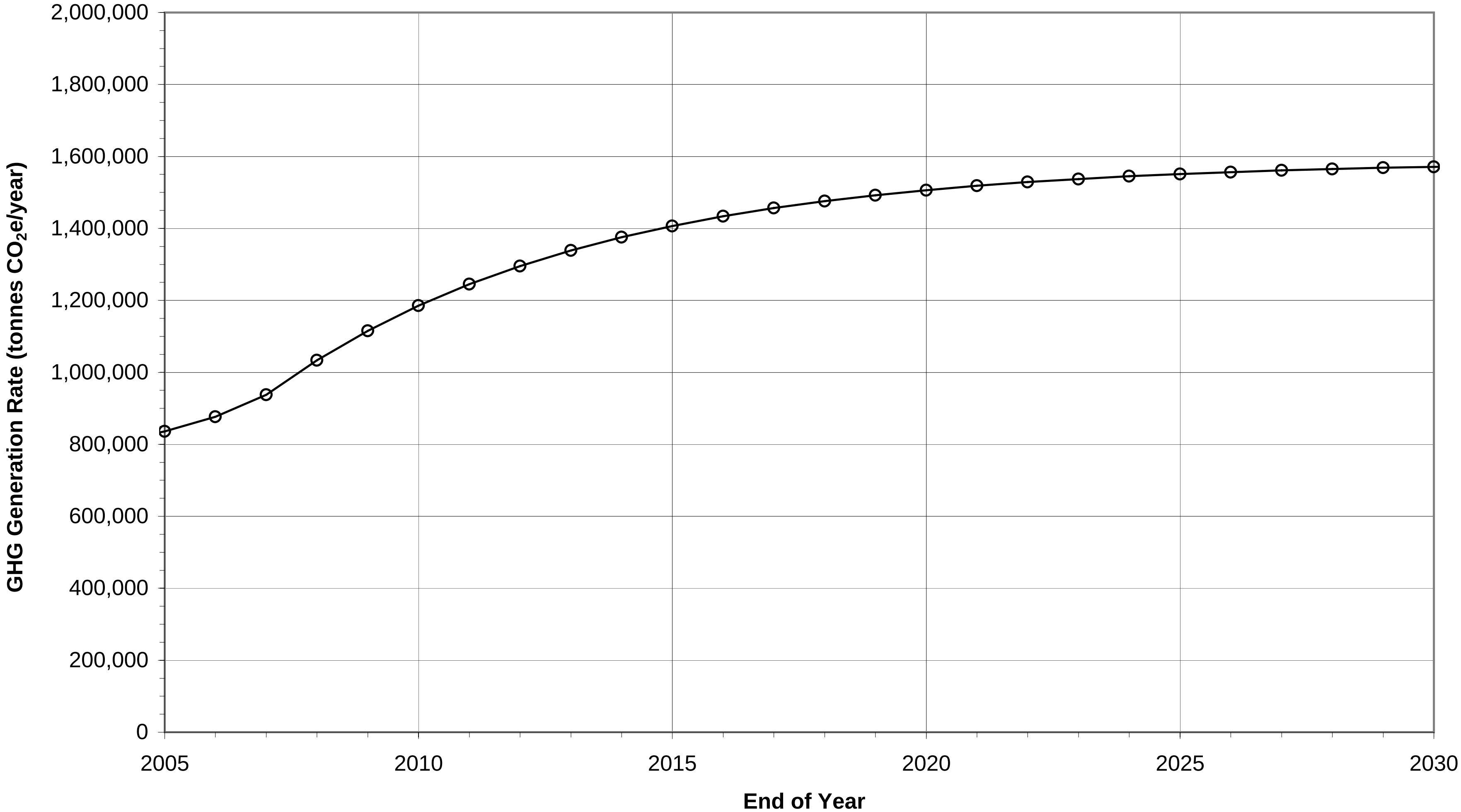

Greenhouse Gas Generation Rate
Foothills Landfill, Prince George, BC
(L_o = 112 m^3/tonnes, k = 0.05/year)
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
GHG Generation Rate (tonnes CO_2e/year)
2005
2010
2015
2020
2025
2030
End of Year

FIGURE L1-15

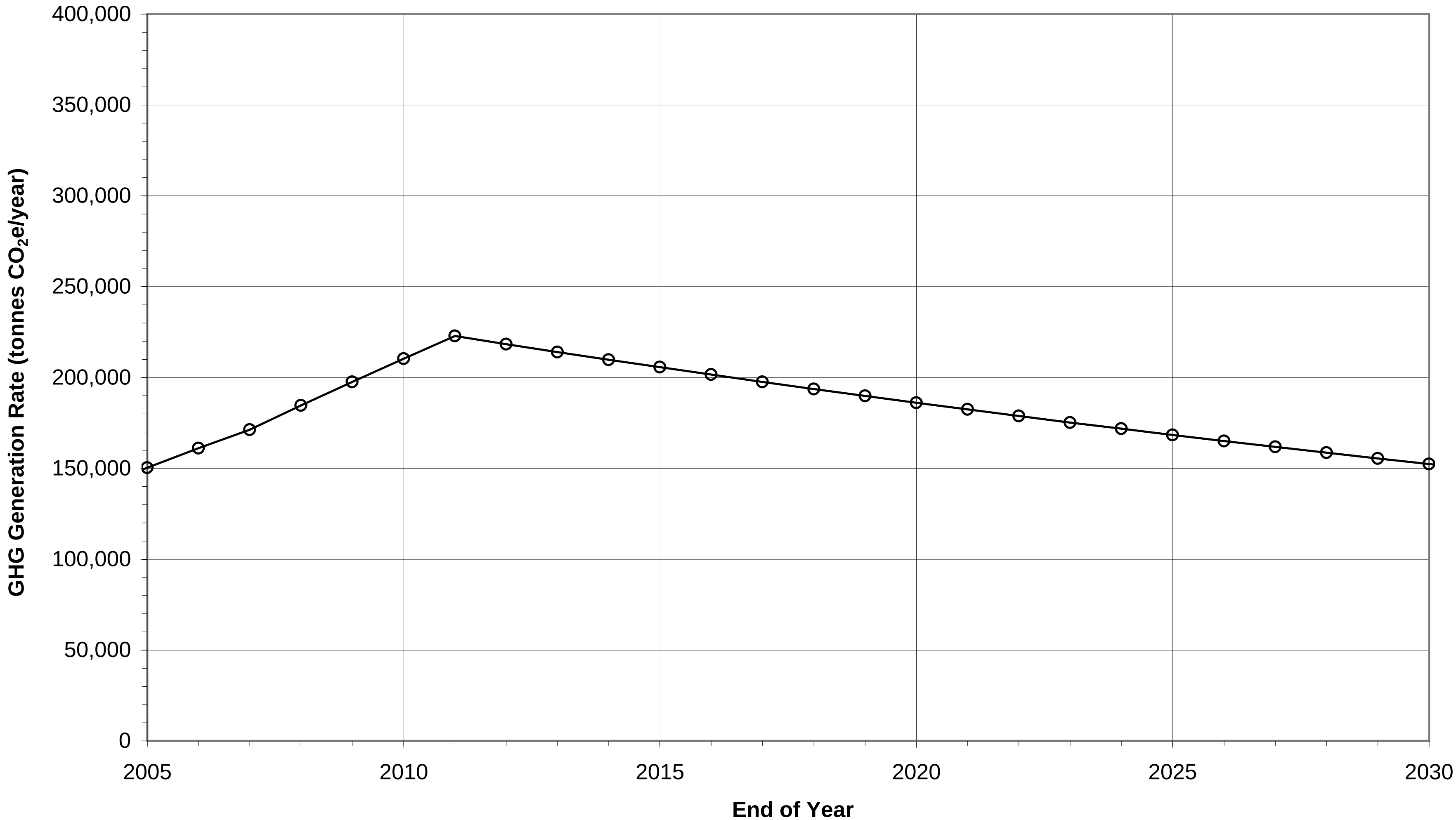

Greenhouse Gas Generation Rate
Bailey Sanitary Landfill, Chilliwack, BC
(L_o = 147 m^3/tonnes, k = 0.176/year)
GHG Generation Rate (tonnes CO_2e/year)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2005
2010
2015
2020
2025
2030
End of Year

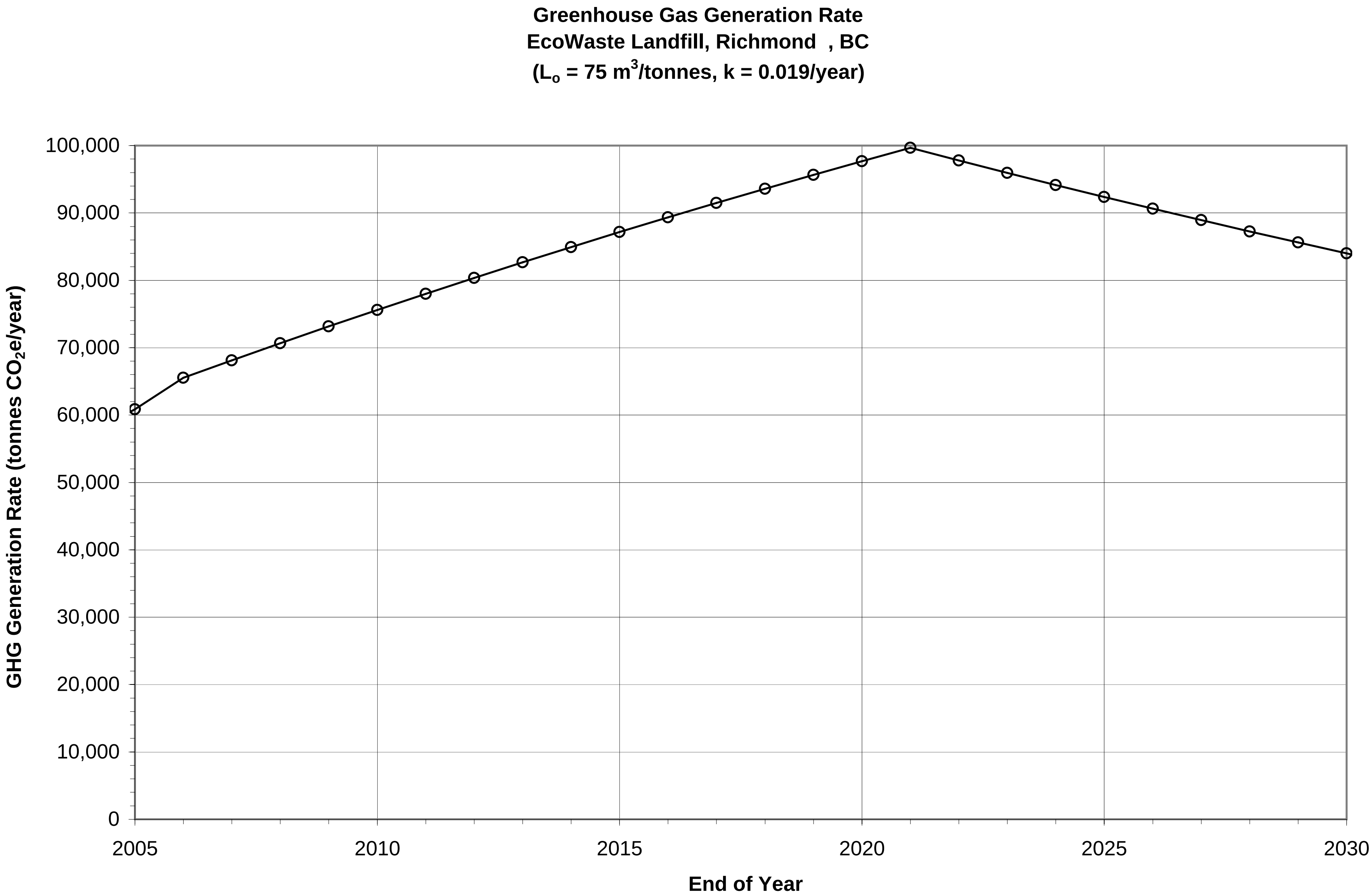

Greenhouse Gas Generation Rate
Mini's Pit Landfill, Mission, BC
(L_o = 155 m^3/tonnes, k = 0.210/year)
GHG Generation Rate (tonnes CO_2e/year)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2005
2010
2015
2020
2025
2030
End of Year

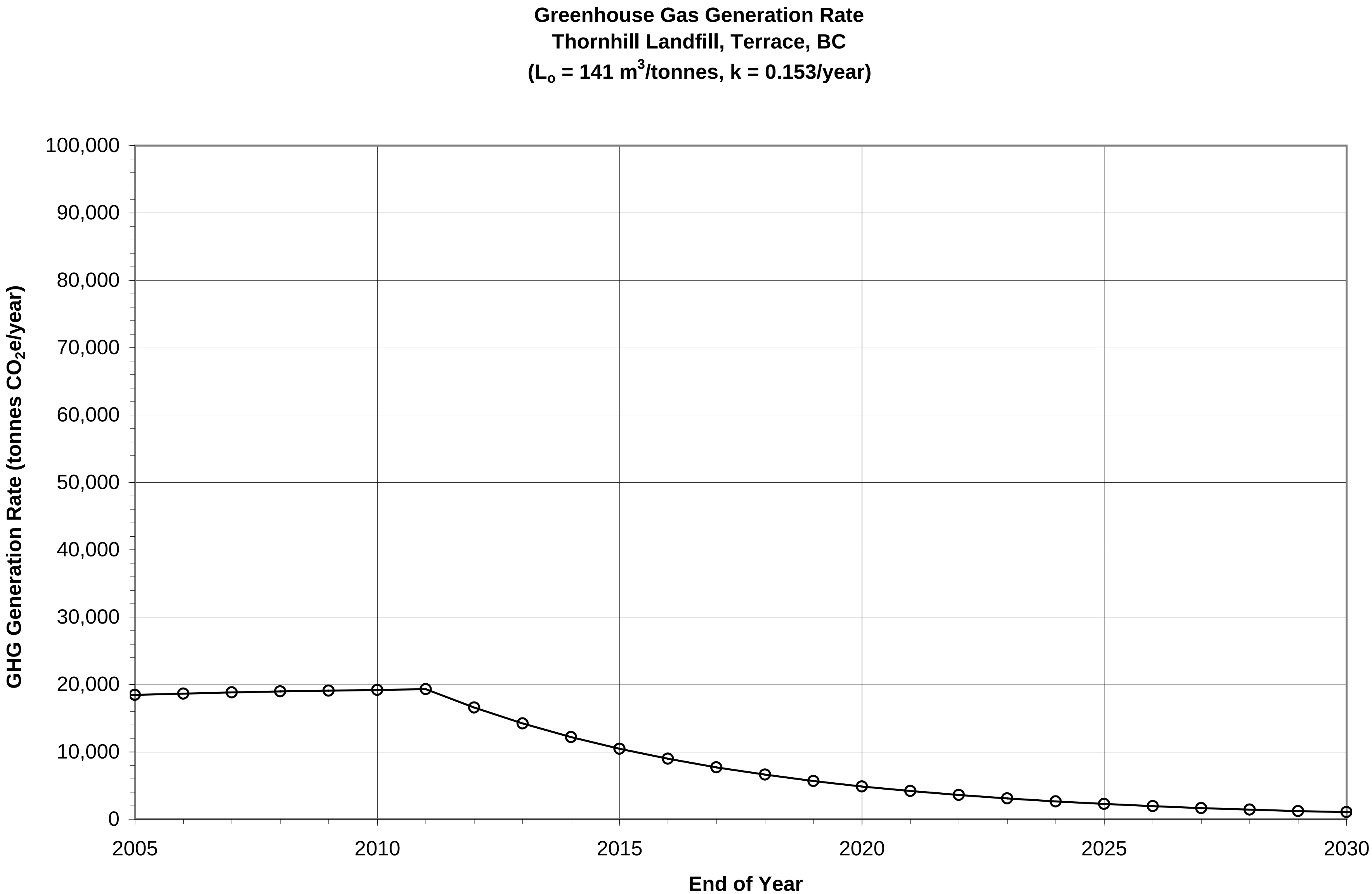
Greenhouse Gas Generation Rate
Vancouver Landfill, Delta, BC
(L_o = 150 m^3/tonnes, k = 0.16/year)

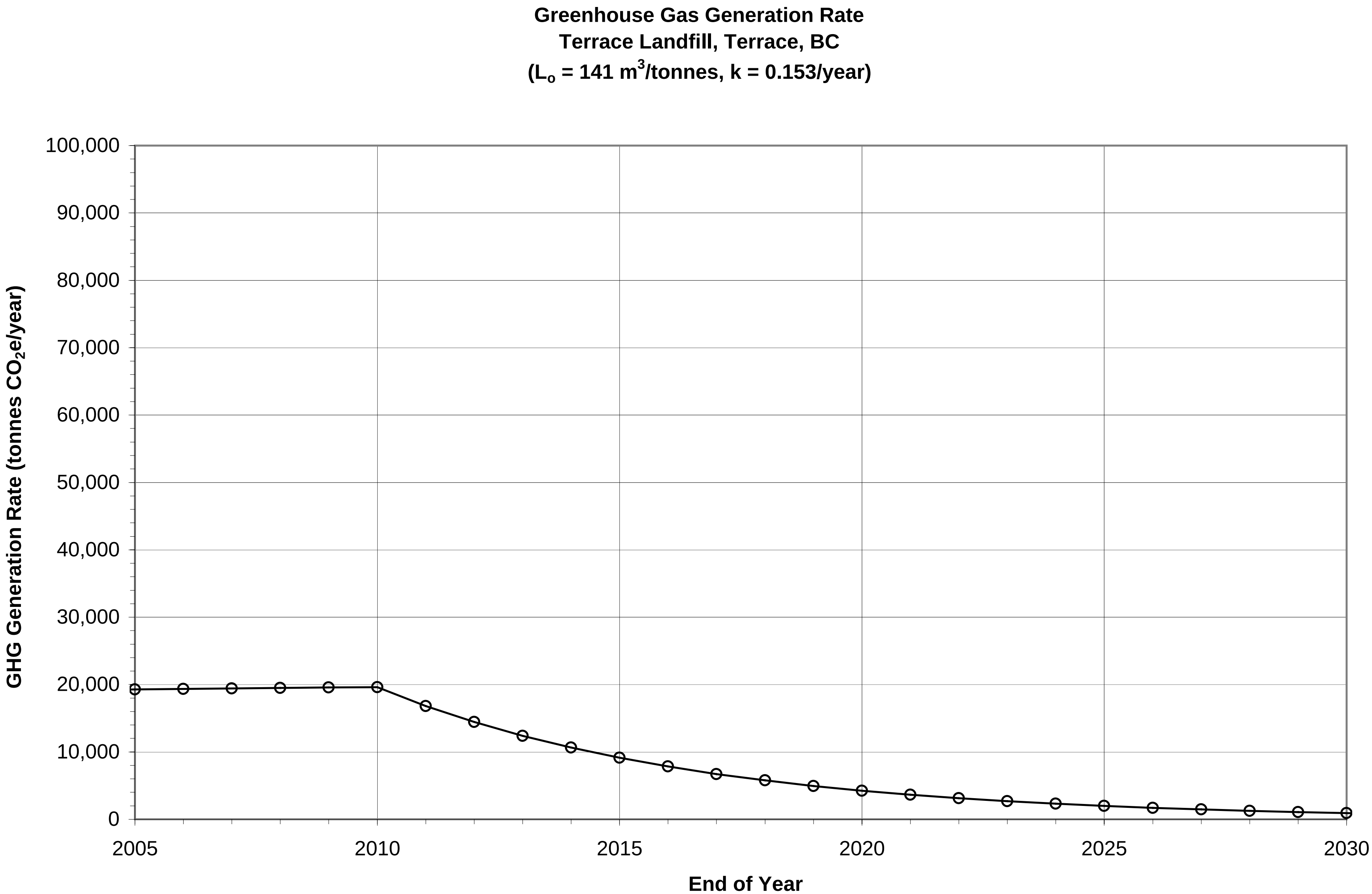


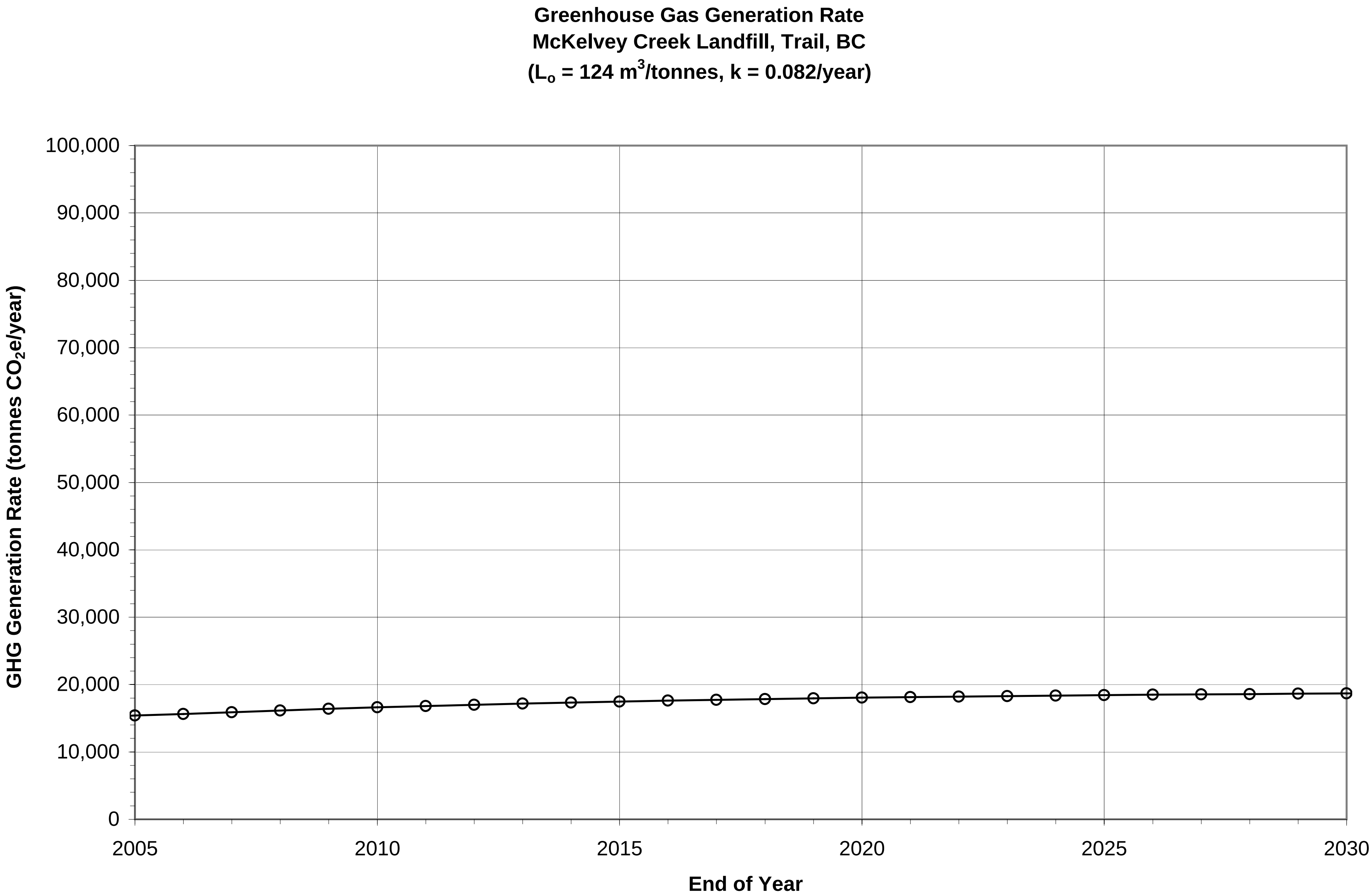
Greenhouse Gas Generation Rate
Cache Creek Landfill, Cache Creek, BC
(L_o = 100 m^3/tonnes, k = 0.02/year)

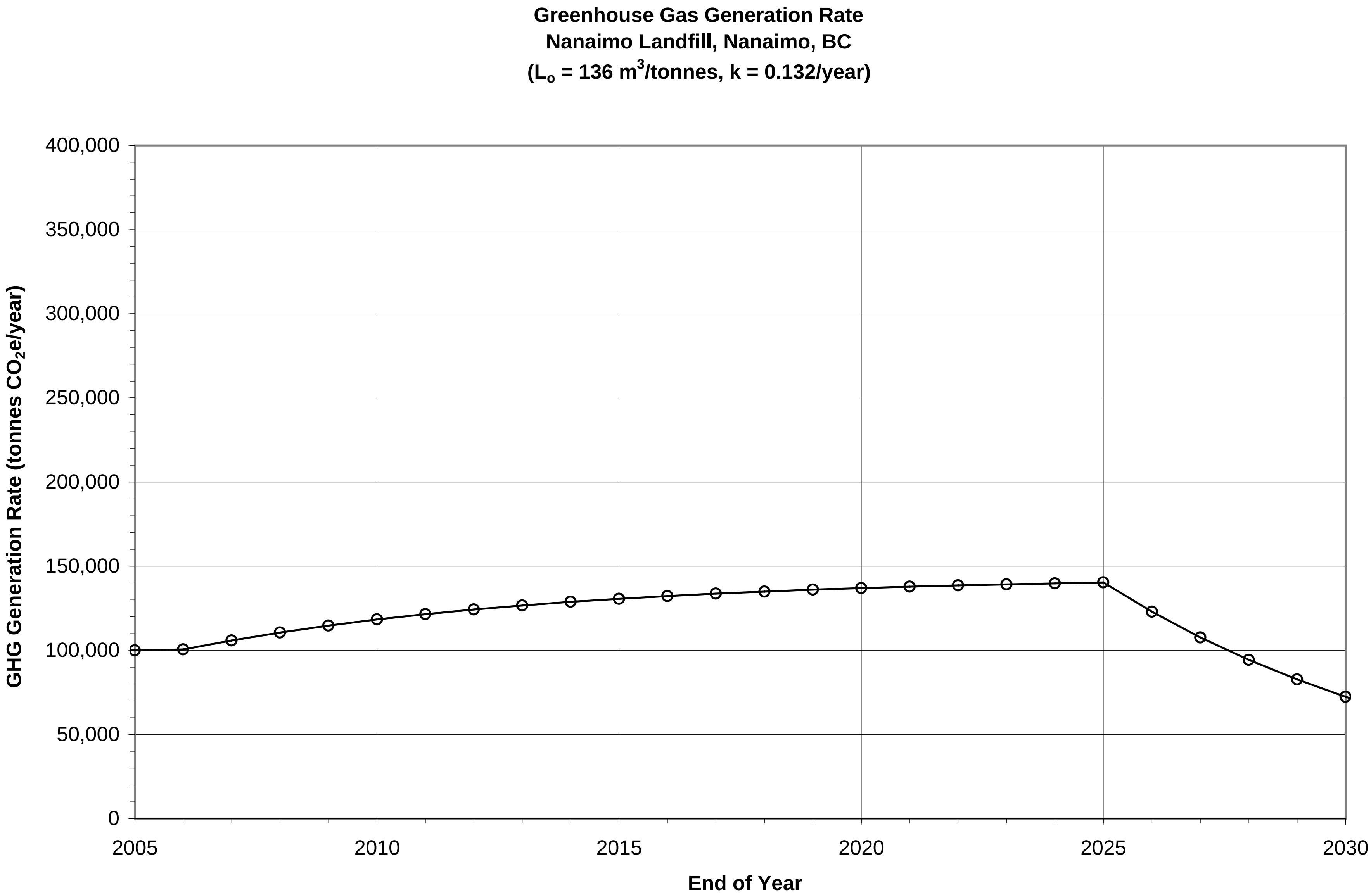


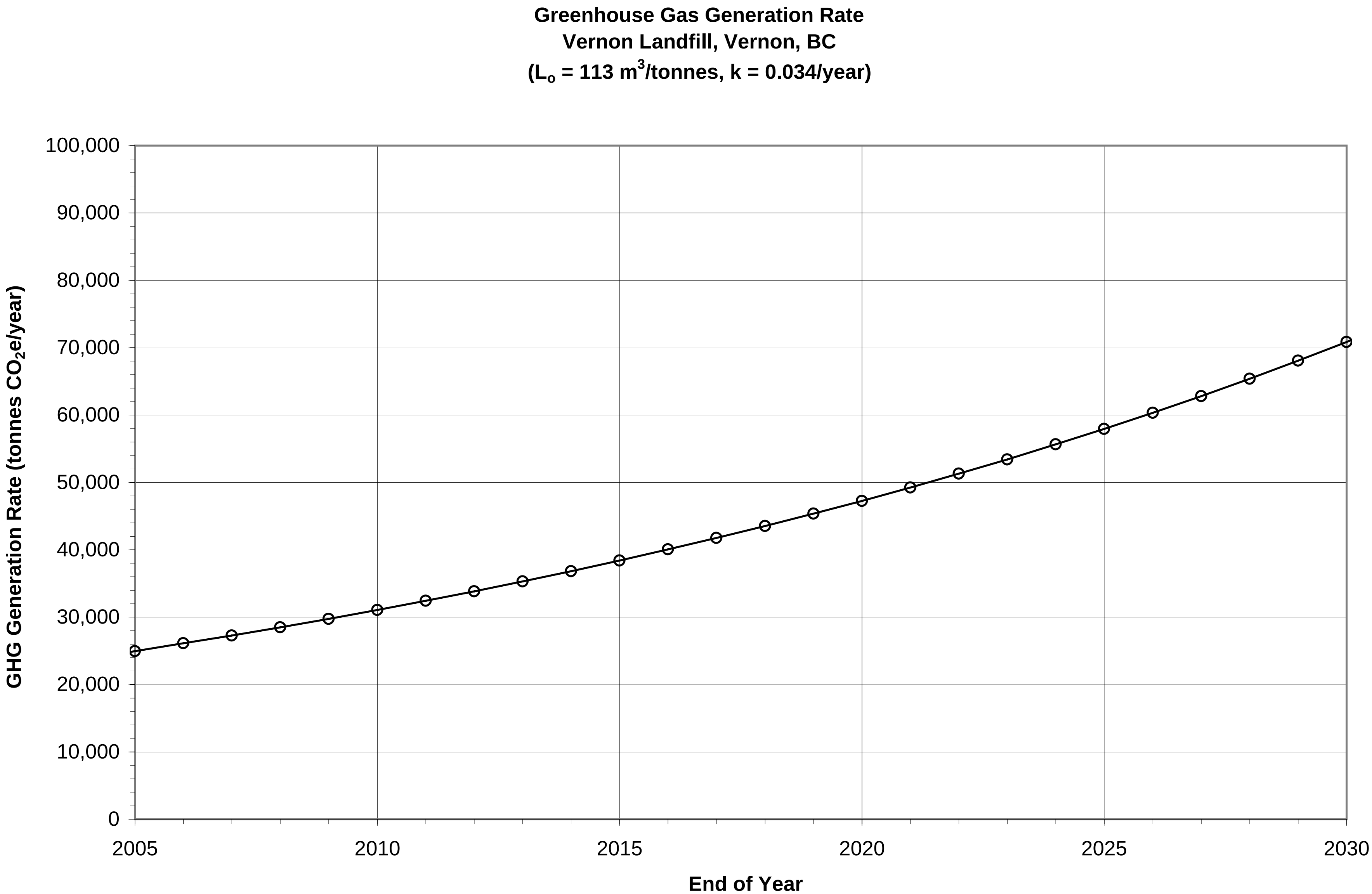

Greenhouse Gas Generation Rate
EcoWaste Landfill, Richmond , BC
(L_o = 75 m^3/tonnes, k = 0.019/year)
GHG Generation Rate (tonnes CO_2e/year)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2005
2010
2015
2020
2025
2030
End of Year

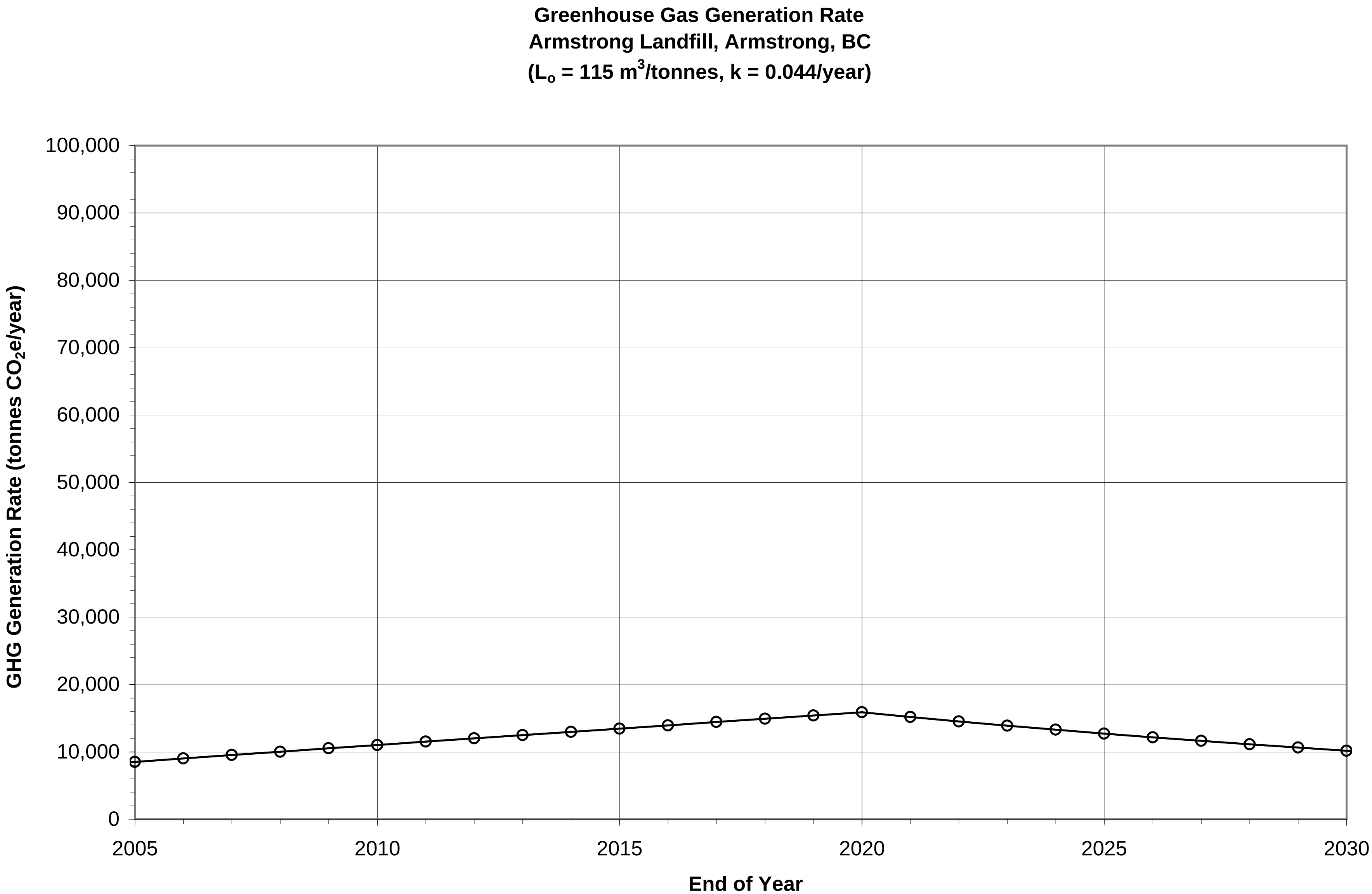

Greenhouse Gas Generation Rate
Thornhill Landfill, Terrace, BC
(L_o = 141 m^3/tonnes, k = 0.153/year)
GHG Generation Rate (tonnes CO_2e/year)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2005
2010
2015
2020
2025
2030
End of Year

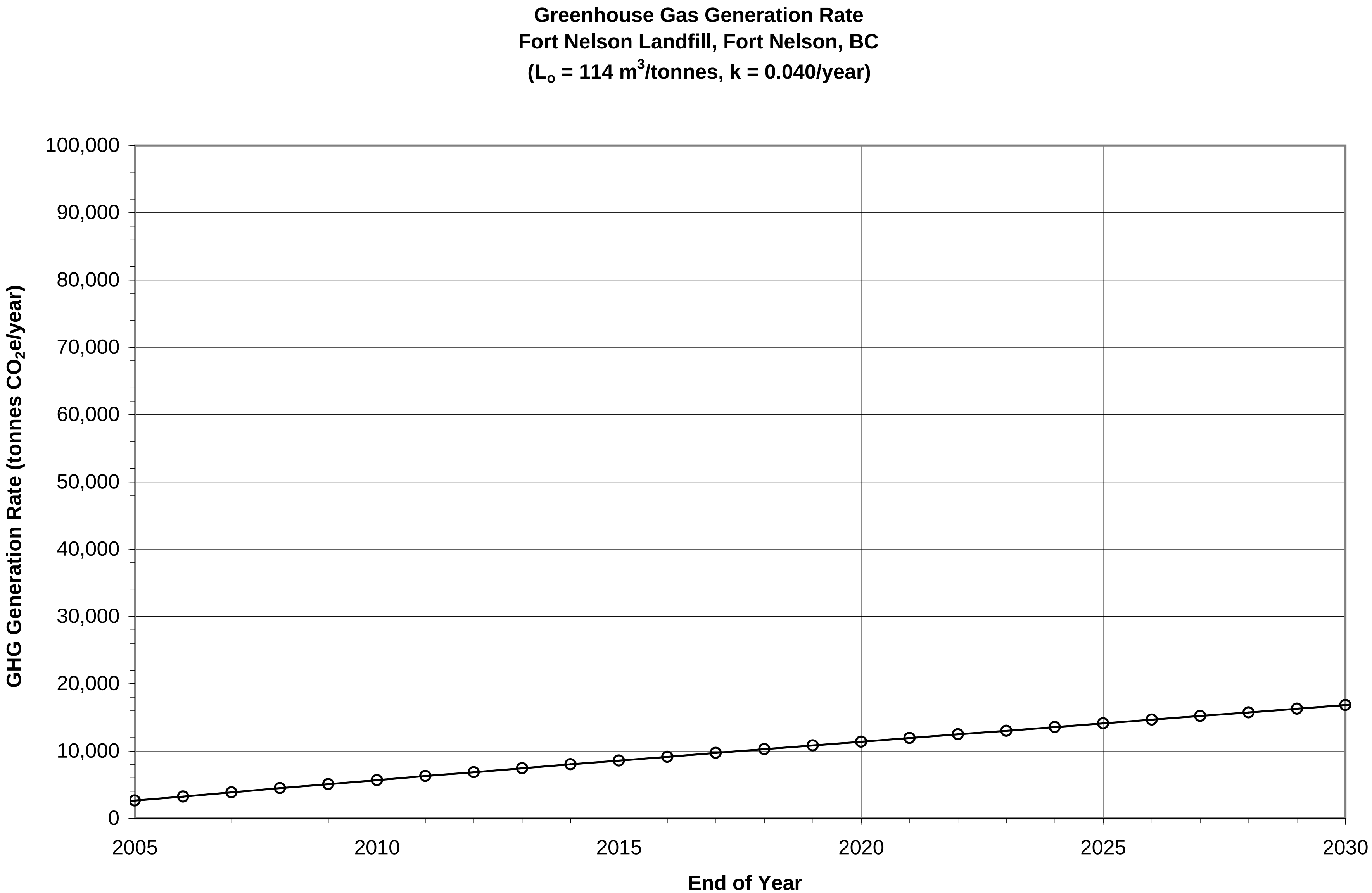

Greenhouse Gas Generation Rate
Terrace Landfill, Terrace, BC
(L_o = 141 m^3/tonnes, k = 0.153/year)
GHG Generation Rate (tonnes CO_2e/year)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2005
2010
2015
2020
2025
2030
End of Year

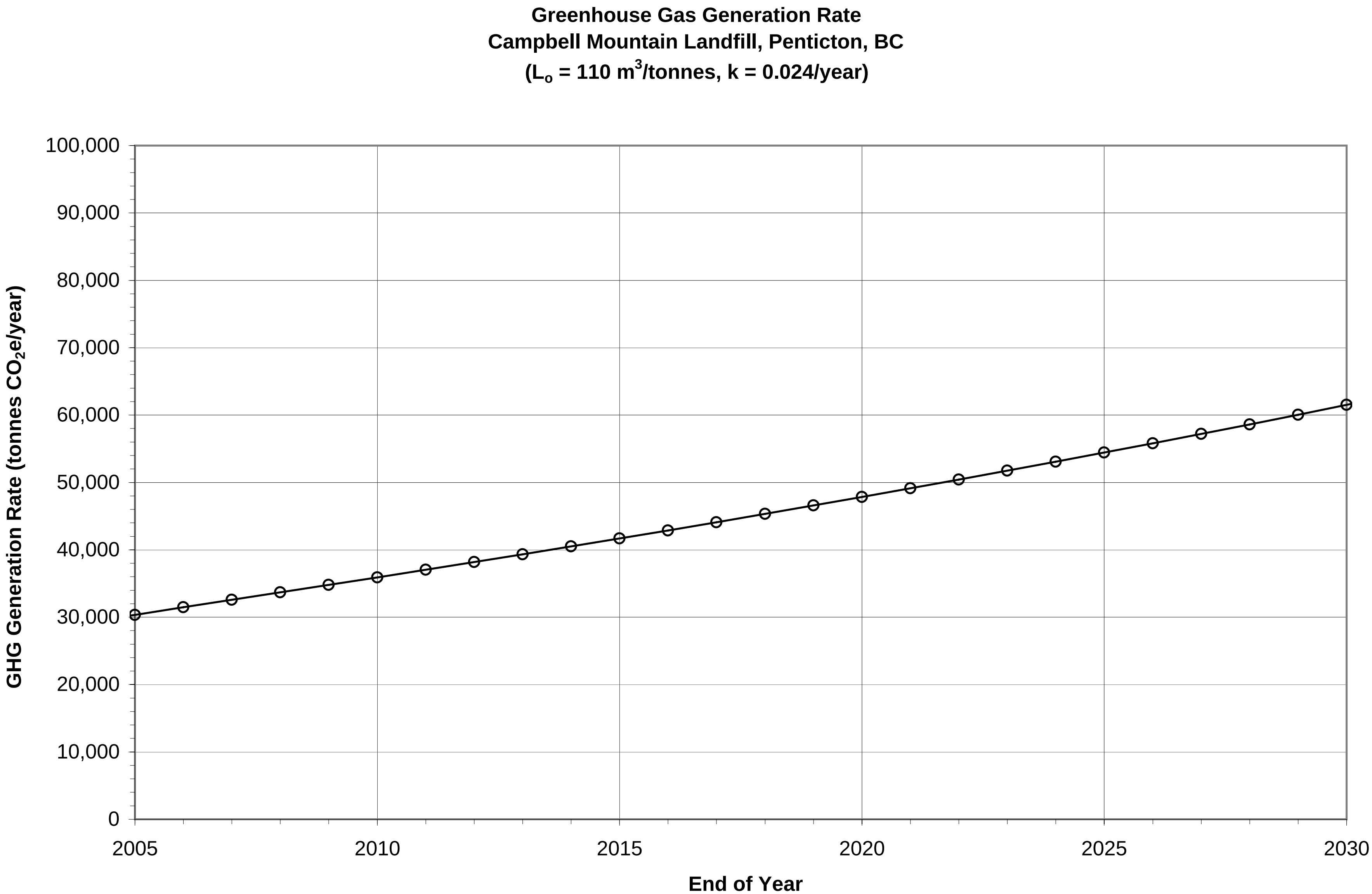

Greenhouse Gas Generation Rate
McKelvey Creek Landfill, Trail, BC
(L_o = 124 m^3/tonnes, k = 0.082/year)
GHG Generation Rate (tonnes CO_2e/year)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2005
2010
2015
2020
2025
2030
End of Year

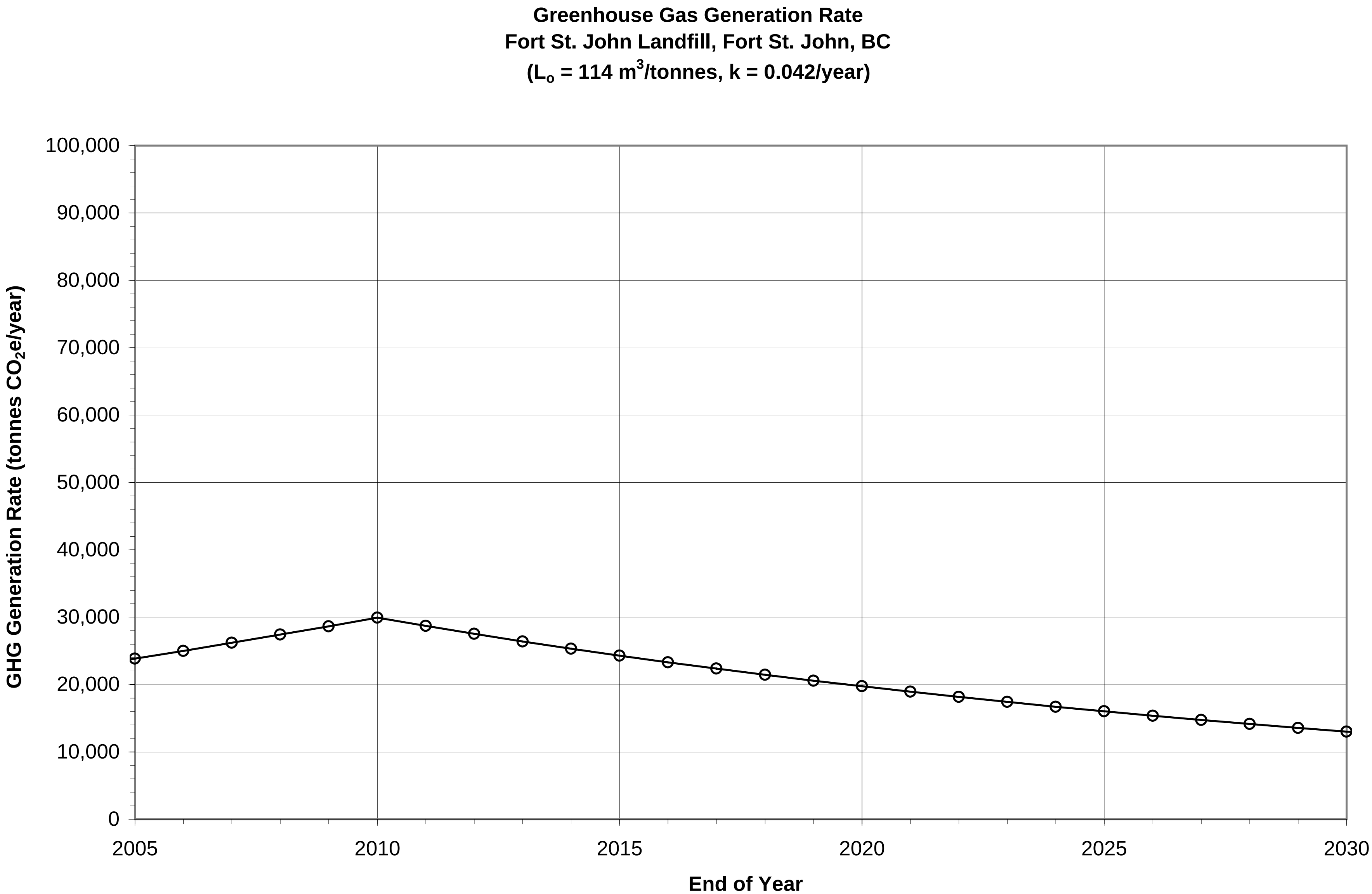

Greenhouse Gas Generation Rate
Nanaimo Landfill, Nanaimo, BC
(L_o = 136 m^3/tonnes, k = 0.132/year)
GHG Generation Rate (tonnes CO_2e/year)
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
2005
2010
2015
2020
2025
2030
End of Year

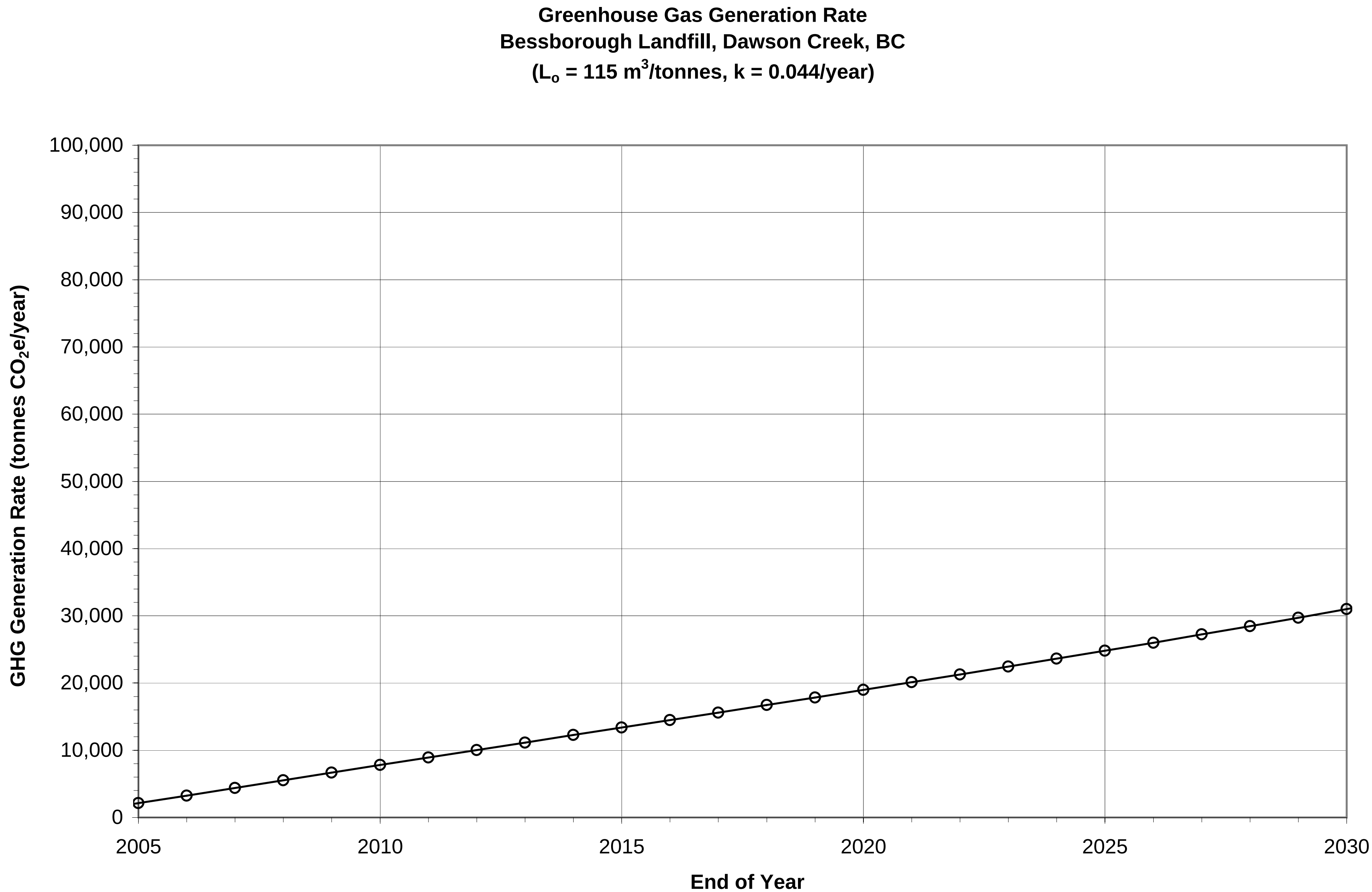

Greenhouse Gas Generation Rate
Vernon Landfill, Vernon, BC
(L_o = 113 m^3/tonnes, k = 0.034/year)
GHG Generation Rate (tonnes CO_2e/year)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2005
2010
2015
2020
2025
2030
End of Year

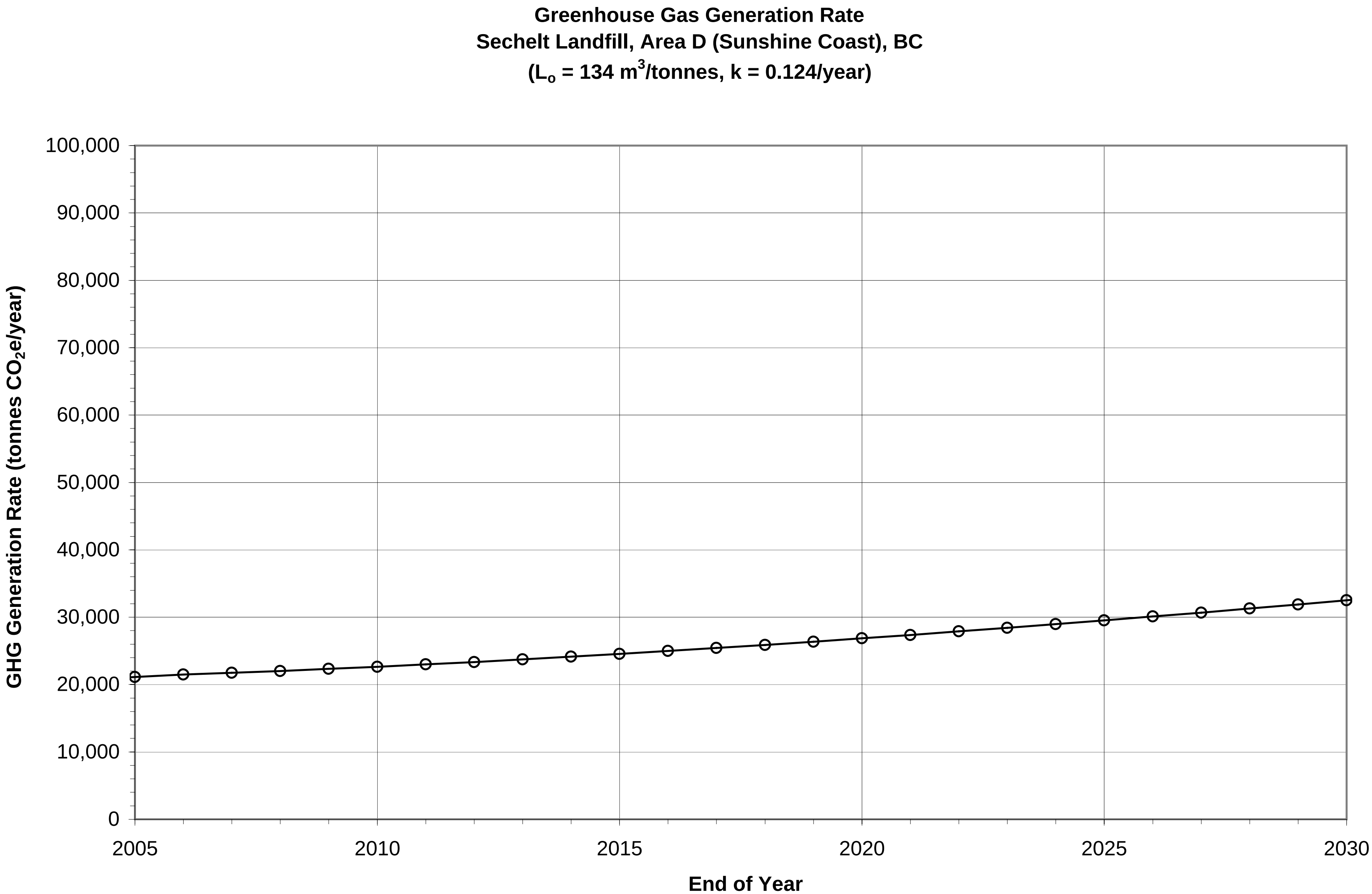

Greenhouse Gas Generation Rate
Armstrong Landfill, Armstrong, BC
(L_o = 115 m^3/tonnes, k = 0.044/year)
GHG Generation Rate (tonnes CO_2e/year)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2005
2010
2015
2020
2025
2030
End of Year

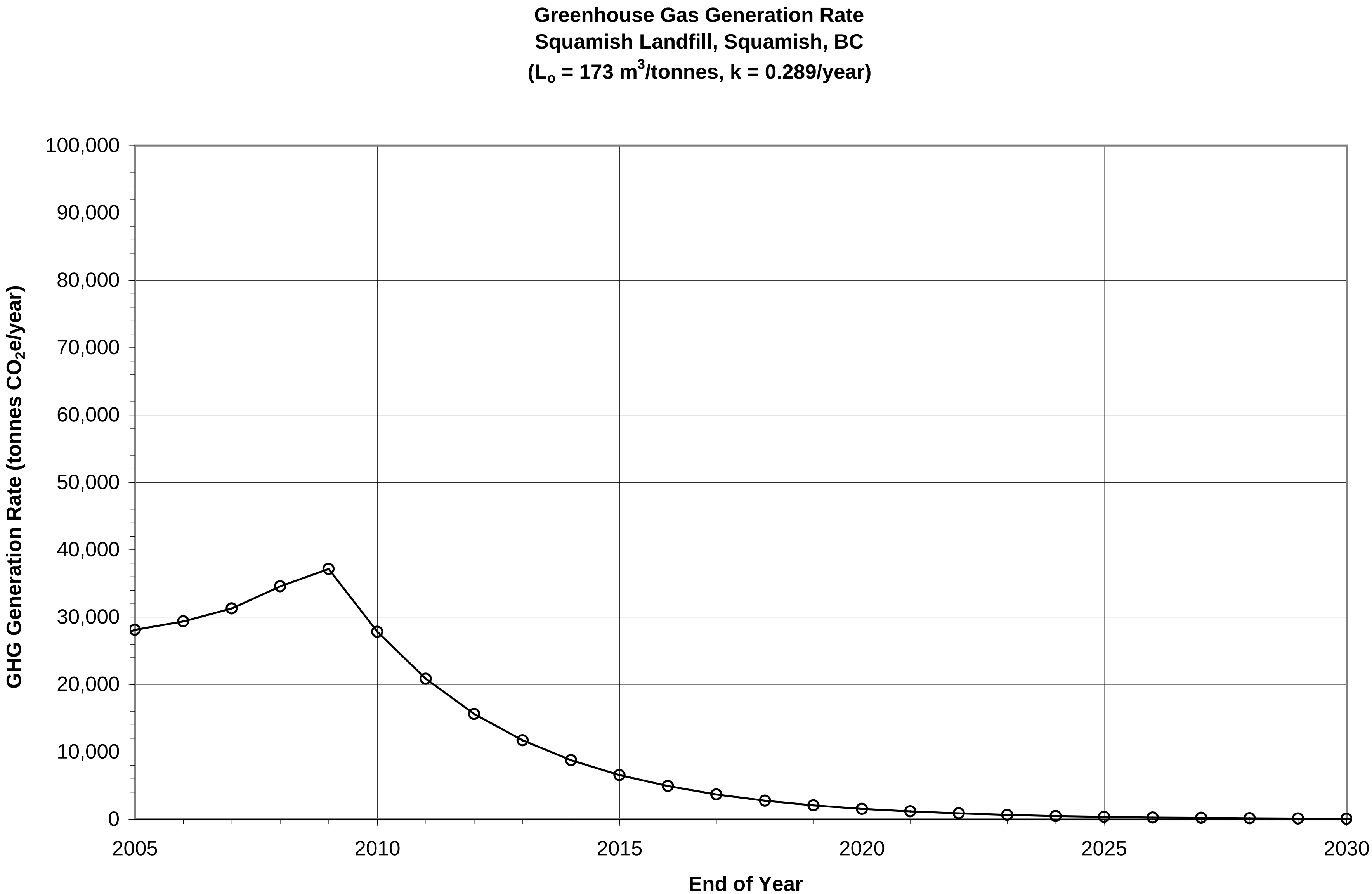

Greenhouse Gas Generation Rate
Fort Nelson Landfill, Fort Nelson, BC
(L_o = 114 m^3/tonnes, k = 0.040/year)
GHG Generation Rate (tonnes CO_2e/year)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2005
2010
2015
2020
2025
2030
End of Year


Greenhouse Gas Generation Rate
Campbell Mountain Landfill, Penticton, BC
(Lo = 110 m3/tonnes, k = 0.024/year)
GHG Generation Rate (tonnes CO2e/year)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2005
2010
2015
2020
2025
2030
End of Year


Greenhouse Gas Generation Rate
Fort St. John Landfill, Fort St. John, BC
(L_o = 114 m^3/tonnes, k = 0.042/year)
GHG Generation Rate (tonnes CO_2e/year)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2005
2010
2015
2020
2025
2030
End of Year

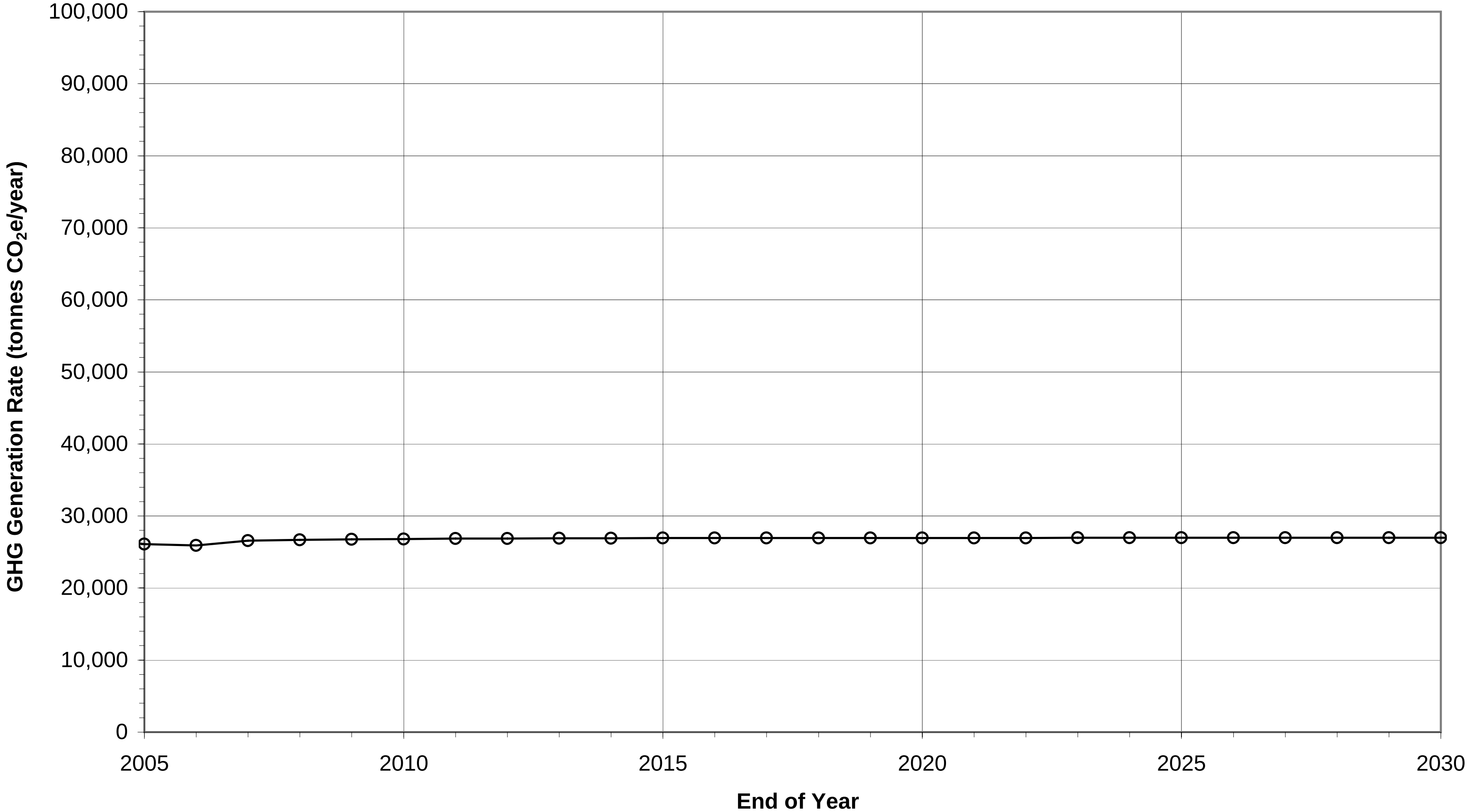

Greenhouse Gas Generation Rate
Bessborough Landfill, Dawson Creek, BC
(L_o = 115 m^3/tonnes, k = 0.044/year)
GHG Generation Rate (tonnes CO_2e/year)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2005
2010
2015
2020
2025
2030
End of Year

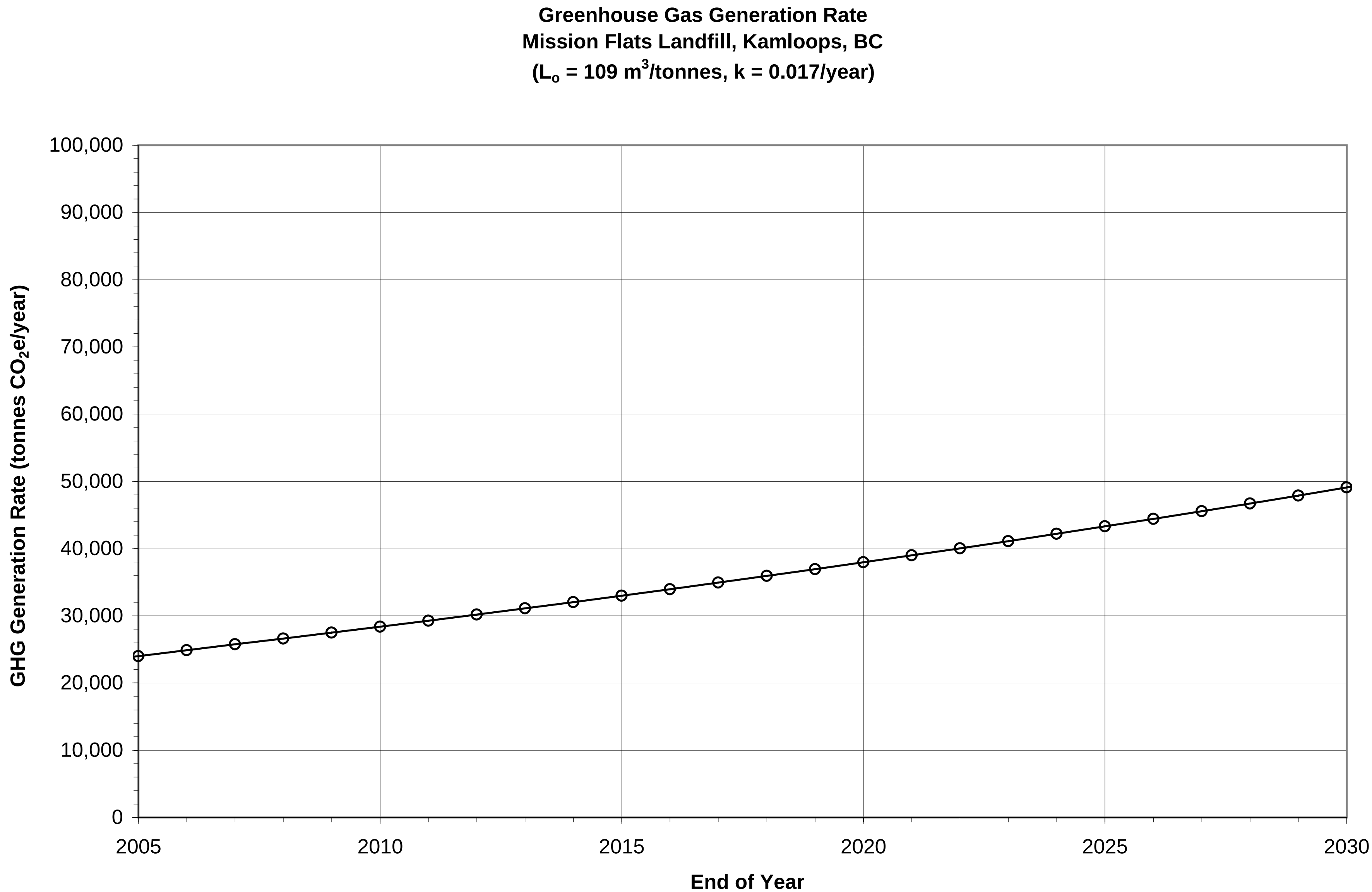

Greenhouse Gas Generation Rate
Sechelt Landfill, Area D (Sunshine Coast), BC
(L_o = 134 m^3/tonnes, k = 0.124/year)
GHG Generation Rate (tonnes CO_2e/year)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2005
2010
2015
2020
2025
2030
End of Year



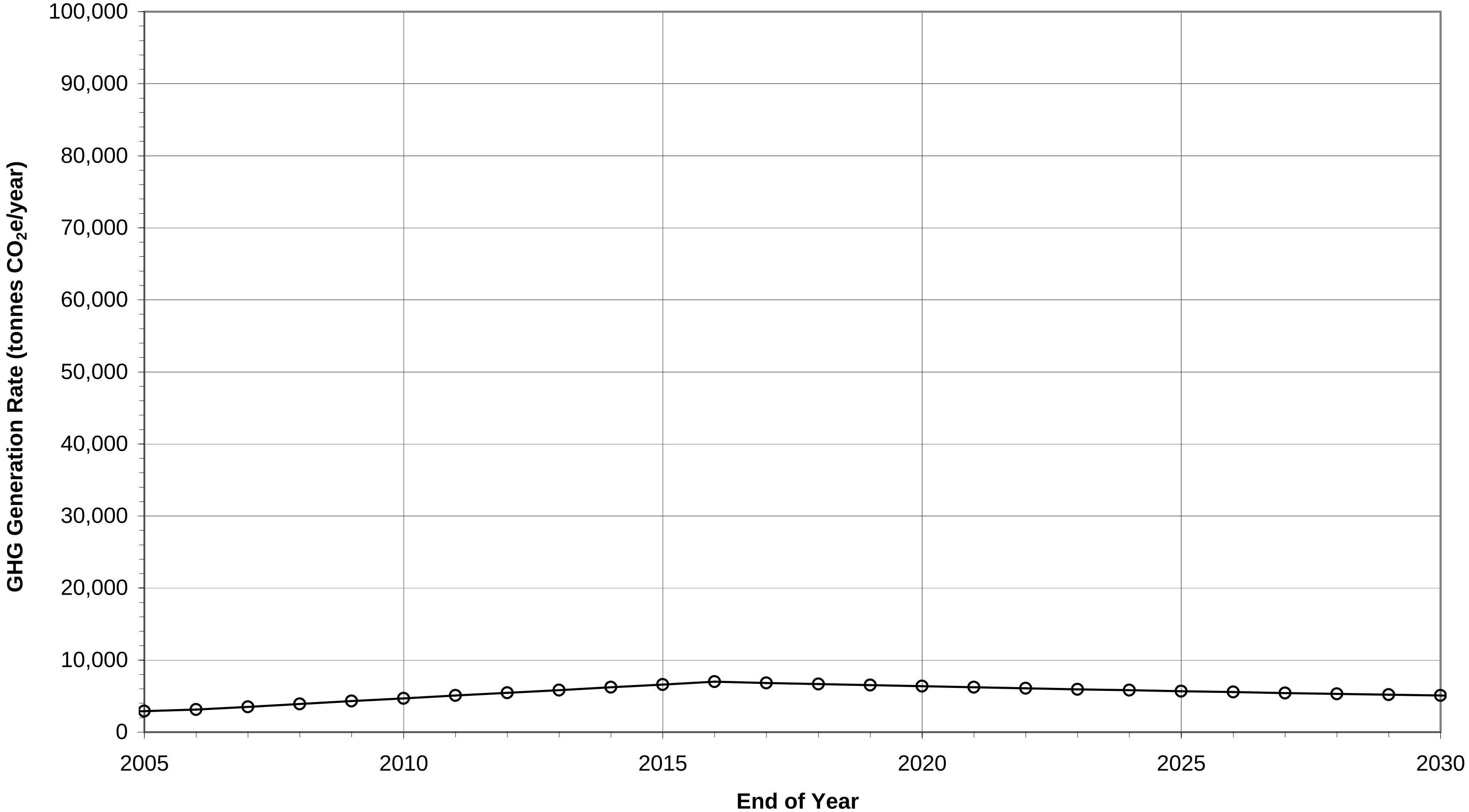
Greenhouse Gas Generation Rate
Squamish Landfill, Squamish, BC
(L_o = 173 m^3/tonnes, k = 0.289/year)
GHG Generation Rate (tonnes CO_2e/year)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2005
2010
2015
2020
2025
2030
End of Year

Greenhouse Gas Generation Rate
Prince Rupert Landfill, Prince Rupert, BC
(L_o = 180 m^3/tonnes, k = 0.318/year)

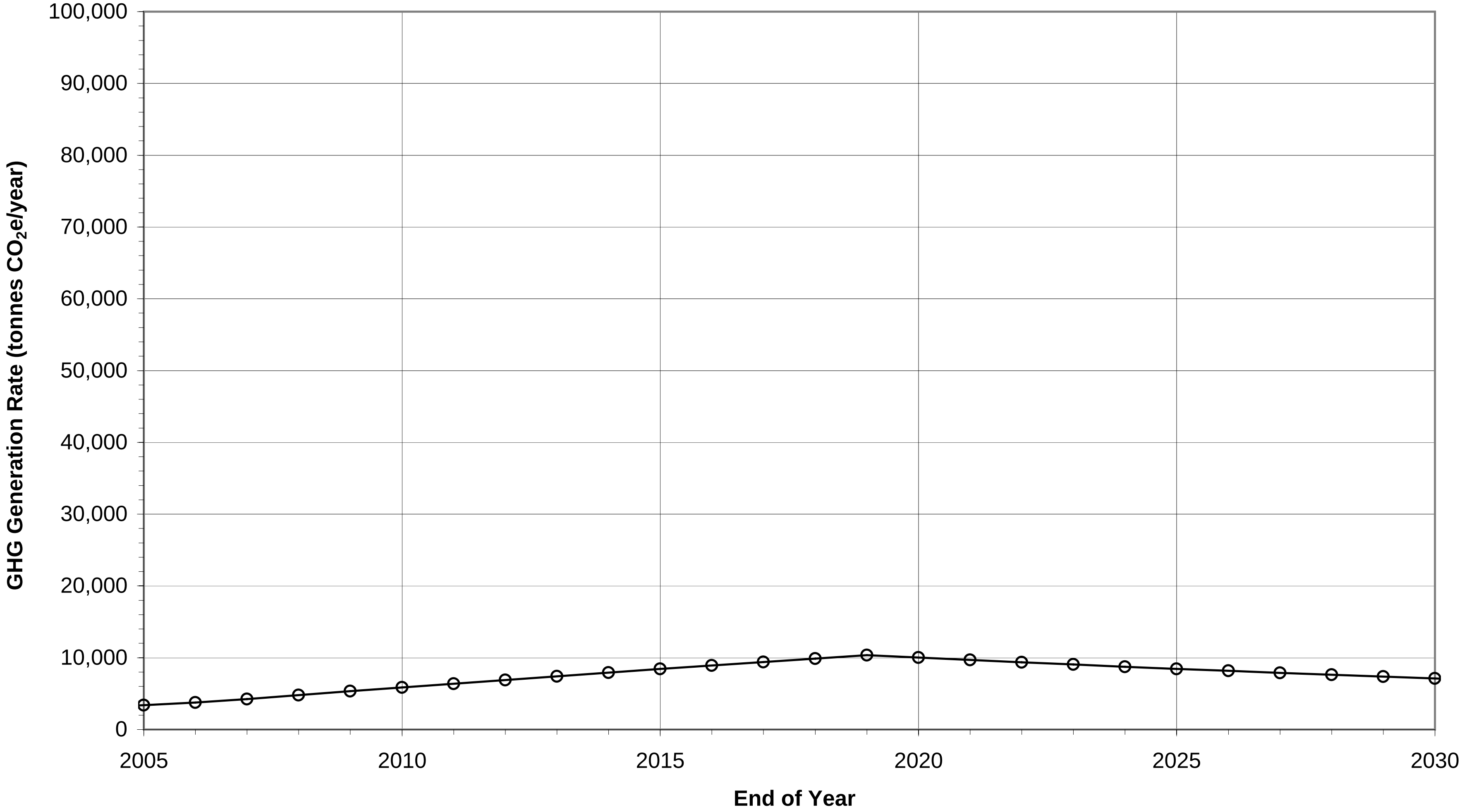



Greenhouse Gas Generation Rate
Mission Flats Landfill, Kamloops, BC
(Lo = 109 m3/tonnes, k = 0.017/year)
GHG Generation Rate (tonnes CO2e/year)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2005
2010
2015
2020
2025
2030
End of Year

Greenhouse Gas Generation Rate
Lower Nicola Landfill, Merritt, BC
(L_o = 110 m^3/tonnes, k = 0.023/year)

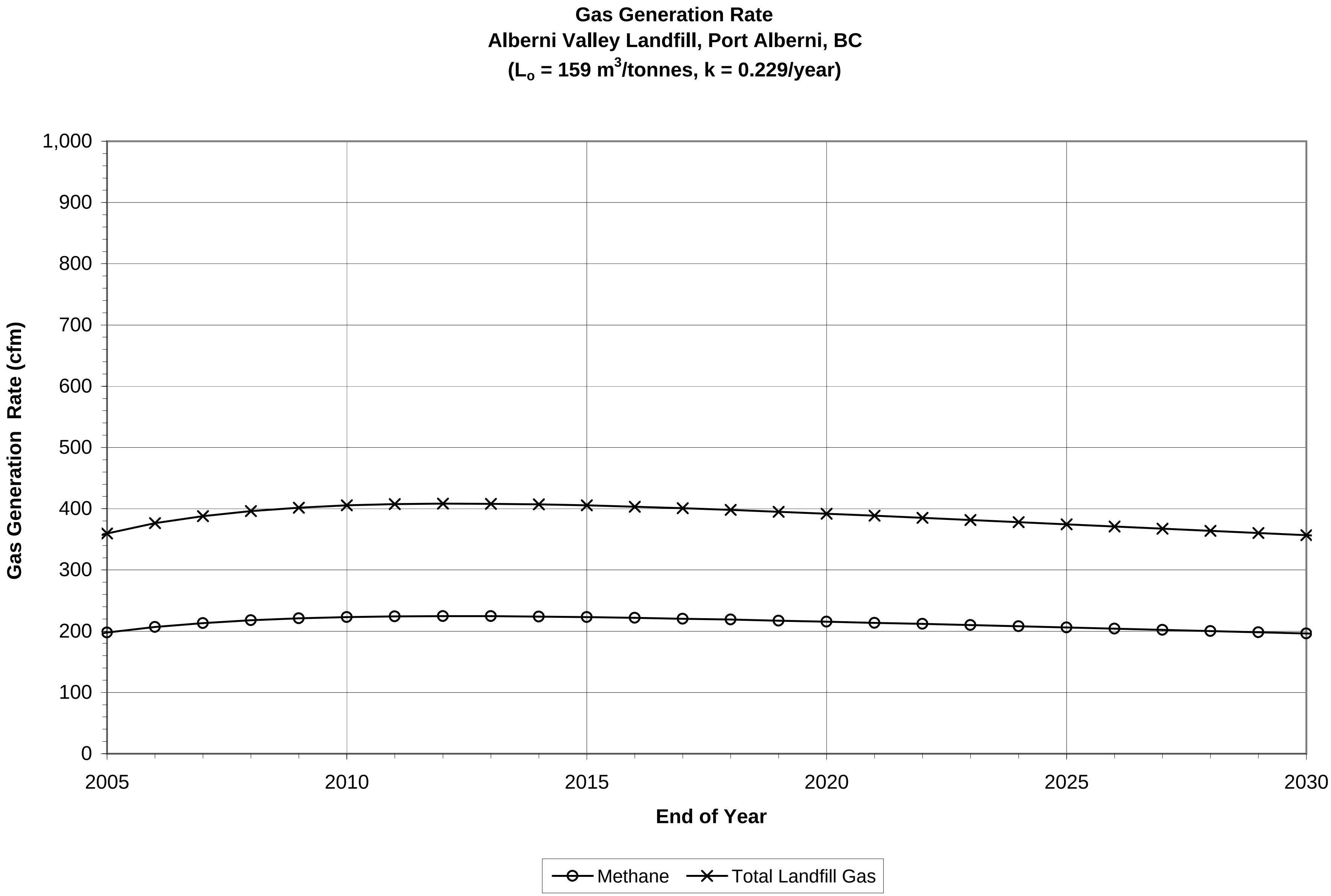


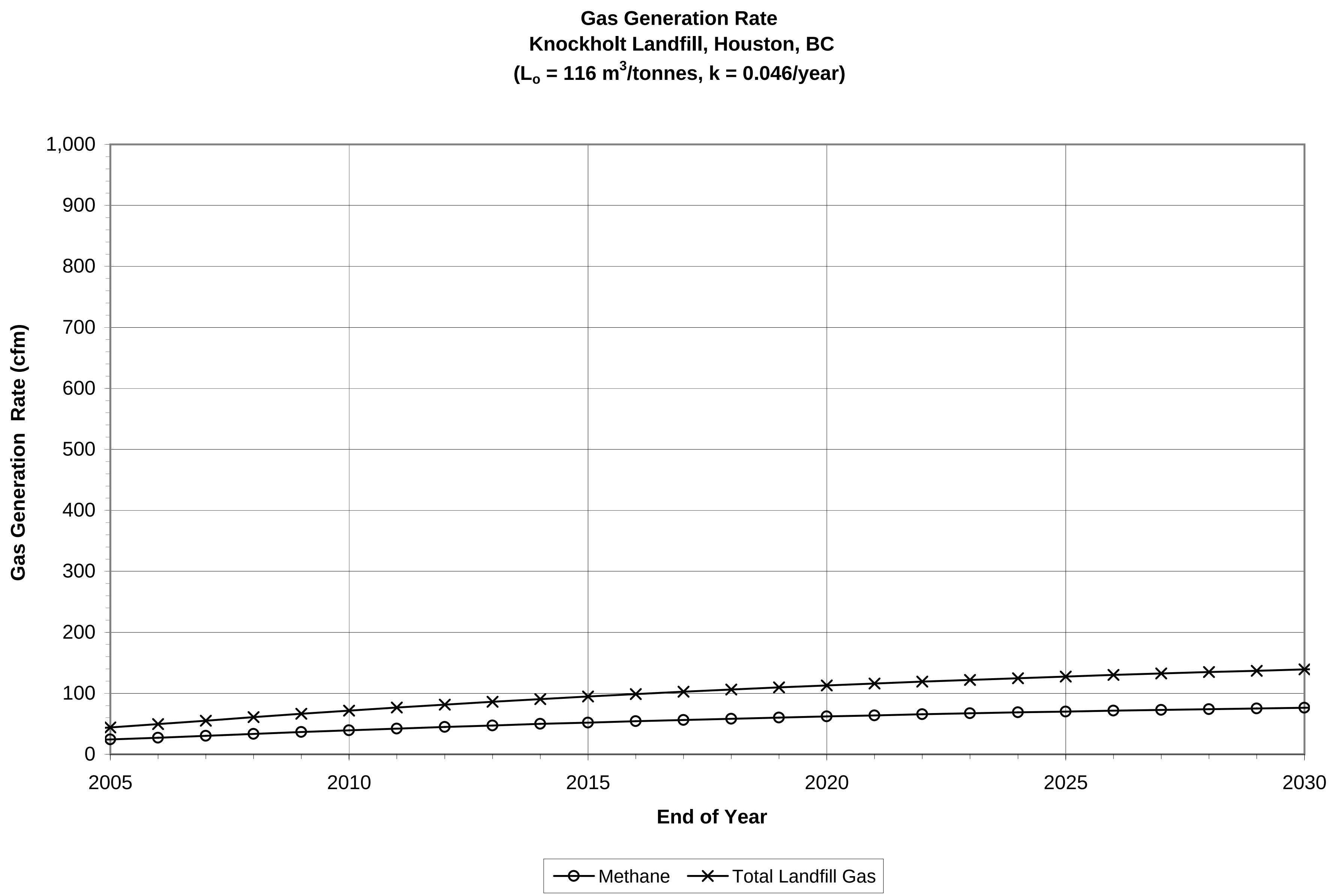
Greenhouse Gas Generation Rate
Heffley Creek Landfill, Heffley Creek, BC
(L_o = 113 m^3/tonnes, k = 0.034/year)

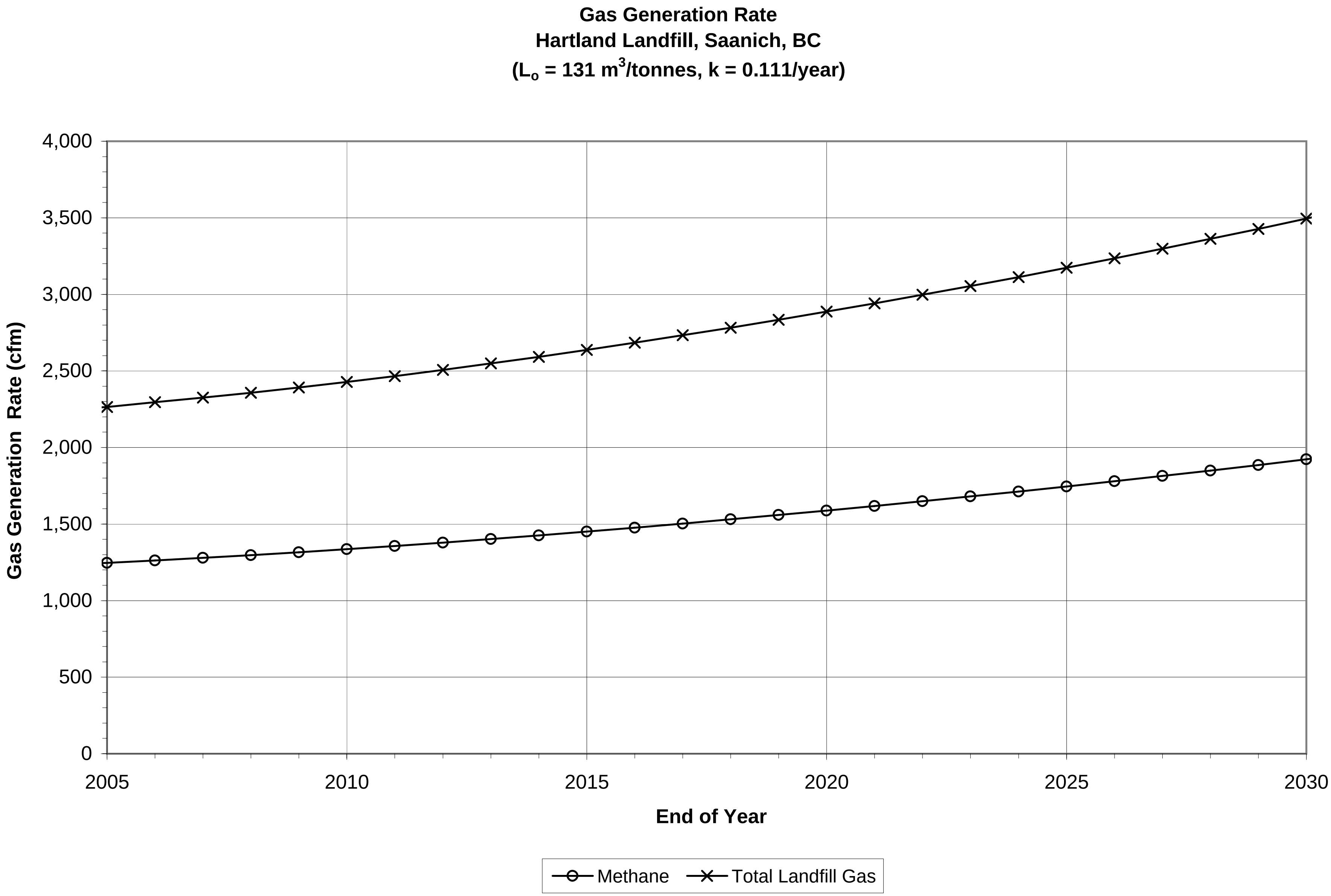


APPENDIX II

PLOTS OF METHANE AND LANDFILL GAS GENERATION FLOW RATES (CFM) WITH TIME FOR EACH LANDFILL

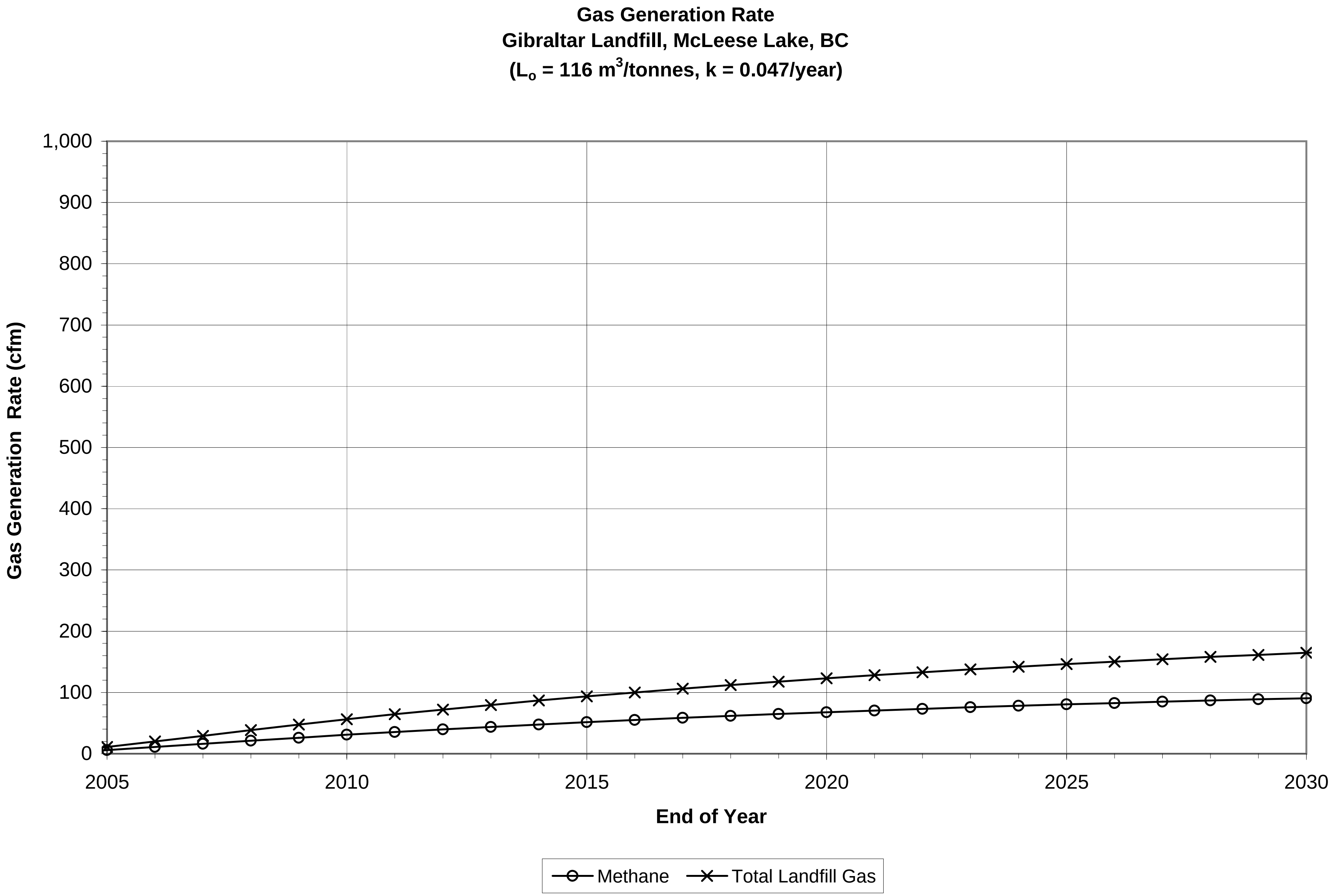

Gas Generation Rate
Alberni Valley Landfill, Port Alberni, BC
(L_o = 159 m^3/tonnes, k = 0.229/year)
Gas Generation Rate (cfm)
1,000
900
800
700
600
500
400
300
200
100
0
2005
2010
2015
2020
2025
2030
End of Year
Methane
Total Landfill Gas

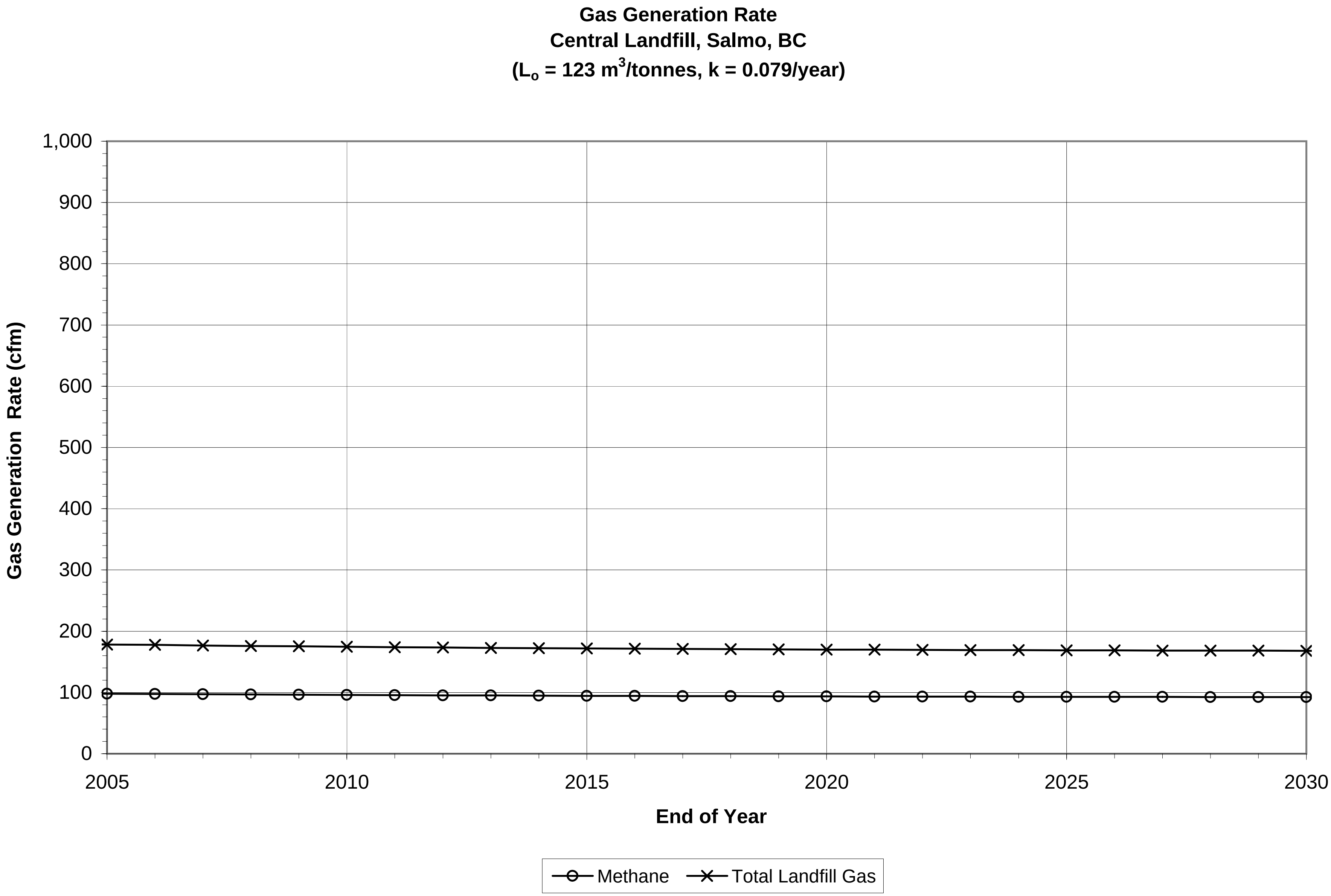

Gas Generation Rate
Knockholt Landfill, Houston, BC
(Lo = 116 m3/tonnes, k = 0.046/year)
1,000
900
800
700
600
500
400
300
200
100
0
Gas Generation Rate (cfm)
2005
2010
2015
2020
2025
2030
End of Year
Methane
Total Landfill Gas



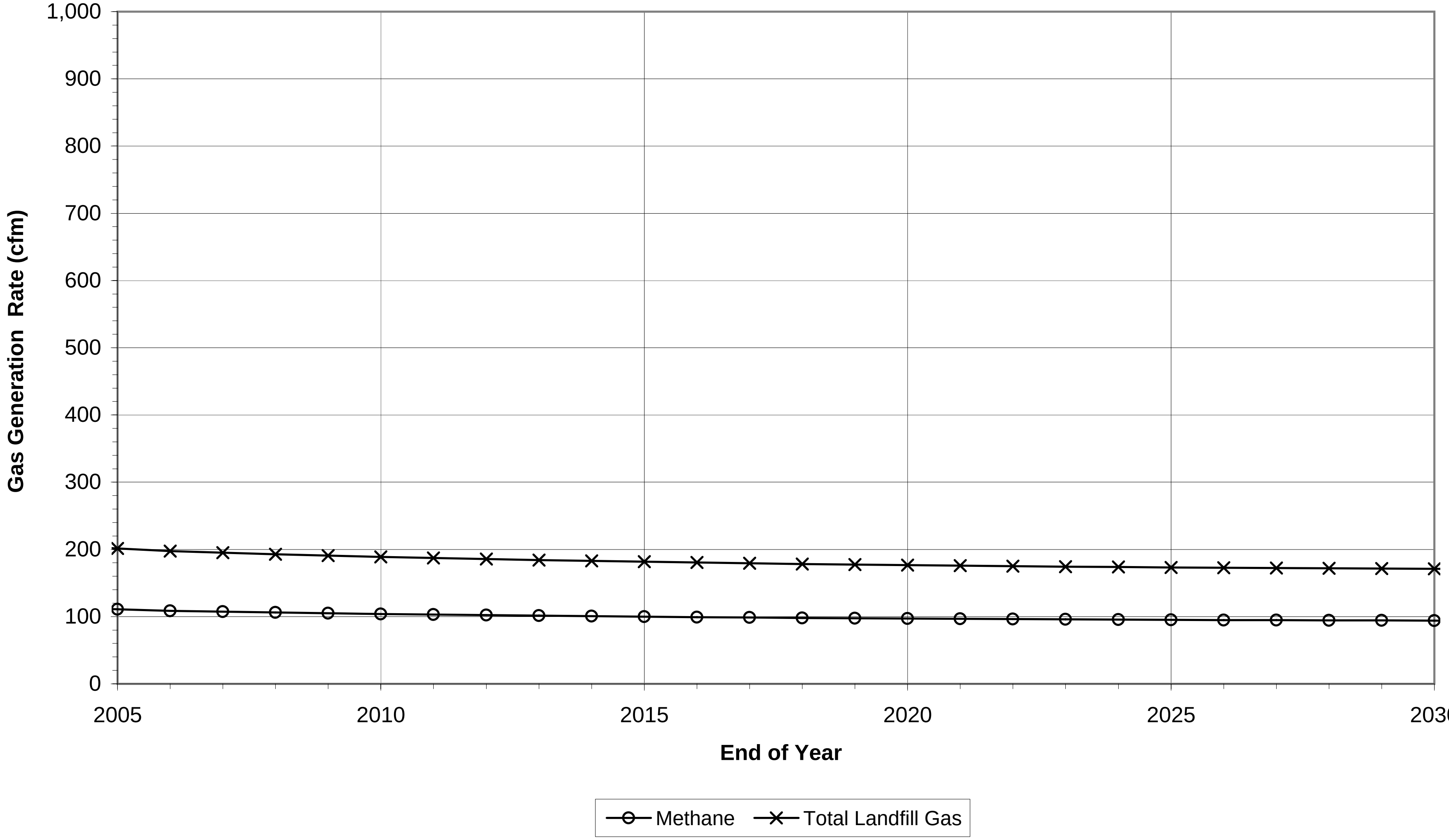
Gas Generation Rate
Hartland Landfill, Saanich, BC
(L_o = 131 m^3/tonnes, k = 0.111/year)
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Gas Generation Rate (cfm)
2005
2010
2015
2020
2025
2030
End of Year
Methane
Total Landfill Gas

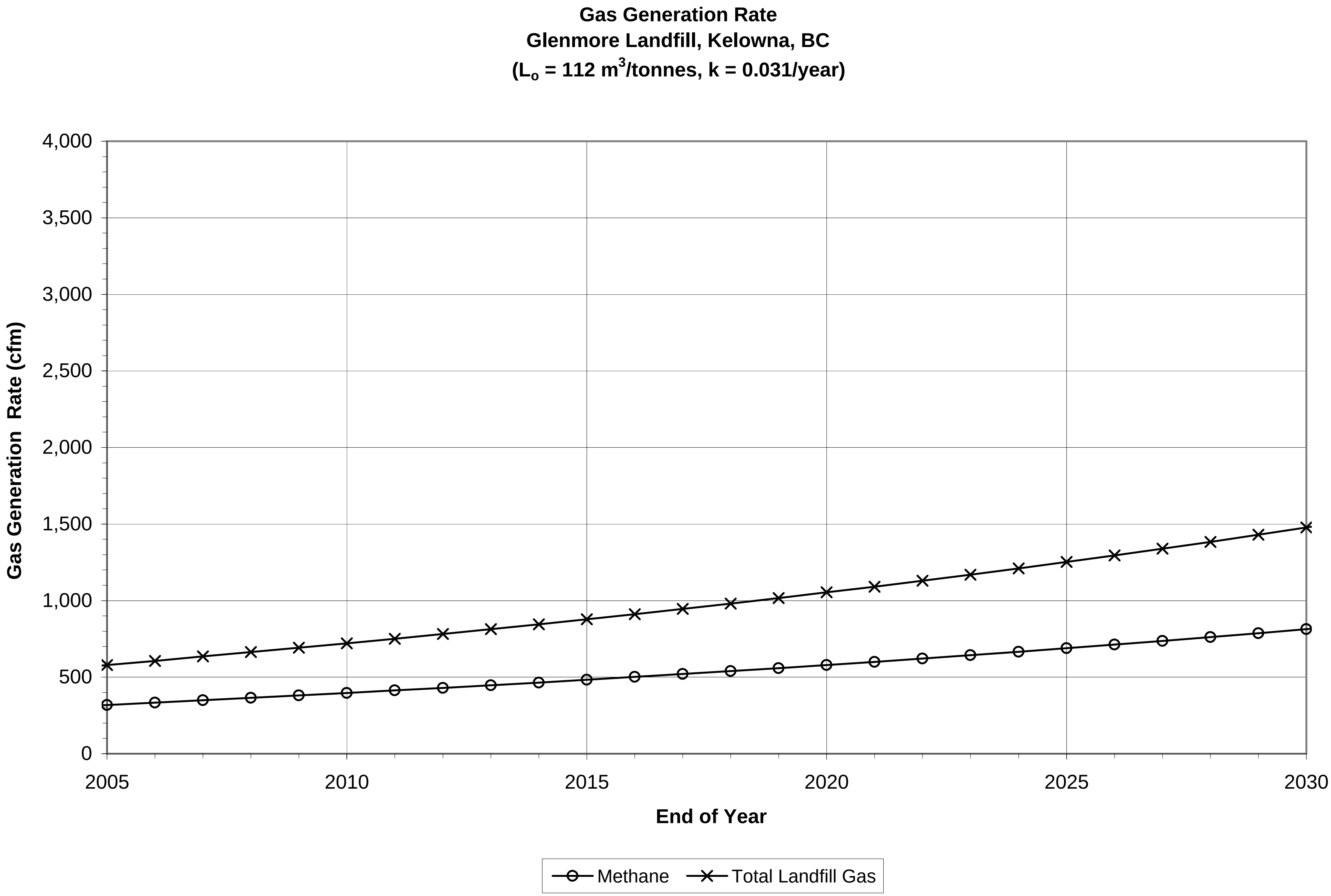
FIGURE L2-4

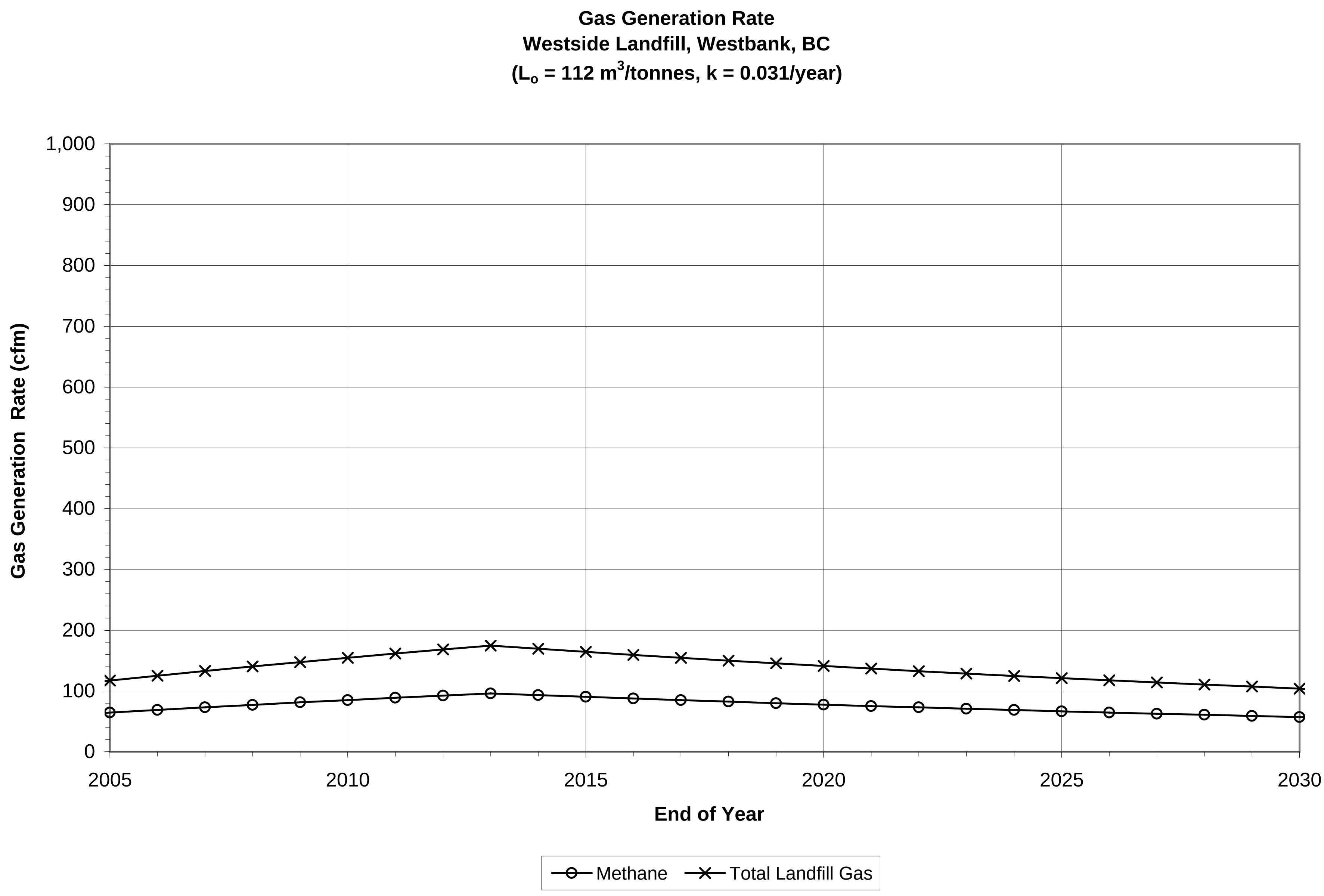

Gas Generation Rate
Gibraltar Landfill, McLeese Lake, BC
(L_o = 116 m^3/tonnes, k = 0.047/year)
Gas Generation Rate (cfm)
1,000
900
800
700
600
500
400
300
200
100
0
2005
2010
2015
2020
2025
2030
End of Year
Methane
Total Landfill Gas

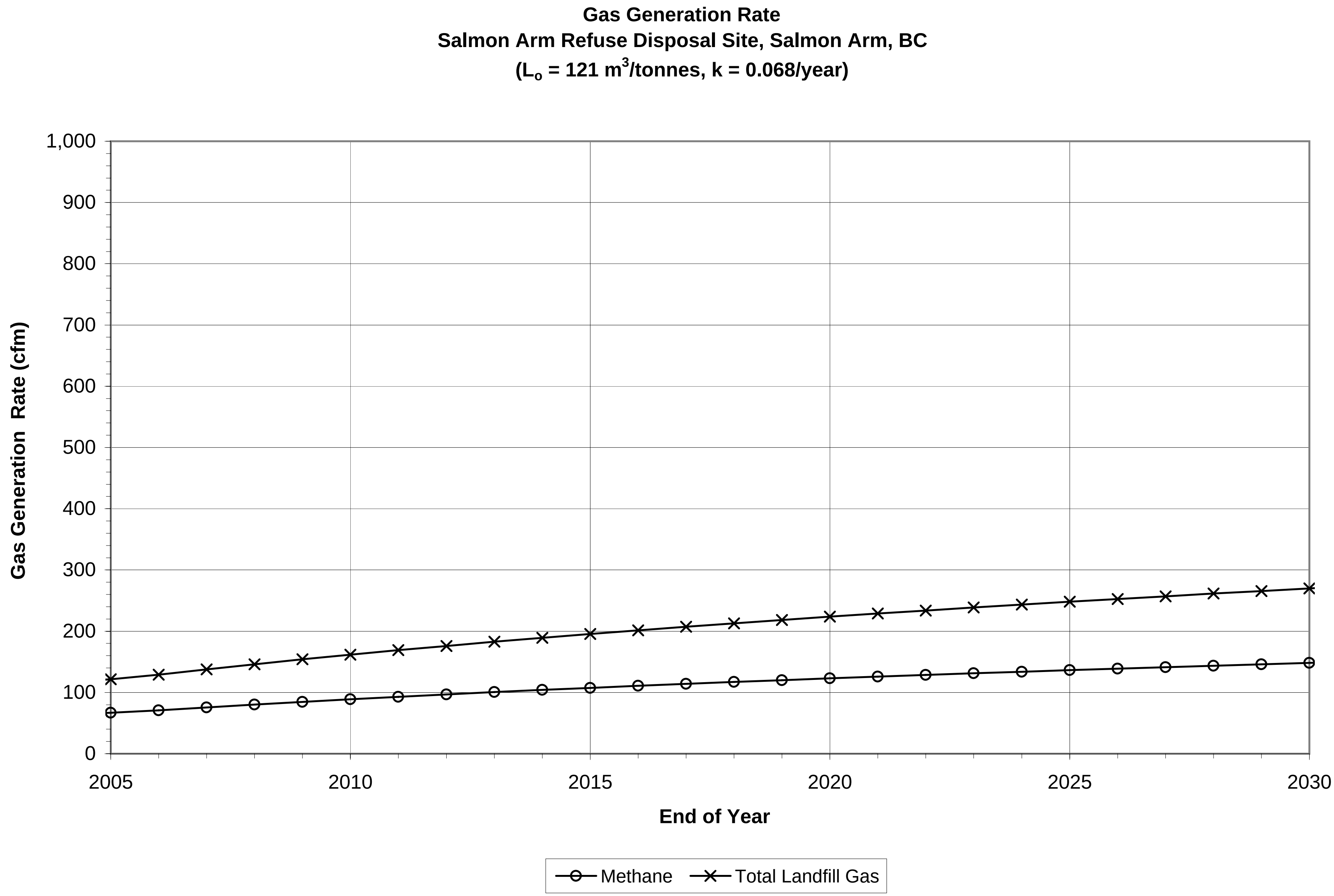

Gas Generation Rate
Central Landfill, Salmo, BC
(L_o = 123 m^3/tonnes, k = 0.079/year)
Gas Generation Rate (cfm)
1,000
900
800
700
600
500
400
300
200
100
0
2005
2010
2015
2020
2025
2030
End of Year
Methane
Total Landfill Gas

Gas Generation Rate
Ootischenia Landfill, Castlegar, BC
(L_o = 123 m^3/tonnes, k = 0.079/year)




Gas Generation Rate
Glenmore Landfill, Kelowna, BC
(L$_o$ = 112 m^3/tonnes, k = 0.031/year)
Gas Generation Rate (cfm)
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
2005
2010
2015
2020
2025
2030
End of Year
Methane
Total Landfill Gas


Gas Generation Rate
Westside Landfill, Westbank, BC
(Lo = 112 m3/tonnes, k = 0.031/year)
Gas Generation Rate (cfm)
1,000
900
800
700
600
500
400
300
200
100
0
2005
2010
2015
2020
2025
2030
End of Year
Methane
Total Landfill Gas


Gas Generation Rate
Salmon Arm Refuse Disposal Site, Salmon Arm, BC
(L$_o$ = 121 m^3/tonnes, k = 0.068/year)
1,000
900
800
700
600
500
400
300
200
100
0
Gas Generation Rate (cfm)
2005
2010
2015
2020
2025
2030
End of Year
Methane
Total Landfill Gas

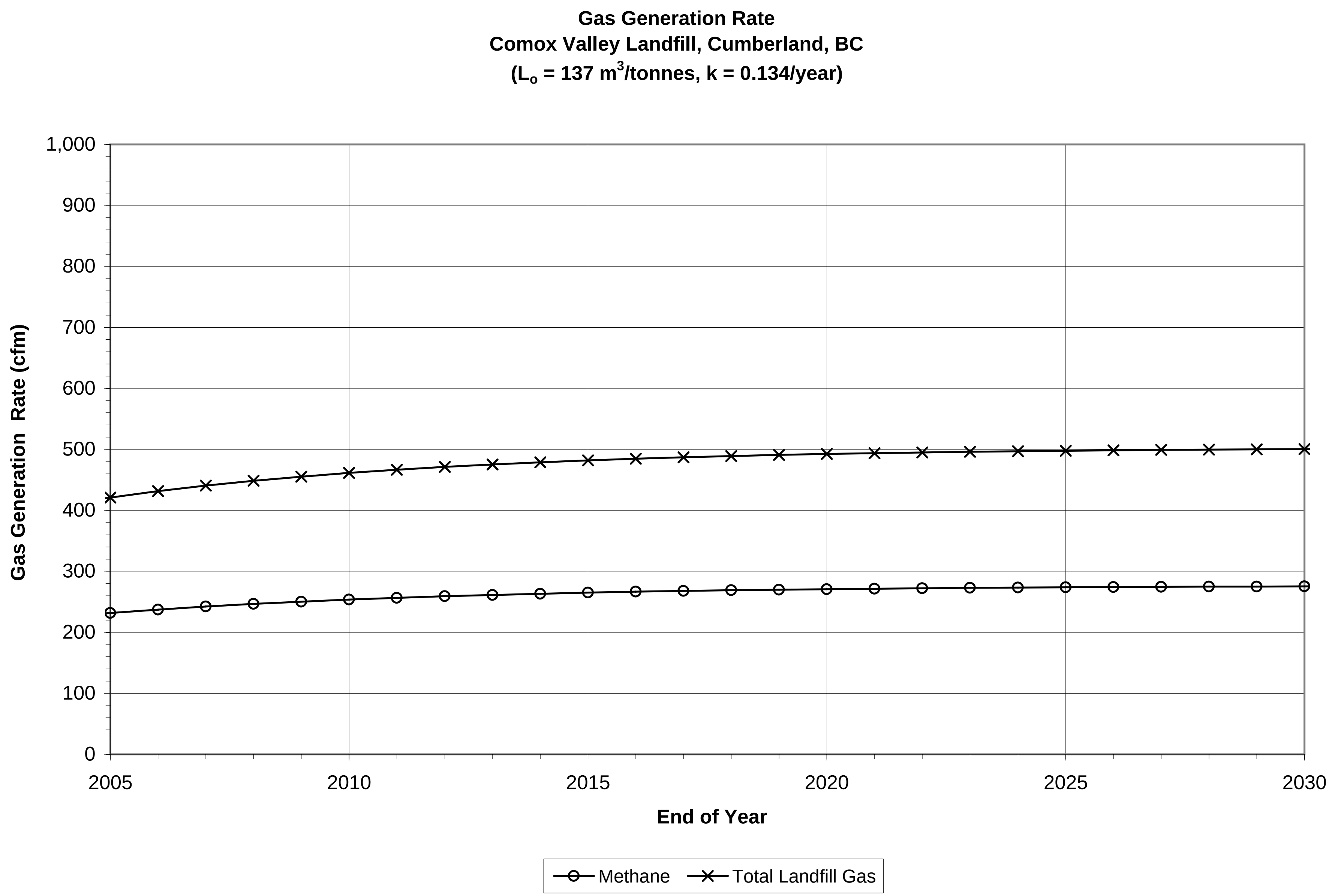
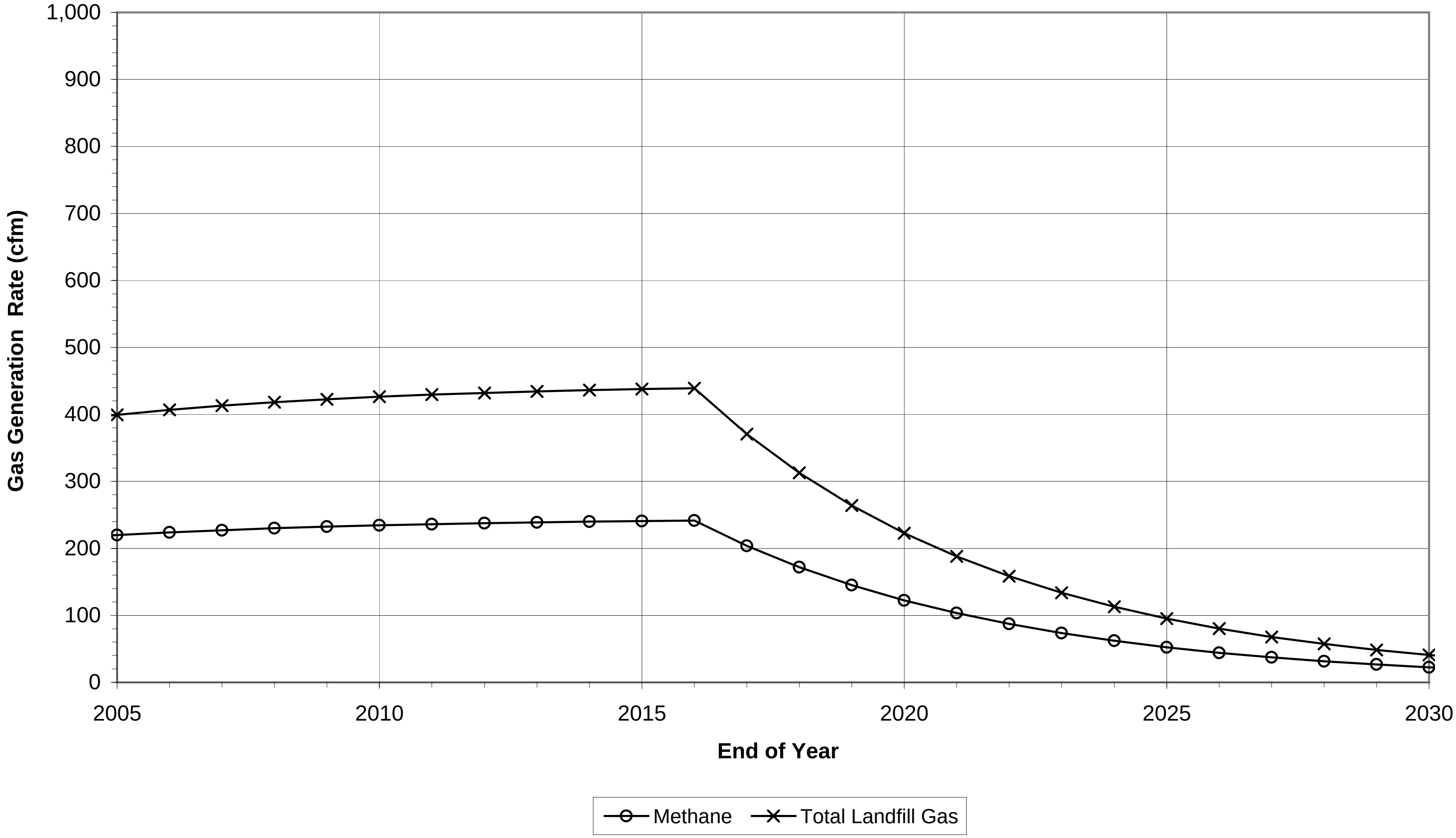

Gas Generation Rate
Comox Valley Landfill, Cumberland, BC
(Lo = 137 m3/tonnes, k = 0.134/year)
Gas Generation Rate (cfm)
1,000
900
800
700
600
500
400
300
200
100
0
2005
2010
2015
2020
2025
2030
End of Year
Methane
Total Landfill Gas

FIGURE L2-11

Gas Generation Rate
Campbell River Landfill, Campbell River, BC
(L_o = 145 m^3/tonnes, k = 0.170/year)



Gas Generation Rate
Central Sub-Regional Landfill, Cranbrook, BC
(L_o = 112 m^3/tonnes, k = 0.031/year)

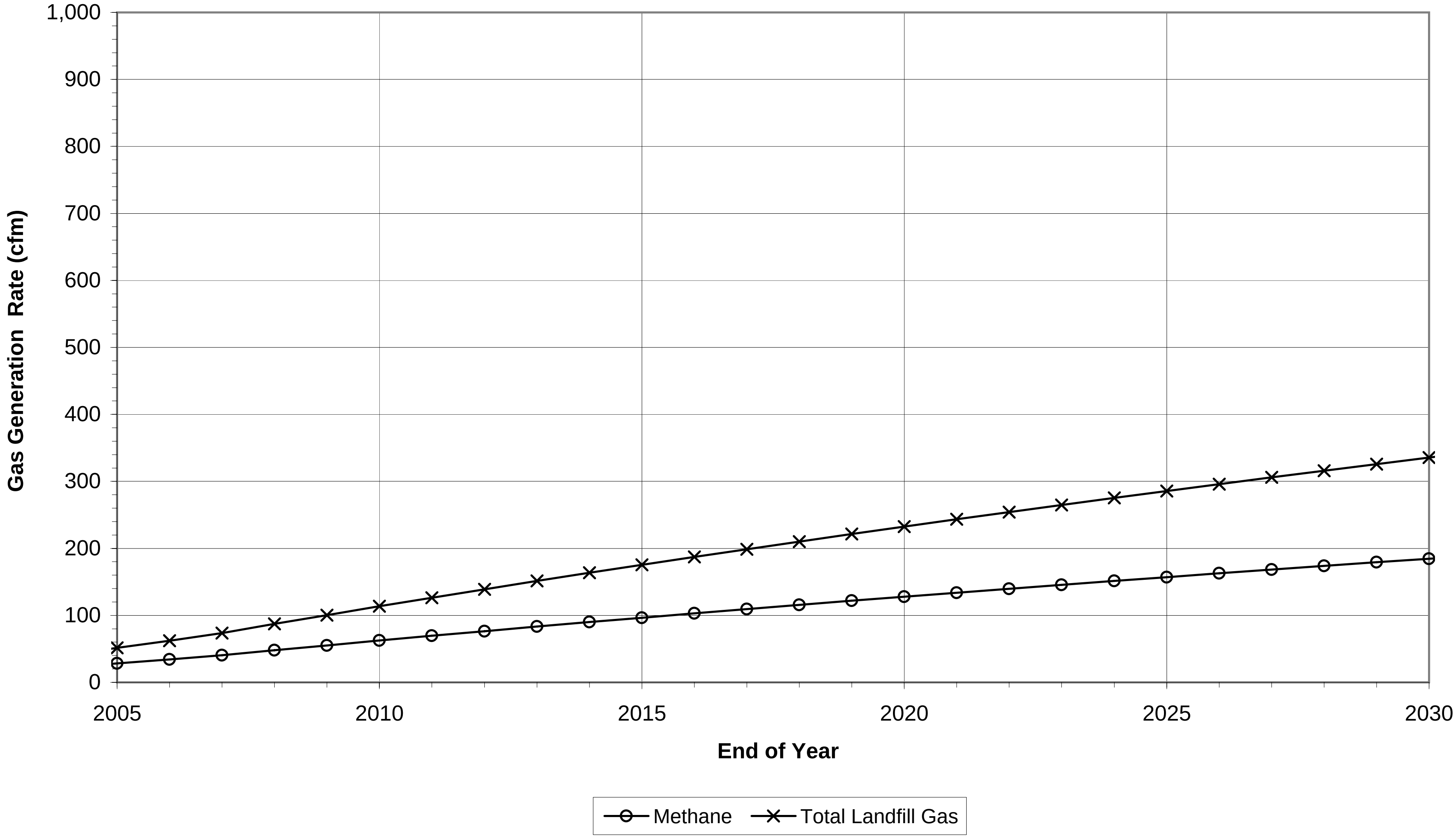
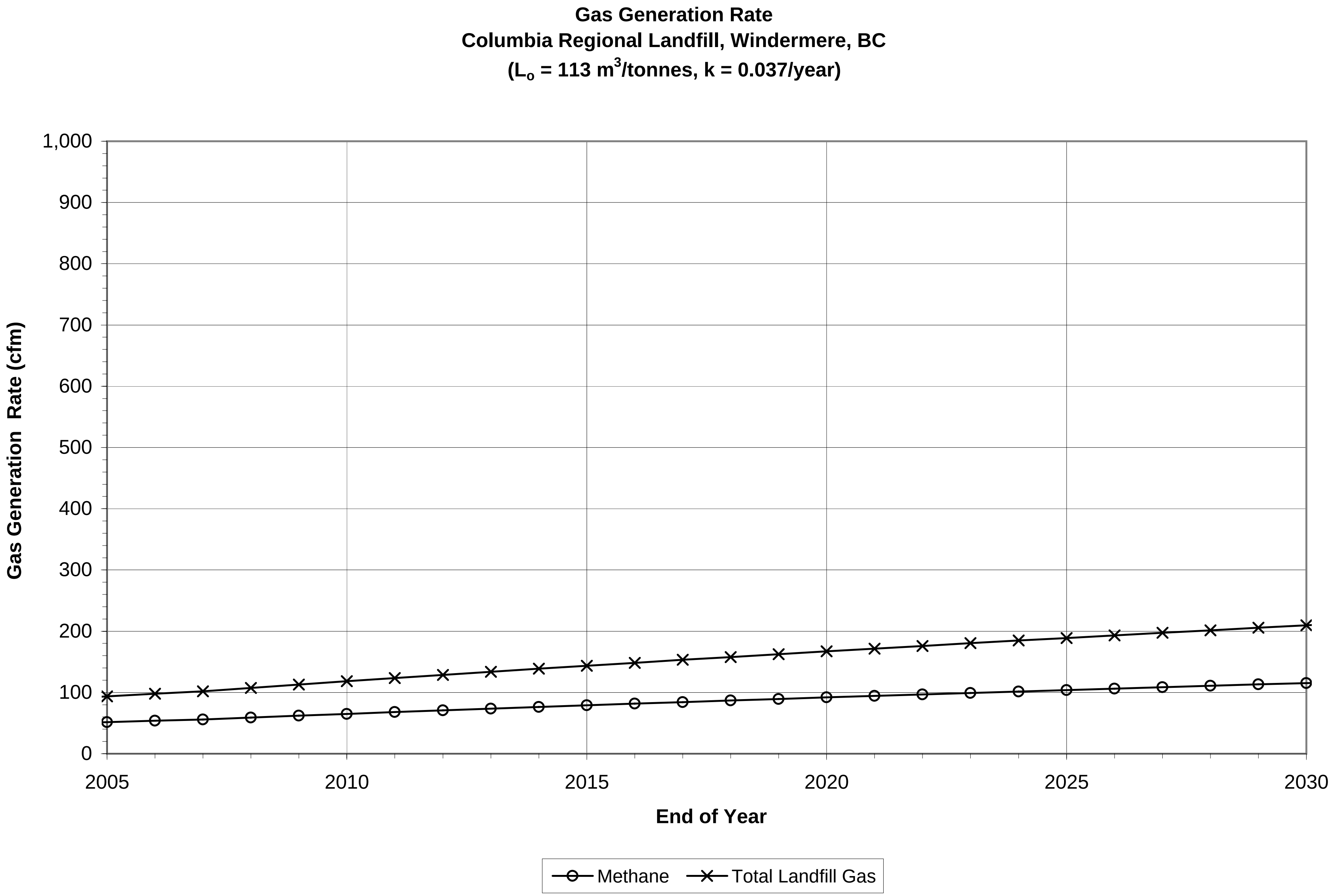
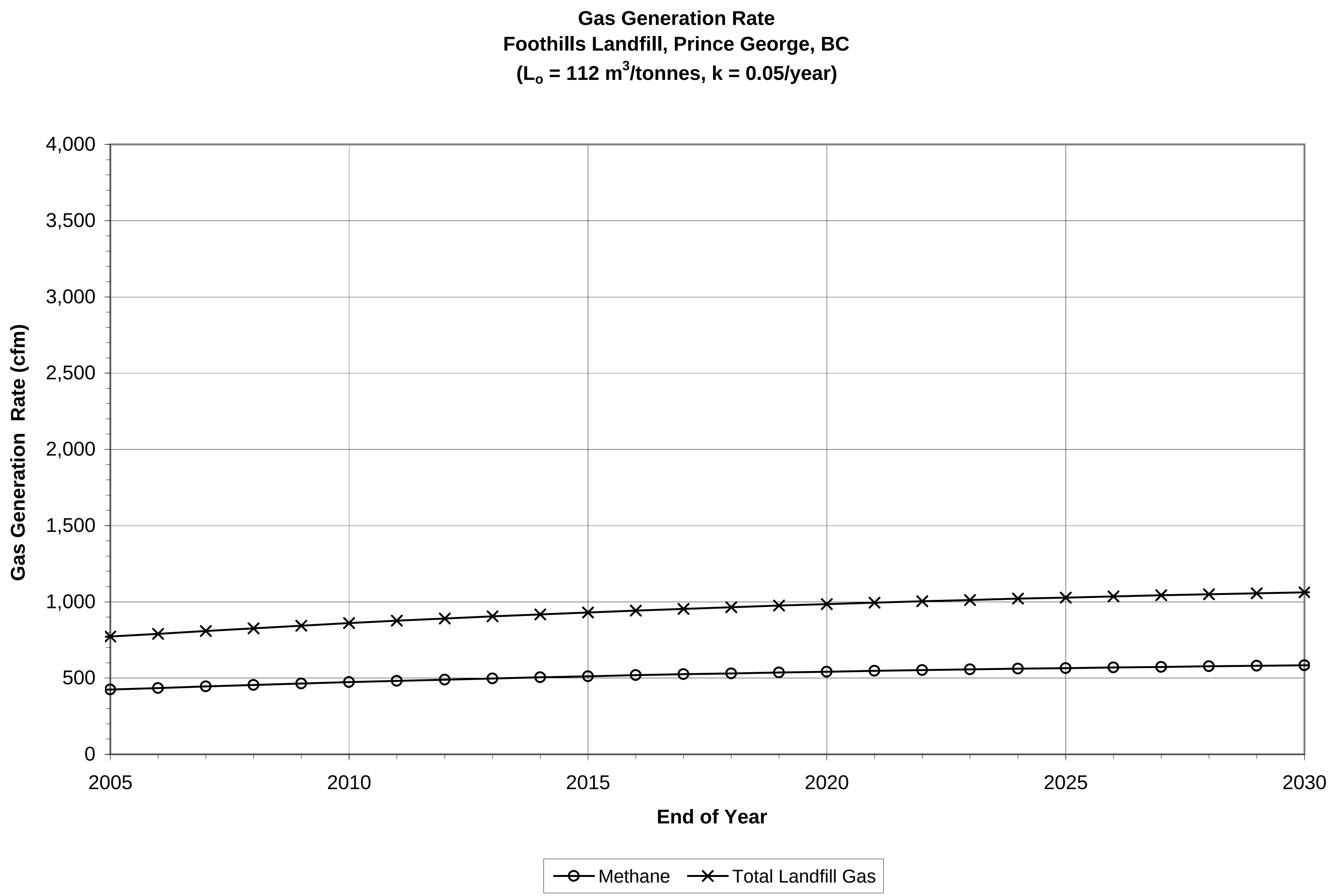


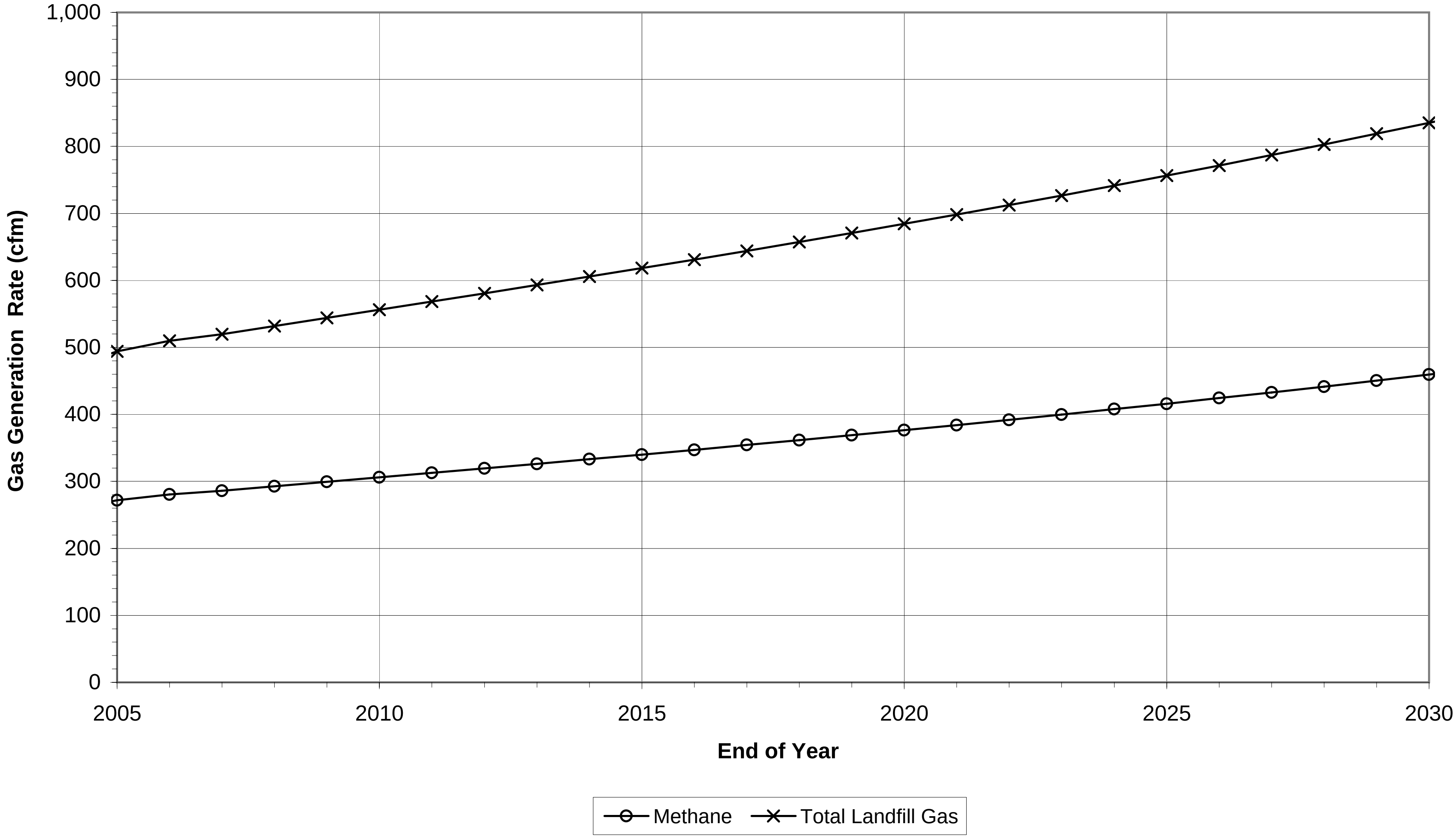
FIGURE L2-13



Gas Generation Rate
Columbia Regional Landfill, Windermere, BC
(L_o = 113 m^3/tonnes, k = 0.037/year)
Gas Generation Rate (cfm)
1,000
900
800
700
600
500
400
300
200
100
0
2005
2010
2015
2020
2025
2030
End of Year
Methane
Total Landfill Gas


Gas Generation Rate
Foothills Landfill, Prince George, BC
(Lo = 112 m3/tonnes, k = 0.05/year)
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Gas Generation Rate (cfm)
2005
2010
2015
2020
2025
2030
End of Year
Methane
Total Landfill Gas

Gas Generation Rate
Bailey Sanitary Landfill, Chilliwack, BC
(L_o = 147 m^3/tonnes, k = 0.176/year)



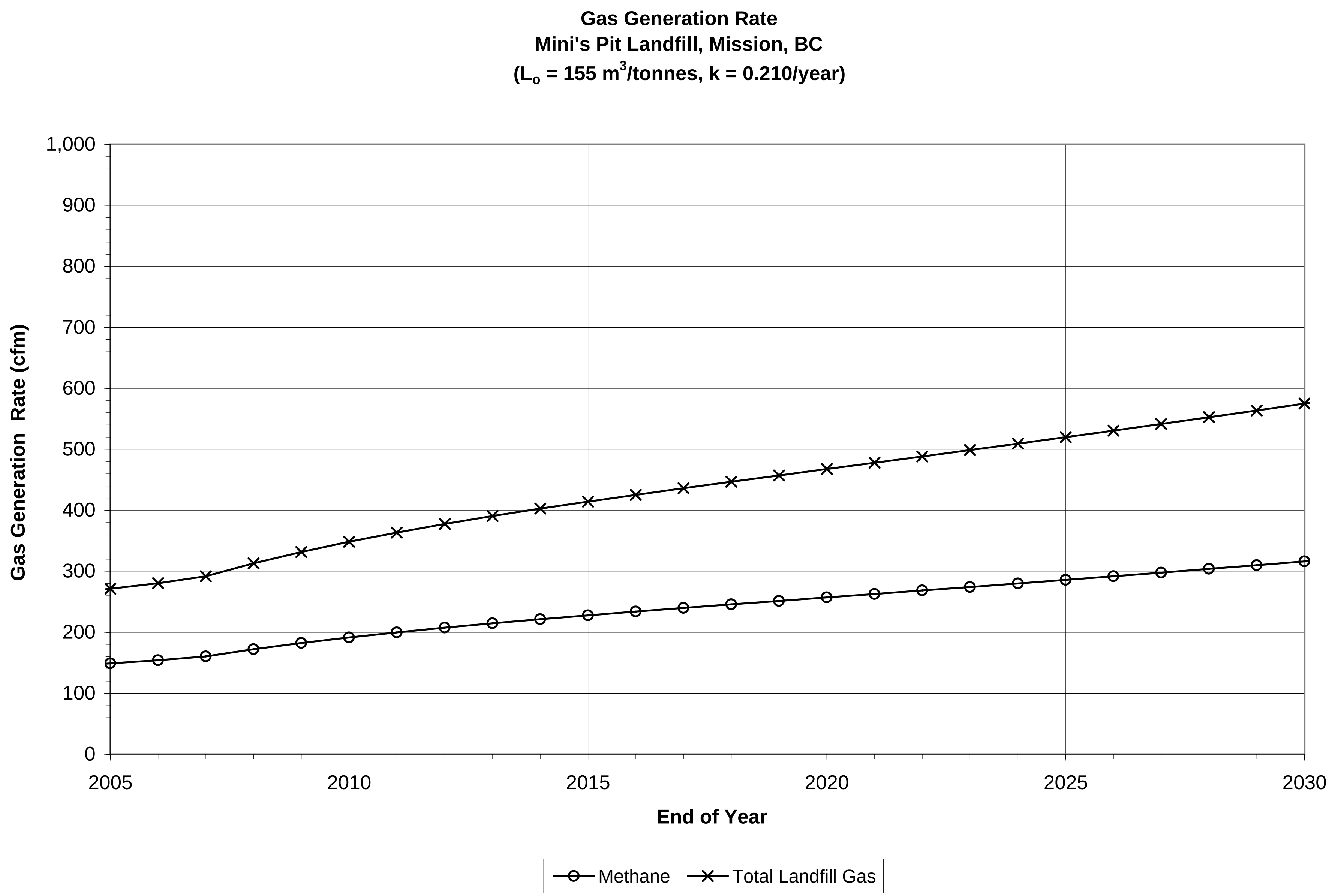
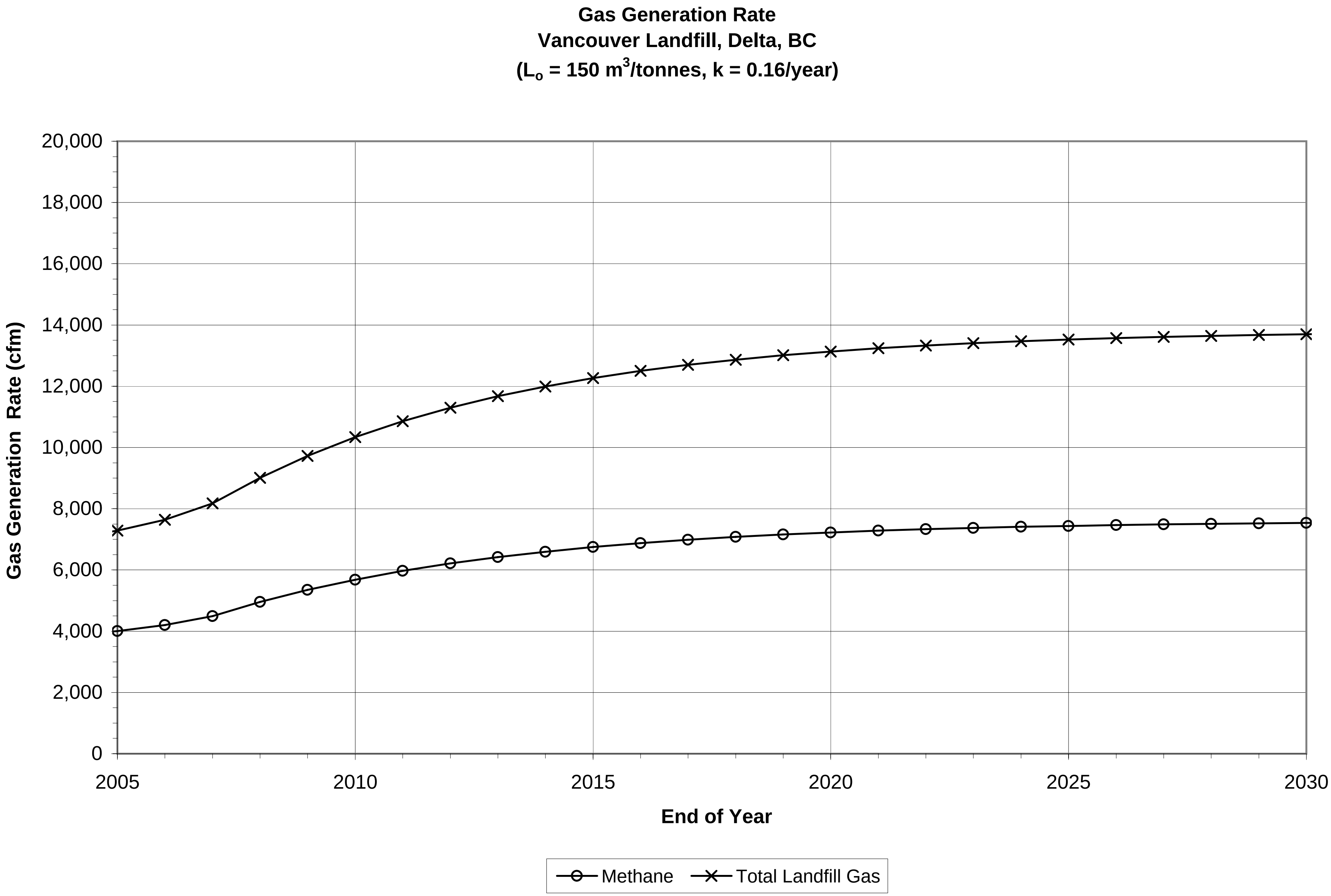
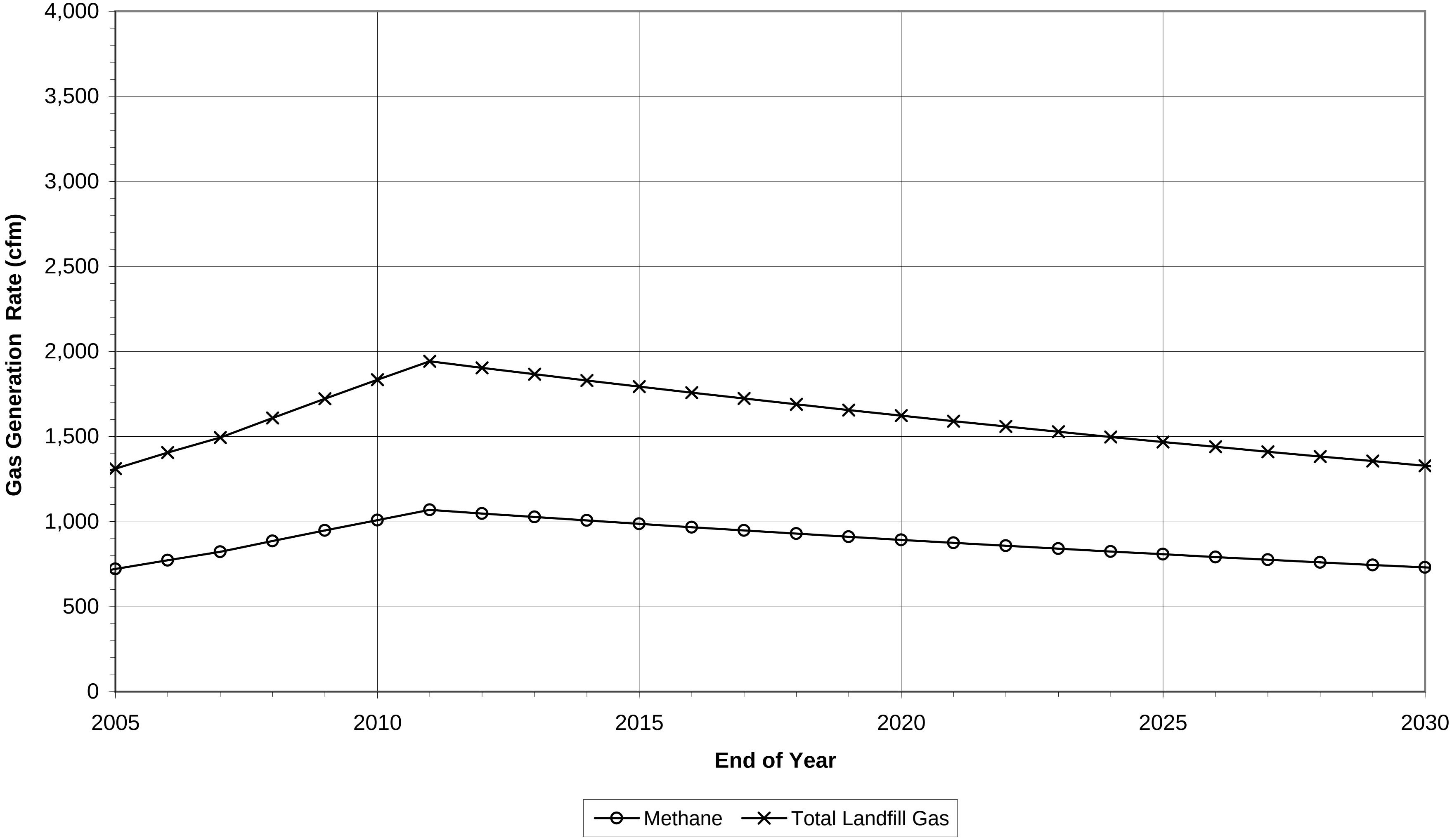

Gas Generation Rate
Mini's Pit Landfill, Mission, BC
(Lo = 155 m3/tonnes, k = 0.210/year)
Gas Generation Rate (cfm)
1,000
900
800
700
600
500
400
300
200
100
0
2005
2010
2015
2020
2025
2030
End of Year
Methane
Total Landfill Gas

FIGURE L2-17


Gas Generation Rate
Vancouver Landfill, Delta, BC
(L_o = 150 m^3/tonnes, k = 0.16/year)
Gas Generation Rate (cfm)
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
2005
2010
2015
2020
2025
2030
End of Year
Methane
Total Landfill Gas

Gas Generation Rate
Cache Creek Landfill, Cache Creek, BC
(L_o = 100 m^3/tonnes, k = 0.02/year)



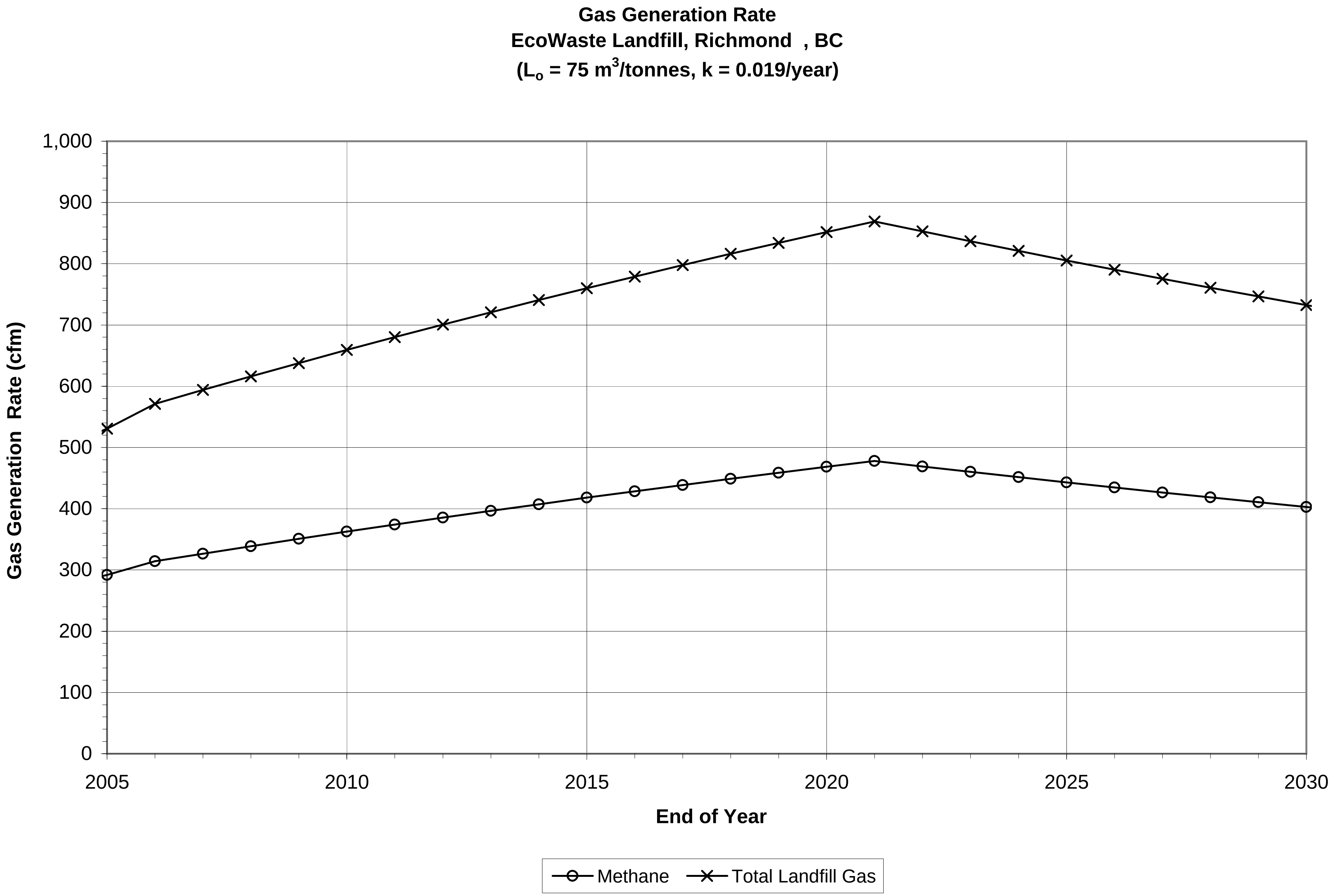
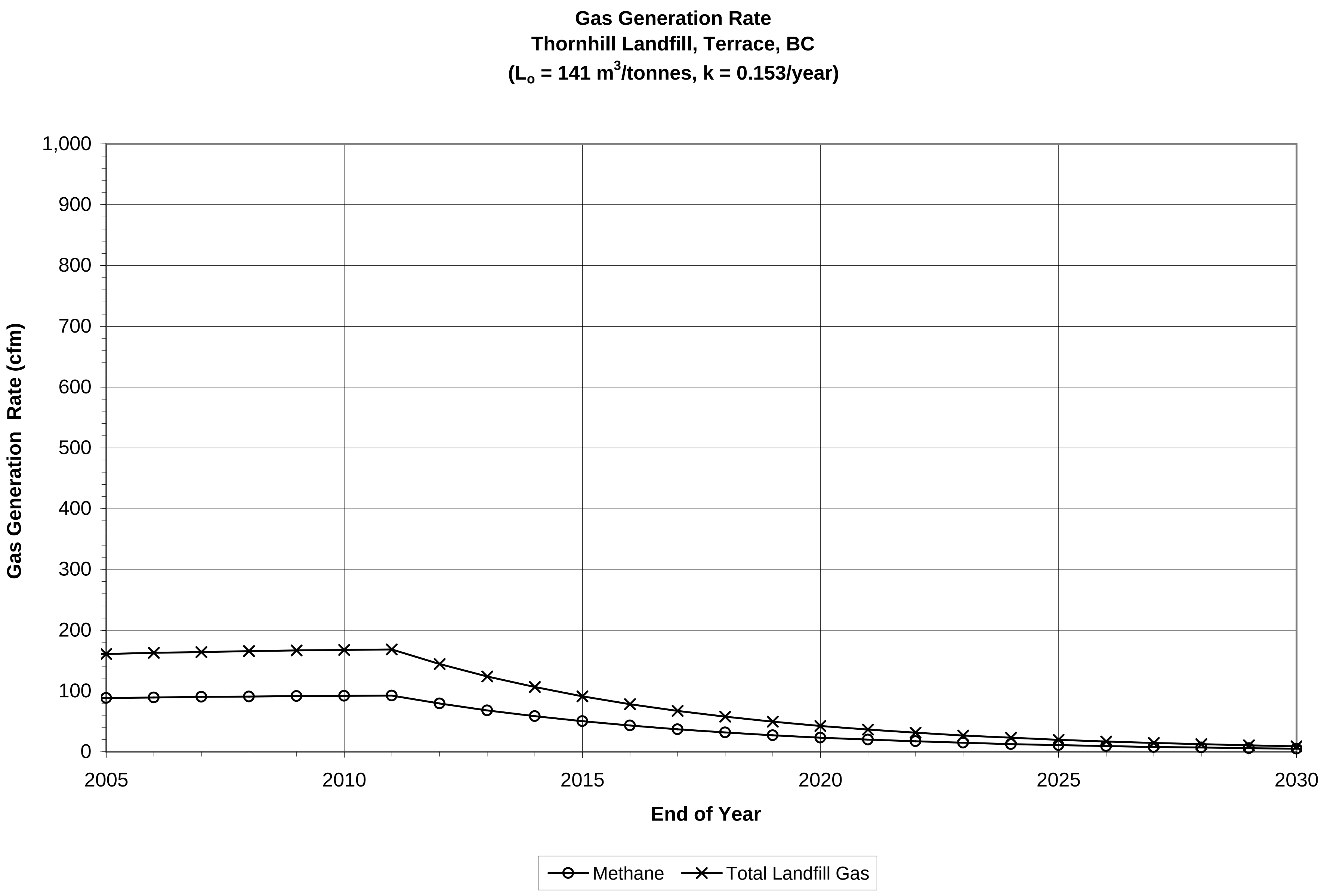
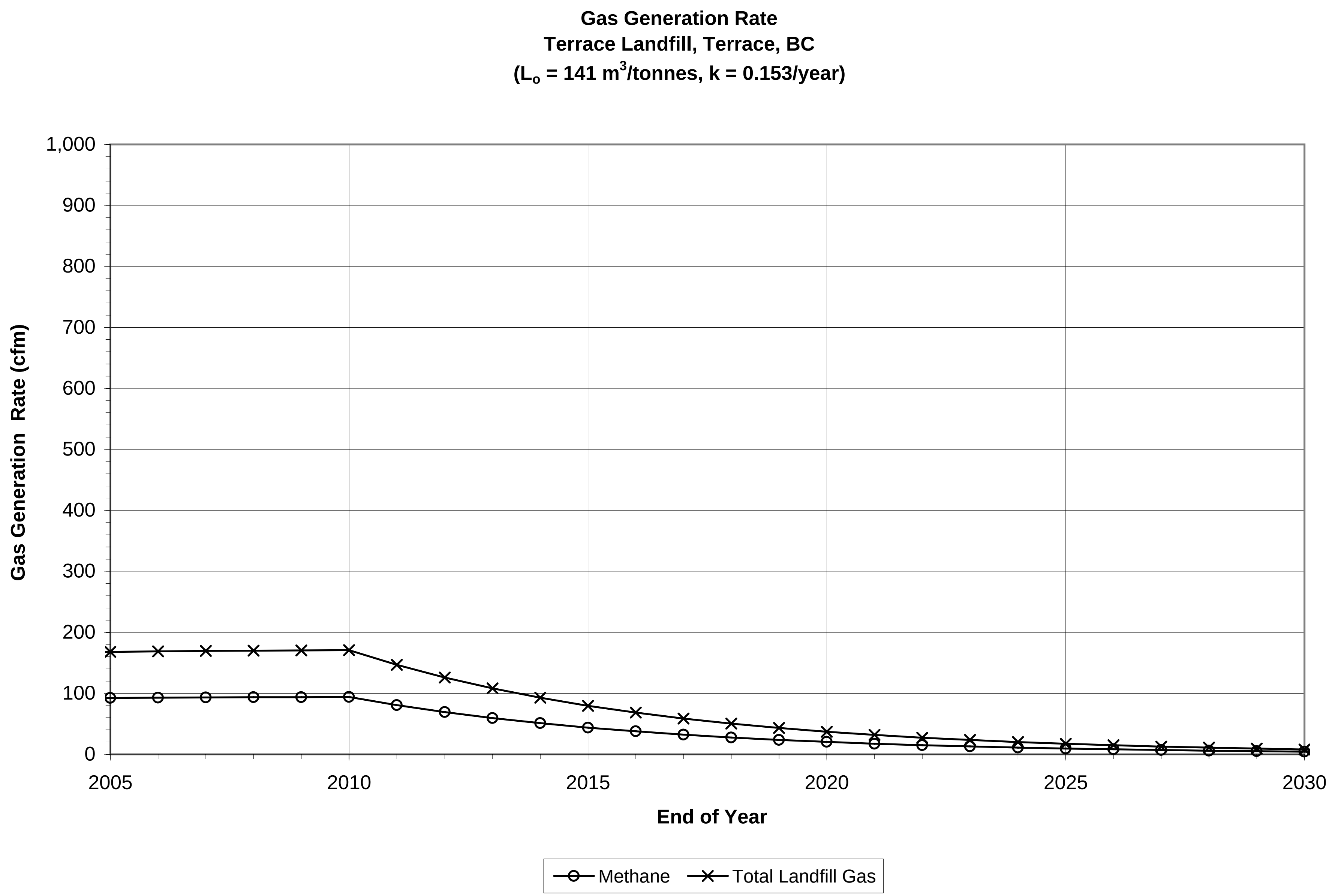

Gas Generation Rate
EcoWaste Landfill, Richmond , BC
(L$_o$ = 75 m^3/tonnes, k = 0.019/year)
Gas Generation Rate (cfm)
1,000
900
800
700
600
500
400
300
200
100
0
2005
2010
2015
2020
2025
2030
End of Year
Methane
Total Landfill Gas

FIGURE L2-20


Gas Generation Rate
Thornhill Landfill, Terrace, BC
(L_o = 141 m^3/tonnes, k = 0.153/year)
Gas Generation Rate (cfm)
1,000
900
800
700
600
500
400
300
200
100
0
2005
2010
2015
2020
2025
2030
End of Year
Methane
Total Landfill Gas


Gas Generation Rate
Terrace Landfill, Terrace, BC
(L_o = 141 m^3/tonnes, k = 0.153/year)
Gas Generation Rate (cfm)
1,000
900
800
700
600
500
400
300
200
100
0
2005
2010
2015
2020
2025
2030
End of Year
Methane
Total Landfill Gas

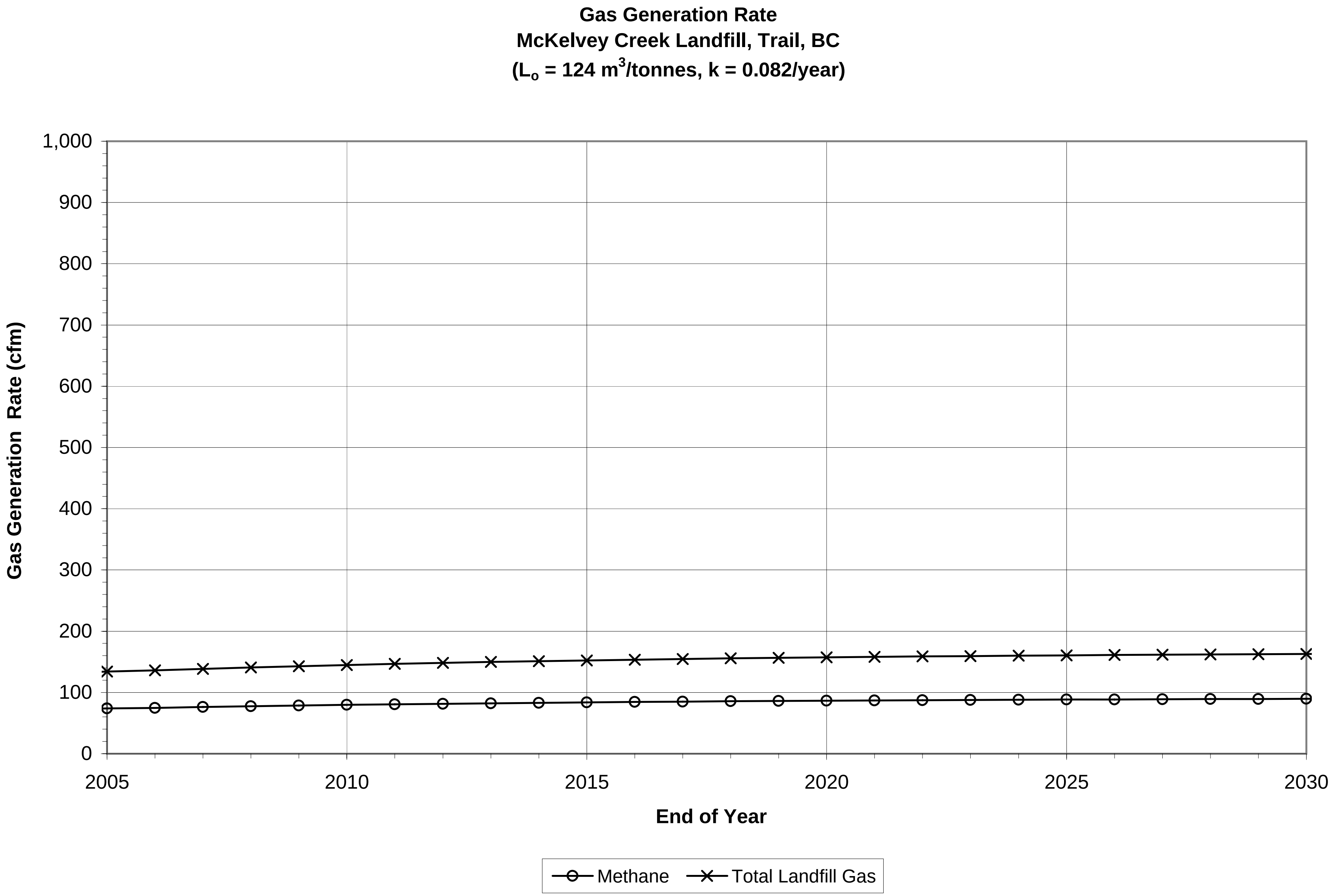
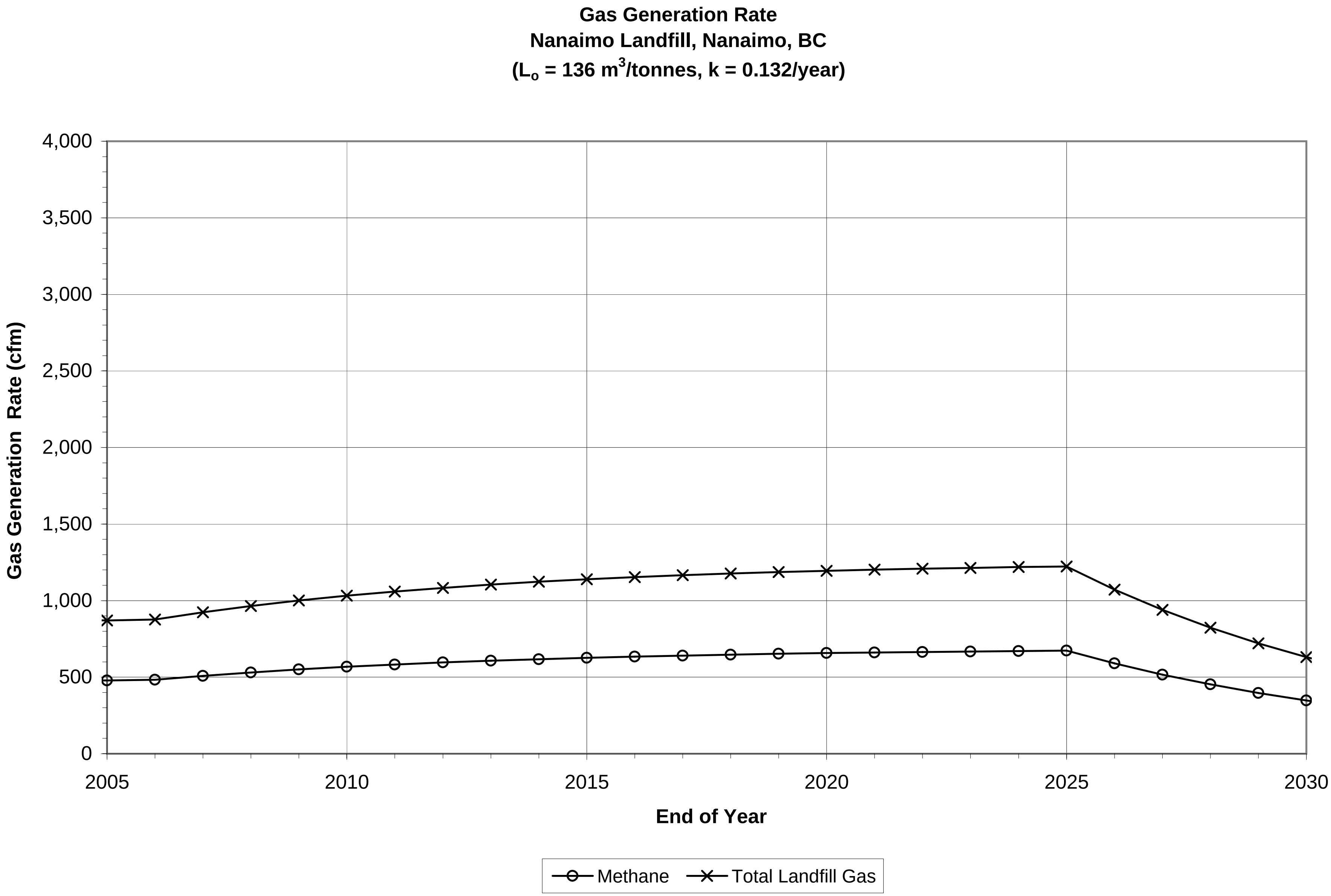
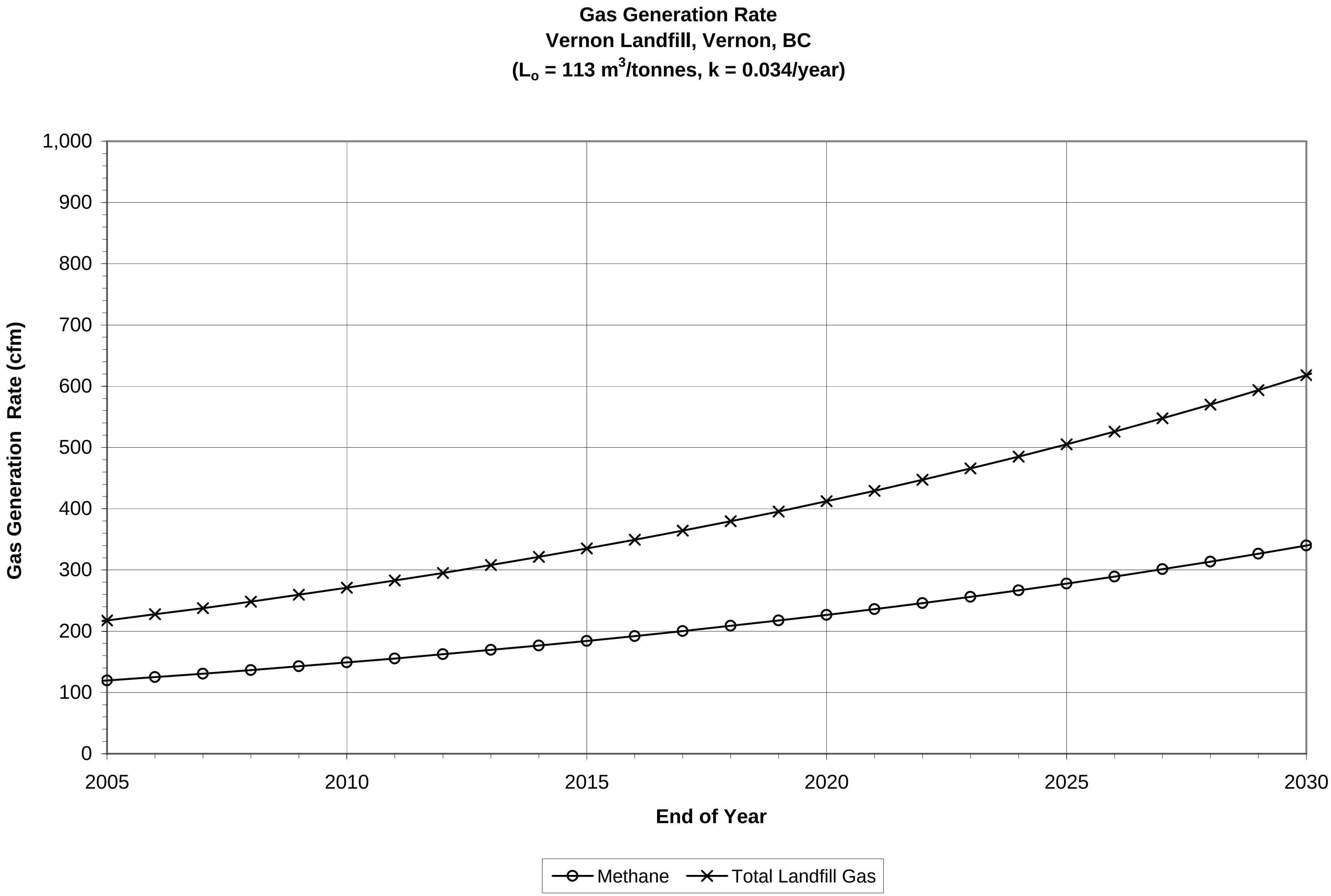

Gas Generation Rate
McKelvey Creek Landfill, Trail, BC
(L_o = 124 m^3/tonnes, k = 0.082/year)
Gas Generation Rate (cfm)
1,000
900
800
700
600
500
400
300
200
100
0
2005
2010
2015
2020
2025
2030
End of Year
Methane
Total Landfill Gas

FIGURE L2-23


Gas Generation Rate
Nanaimo Landfill, Nanaimo, BC
(L_o = 136 m3/tonnes, k = 0.132/year)
Gas Generation Rate (cfm)
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
2005
2010
2015
2020
2025
2030
End of Year
Methane
Total Landfill Gas


Gas Generation Rate
Vernon Landfill, Vernon, BC
(L$_o$ = 113 m^3/tonnes, k = 0.034/year)
Gas Generation Rate (cfm)
1,000
900
800
700
600
500
400
300
200
100
0
2005
2010
2015
2020
2025
2030
End of Year
Methane
Total Landfill Gas

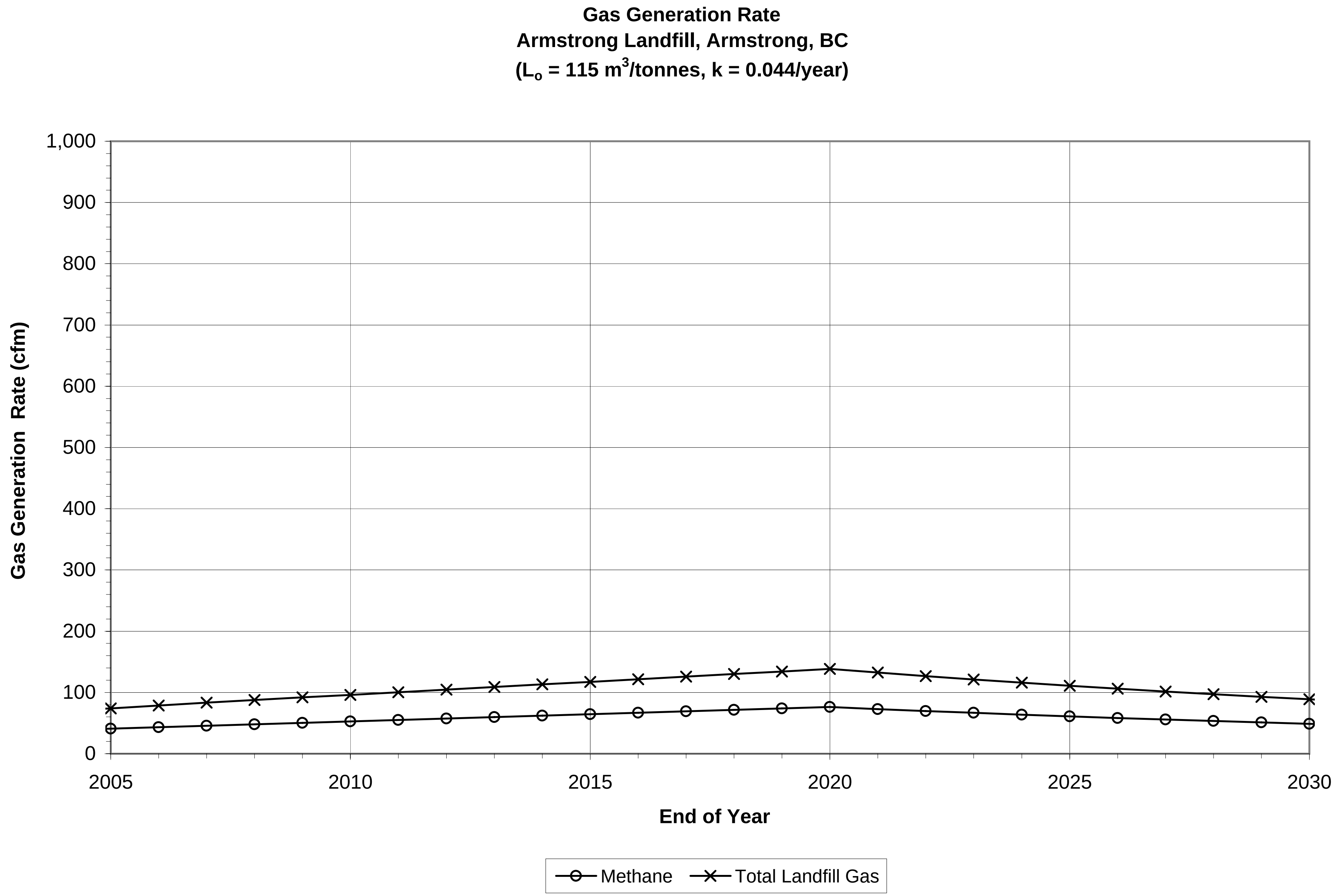
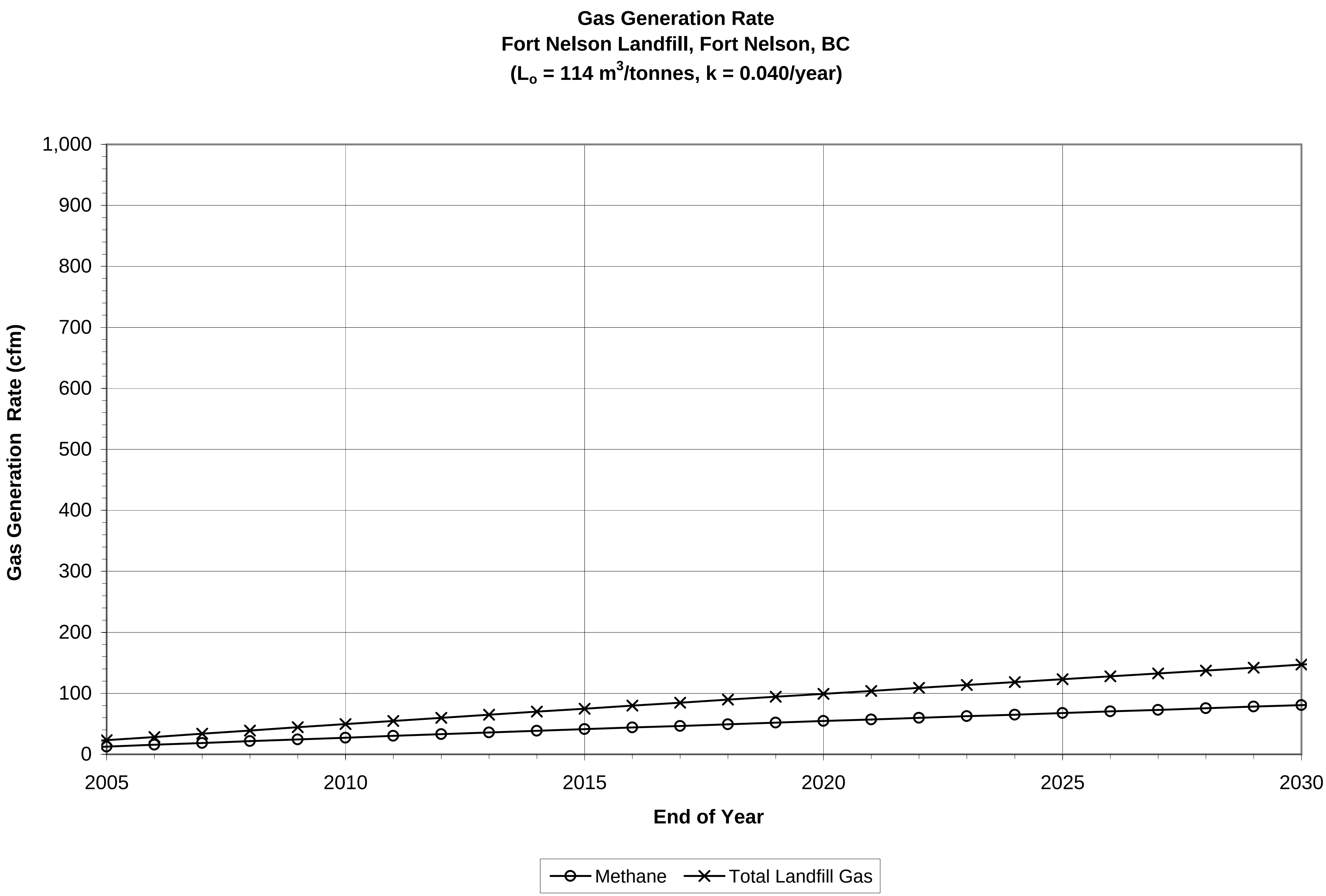
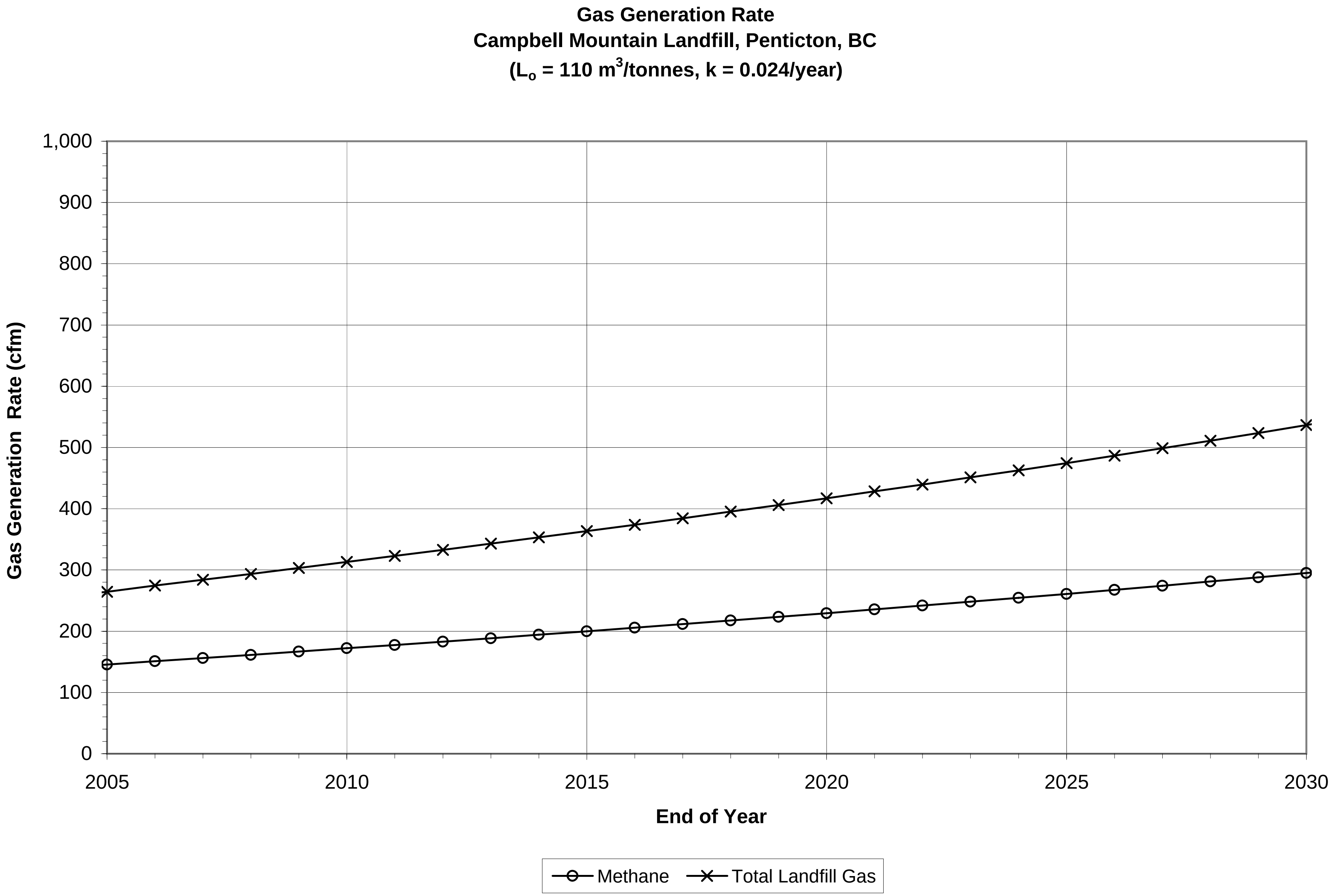
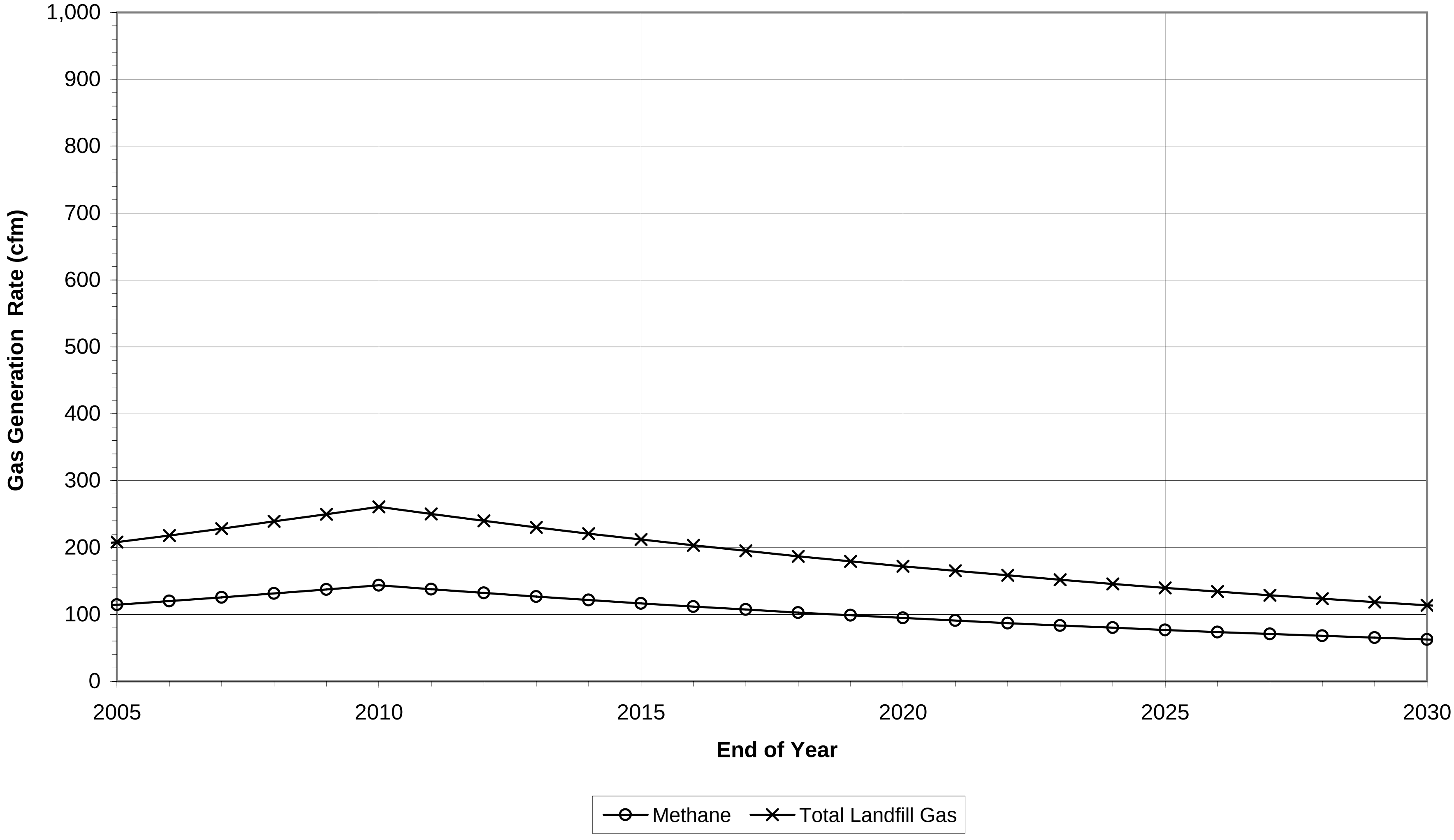

Gas Generation Rate
Armstrong Landfill, Armstrong, BC
(L_o = 115 m³/tonnes, k = 0.044/year)
Gas Generation Rate (cfm)
1,000
900
800
700
600
500
400
300
200
100
0
2005
2010
2015
2020
2025
2030
End of Year
Methane
Total Landfill Gas

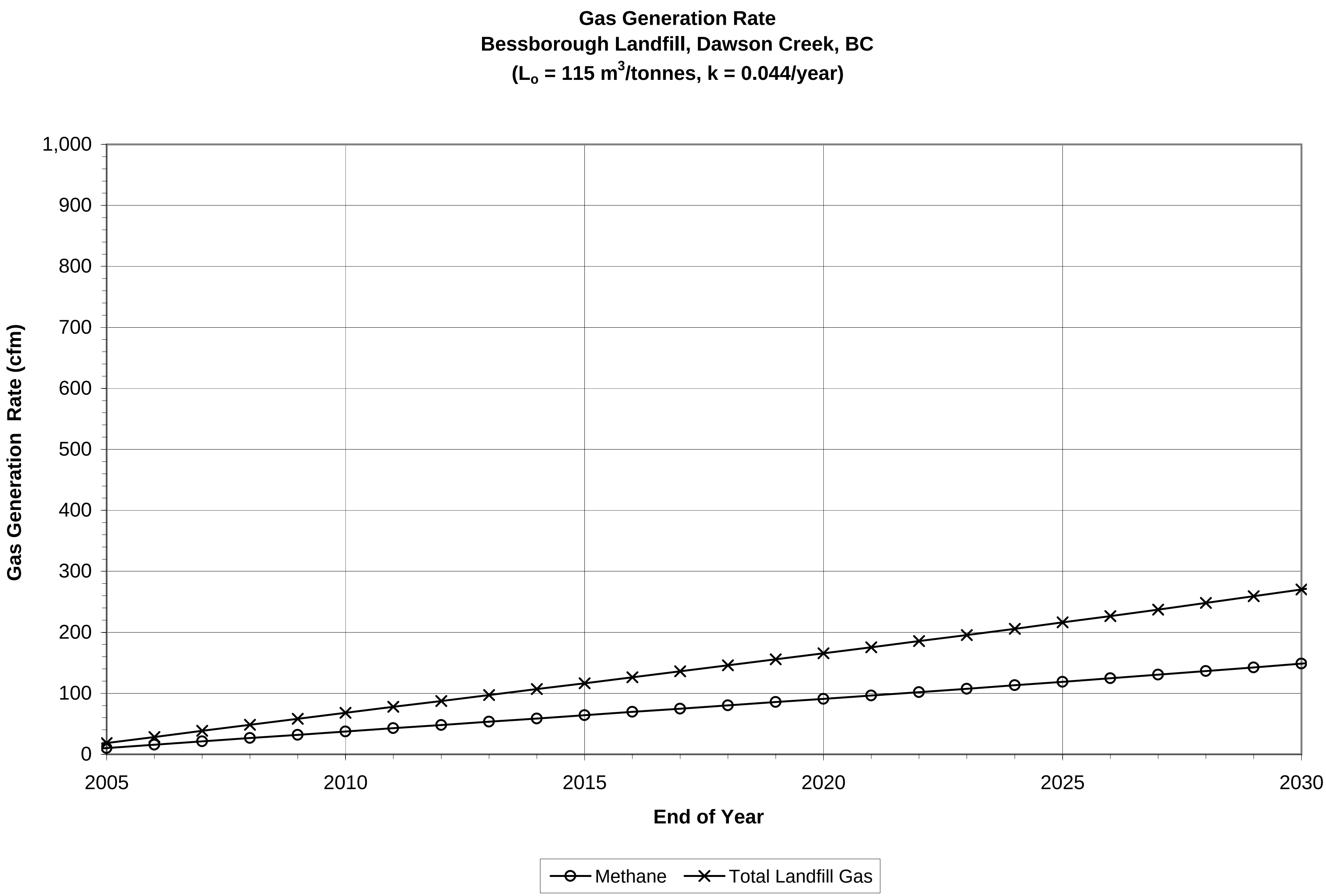
FIGURE L2-26

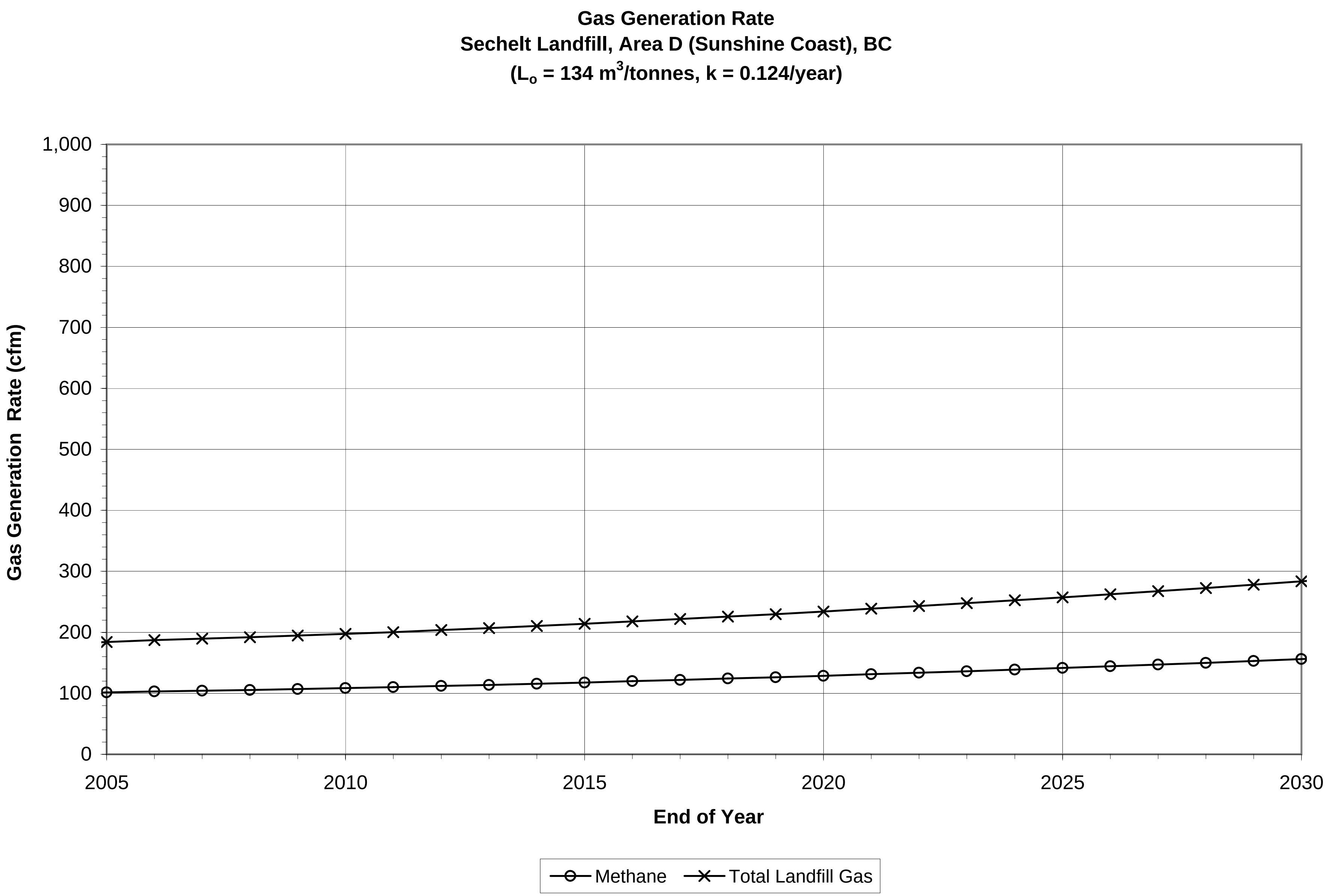

Gas Generation Rate
Fort Nelson Landfill, Fort Nelson, BC
(L$_o$ = 114 m^3/tonnes, k = 0.040/year)
Gas Generation Rate (cfm)
1,000
900
800
700
600
500
400
300
200
100
0
2005
2010
2015
2020
2025
2030
End of Year
Methane
Total Landfill Gas

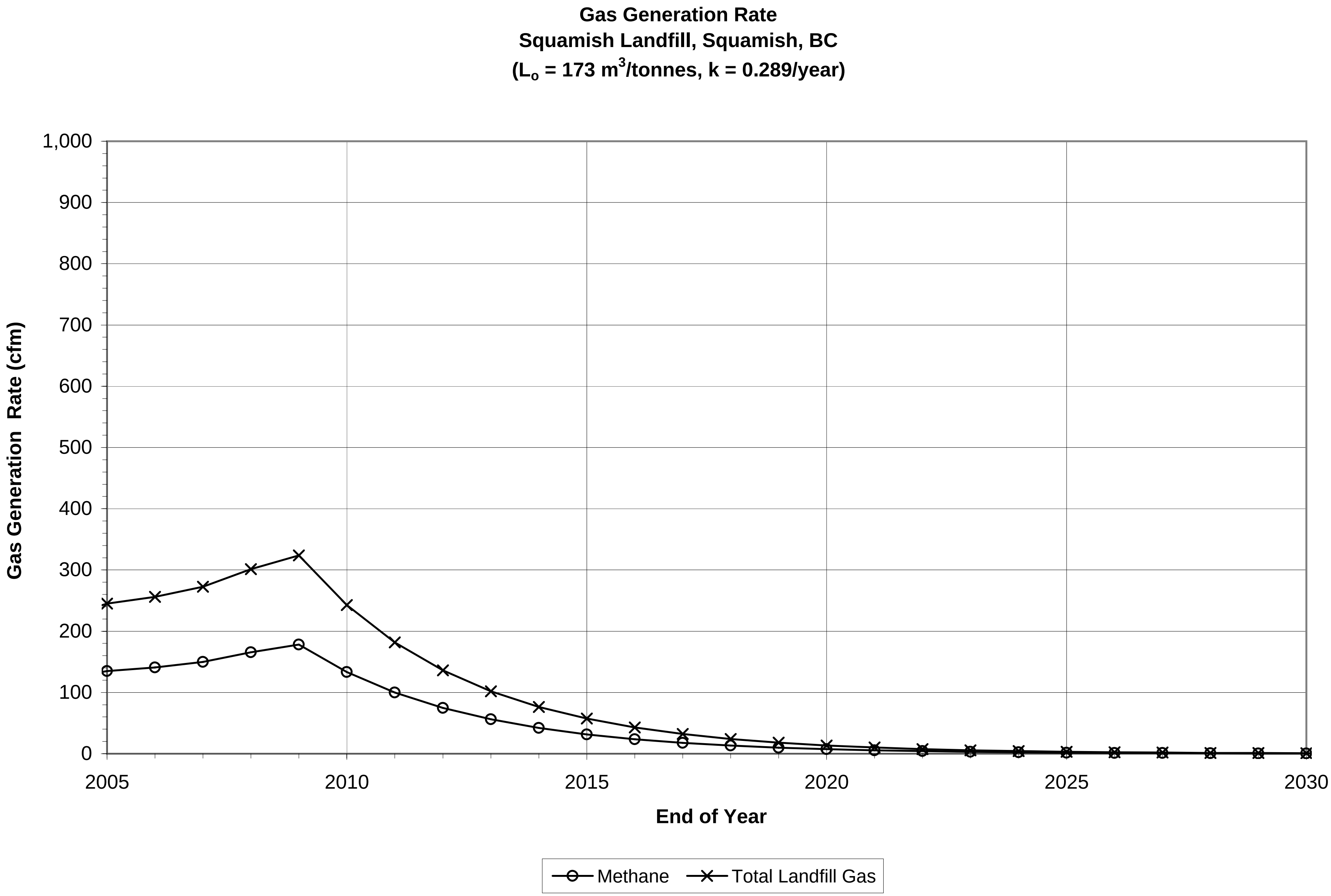

Gas Generation Rate
Campbell Mountain Landfill, Penticton, BC
(Lo = 110 m3/tonnes, k = 0.024/year)
1,000
900
800
700
600
500
400
300
200
100
0
Gas Generation Rate (cfm)
2005
2010
2015
2020
2025
2030
End of Year
Methane
Total Landfill Gas

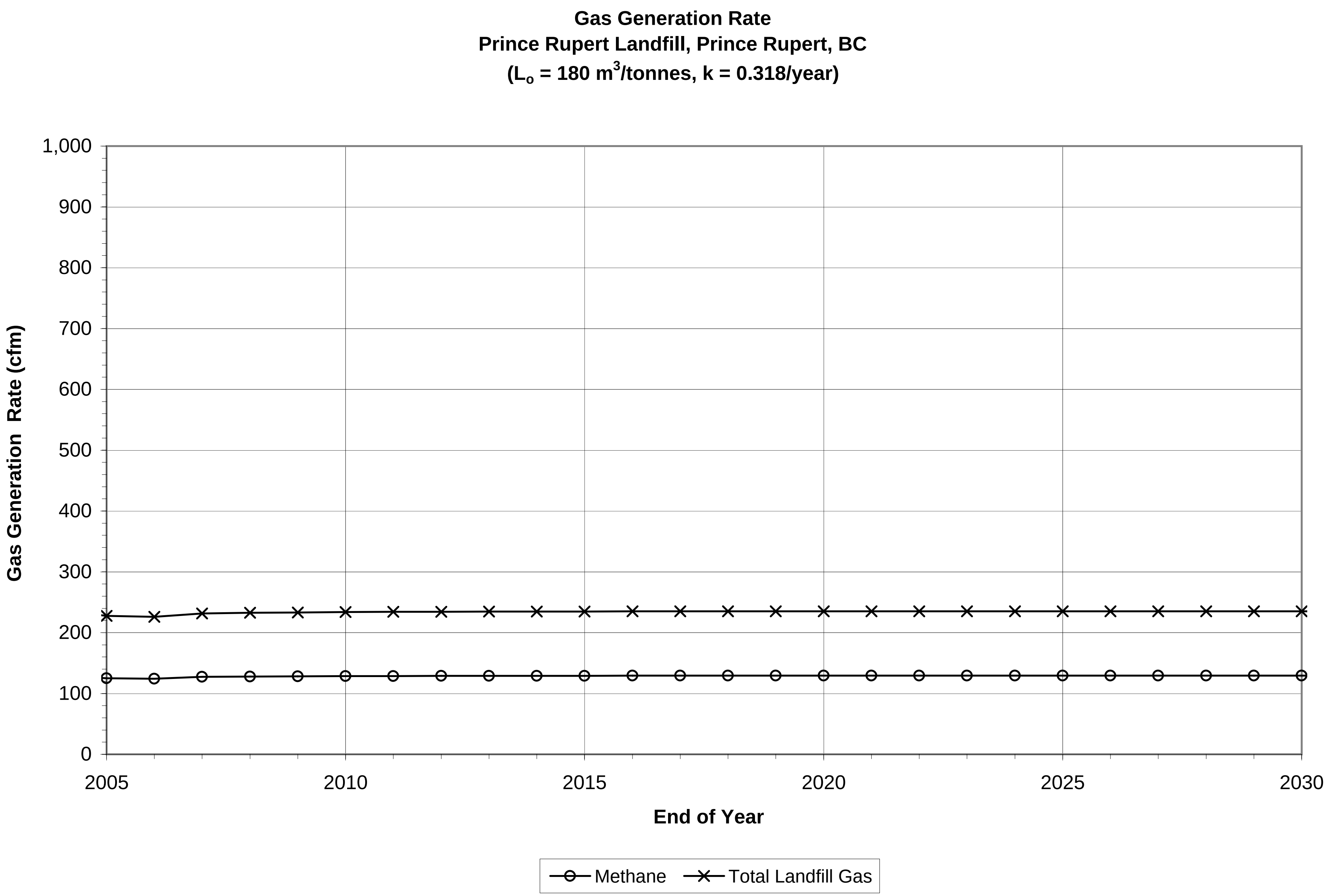
Gas Generation Rate
Fort St. John Landfill, Fort St. John, BC
(L_o = 114 m^3/tonnes, k = 0.042/year)

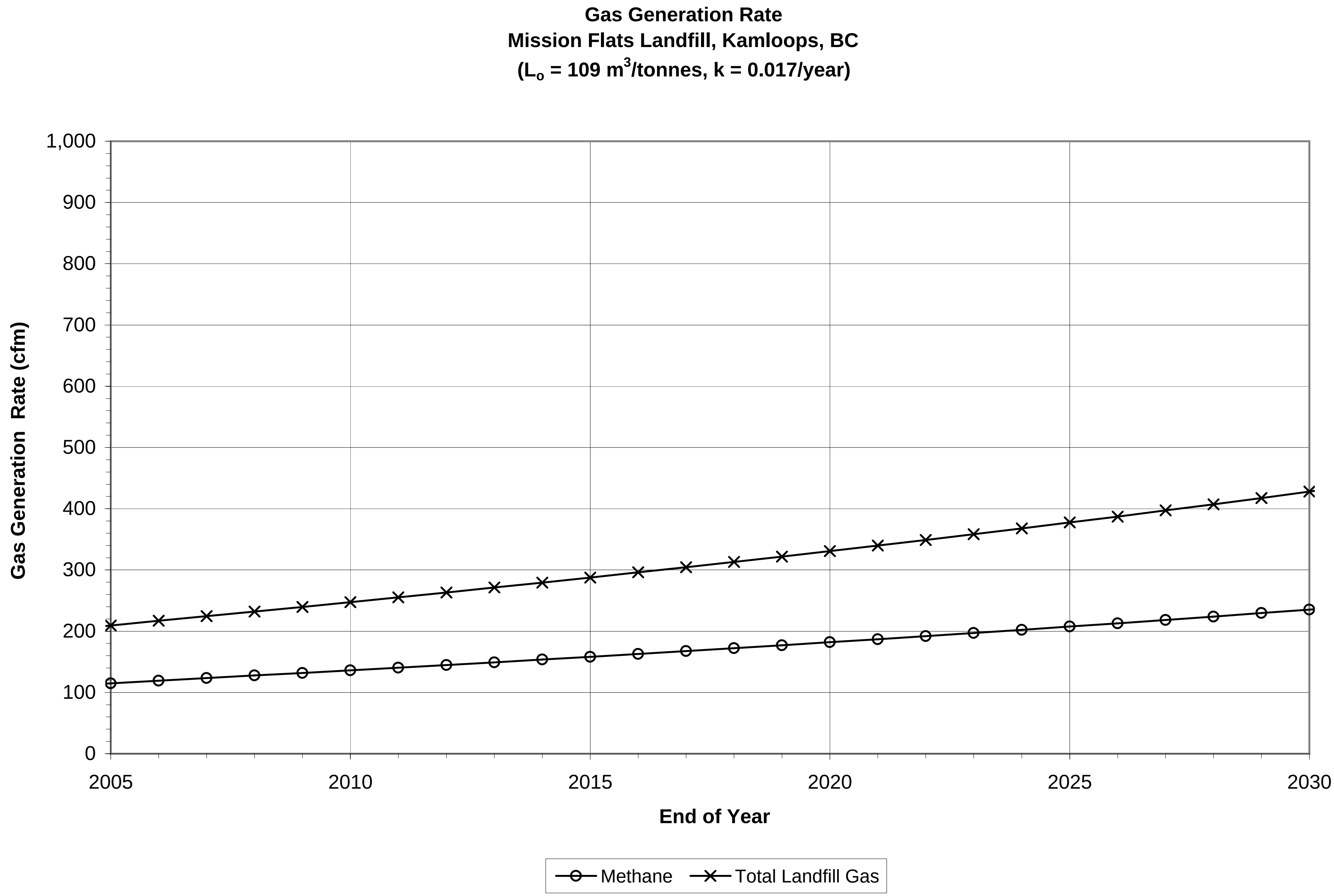


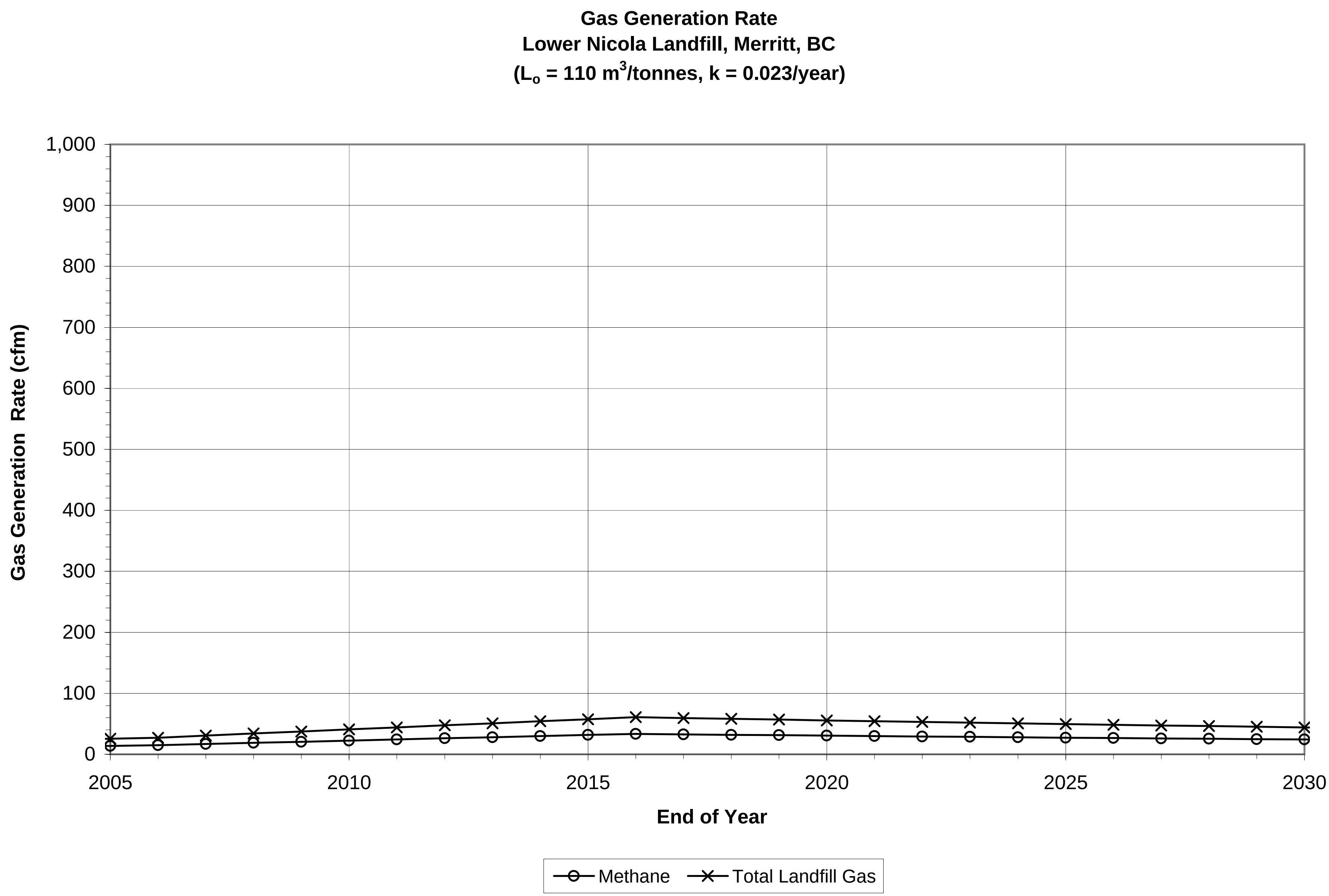

Gas Generation Rate
Bessborough Landfill, Dawson Creek, BC
(L_o = 115 m^3/tonnes, k = 0.044/year)
Gas Generation Rate (cfm)
0
100
200
300
400
500
600
700
800
900
1,000
2005
2010
2015
2020
2025
2030
End of Year
Methane
Total Landfill Gas

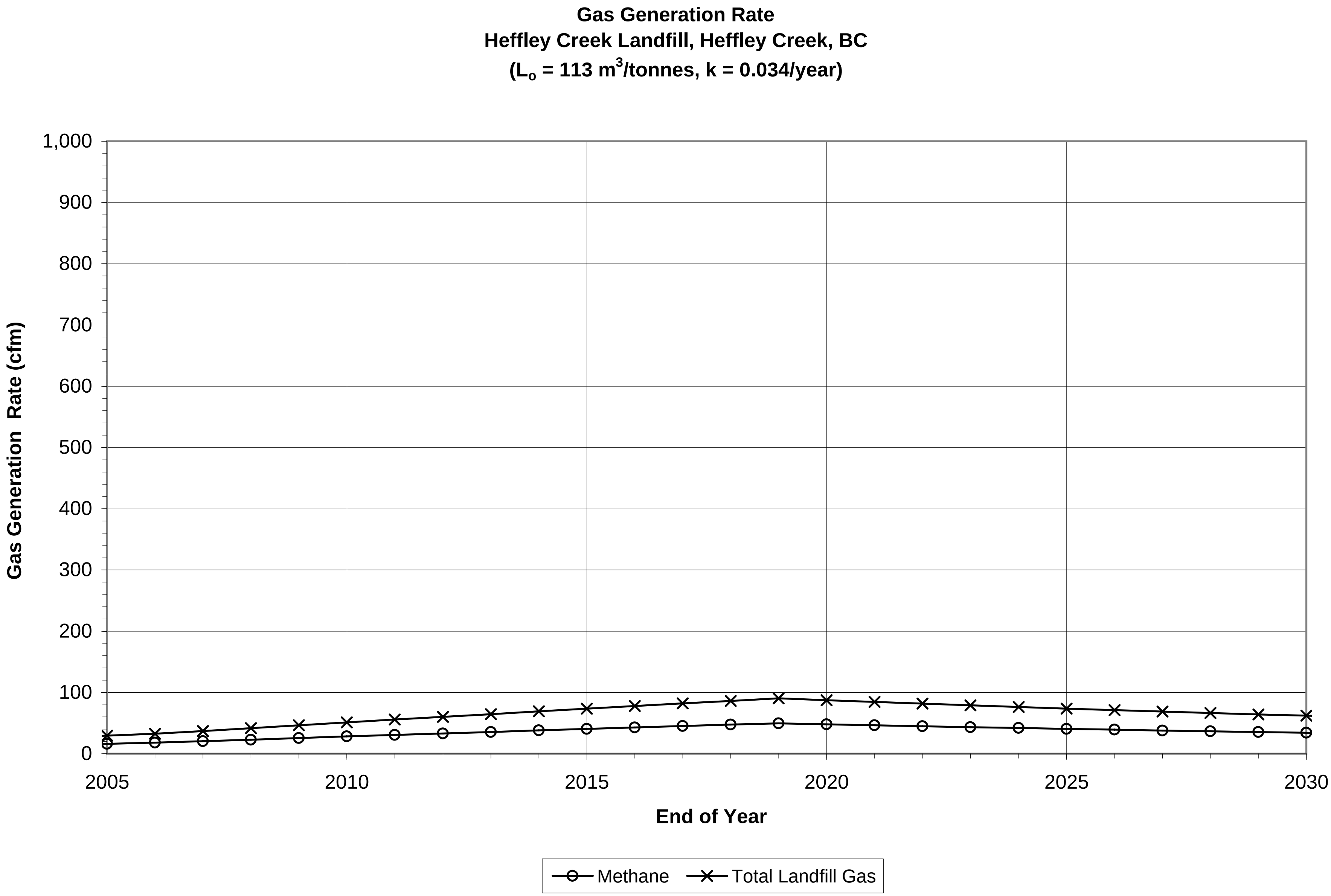

Gas Generation Rate
Sechelt Landfill, Area D (Sunshine Coast), BC
(Lo = 134 m3/tonnes, k = 0.124/year)
Gas Generation Rate (cfm)
0
100
200
300
400
500
600
700
800
900
1,000
2005
2010
2015
2020
2025
2030
End of Year
Methane
Total Landfill Gas


Gas Generation Rate
Squamish Landfill, Squamish, BC
(Lo = 173 m3/tonnes, k = 0.289/year)
Gas Generation Rate (cfm)
1,000
900
800
700
600
500
400
300
200
100
0
2005
2010
2015
2020
2025
2030
End of Year
Methane
Total Landfill Gas


Gas Generation Rate
Prince Rupert Landfill, Prince Rupert, BC
(L_o = 180 m^3/tonnes, k = 0.318/year)
Gas Generation Rate (cfm)
1,000
900
800
700
600
500
400
300
200
100
0
2005
2010
2015
2020
2025
2030
End of Year
Methane
Total Landfill Gas


Gas Generation Rate
Mission Flats Landfill, Kamloops, BC
(Lo = 109 m3/tonnes, k = 0.017/year)
1,000
900
800
700
600
500
400
300
200
100
0
Gas Generation Rate (cfm)
2005
2010
2015
2020
2025
2030
End of Year
Methane
Total Landfill Gas


Gas Generation Rate
Lower Nicola Landfill, Merritt, BC
(Lo = 110 m3/tonnes, k = 0.023/year)
Gas Generation Rate (cfm)
1,000
900
800
700
600
500
400
300
200
100
0
2005
2010
2015
2020
2025
2030
End of Year
Methane
Total Landfill Gas


Gas Generation Rate
Heffley Creek Landfill, Heffley Creek, BC
(L_o = 113 m^3/tonnes, k = 0.034/year)
Gas Generation Rate (cfm)
1,000
900
800
700
600
500
400
300
200
100
0
2005
2010
2015
2020
2025
2030
End of Year
Methane
Total Landfill Gas

APPENDIX III

DETERMINATION OF AVERAGE AUTOMOBILE CO_2E EMISSIONS IN CANADA

DETERMINATION OF AVERAGE AUTOMOBILE CO_2e EMISSIONS IN CANADA

From Table 2.3 of *Transportation and Climate Change: Options for Action, Options* paper of the Transportation Climate Change Table, November 1999, the number of cars (gasoline) vehicles in Canada was estimated to be 11.9 million in 1996.

The population of Canada in 1996 was 29,610,757 according to Statistics Canada (http://www.statcan.ca/english/freepub/98-187-XIE/pop.htm). The population of Canada in 2005 was 32,312,077. Assuming the number of vehicles is proportional to population, it is estimated that there were an additional 9% more cars in 2005 than in 1996, or 13 million cars.

According to the Canadian government's submission to the UN Framework Convention on Climate Change "National Inventory Report, 1990-2005: Greenhouse Gas Sources and Sinks in Canada", Section 3.2.3, GHG emissions of light duty gasoline vehicles in 2005 was 41.2 million tonnes CO_2e.

Therefore, assuming "cars" in the 1996 report are equivalent to "light duty gasoline vehicles" in the National Inventory, the average automobile emissions in 2005 is estimated to be 41,200,000 tonnes CO_2e/13,000,000 cars, or approximately 3 tonnes CO_2e/car.

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APPENDIX IV

ESTIMATE OF METHANE EMISSIONS FROM WOODWASTE IN LANDFILLS

ESTIMATE OF METHANE EMISSIONS FROM WOODWASTE IN LANDFILLS

Wood is approximately 50% carbon, 44% oxygen, and 6% hydrogen by dry weight, with trace amounts of nitrogen and other constituents. For this simplified analysis, the nitrogen and other trace constituents will be neglected. Thus, for each mole of carbon in wood, there are 0.66 moles of oxygen and 1.44 moles of hydrogen. Therefore, a simplified and very approximate formula for the chemical composition of wood is:

$$C_5H_7O_3$$

A very simplified equation representing the anaerobic decomposition of wood is:

$$C_5H_7O_3 + 1.75H_2O \rightarrow 2.625CH_4 + 2.375CO_2$$

The first (wood) term has a molecular weight of 115. The methane term has a molecular weight of 42. Therefore, the volume of methane produced per tonne of wood at 50% moisture content by wet weight if all the wood anaerobically decomposes and at a methane gas density of 0.67 kg/m^3 at 20ºC is:

$$\text{Methane } (m^3) = (42 * 500 \text{ kg})/(115 * 0.67 \text{ kg/m}^3) = 272 \text{ m}^3 \text{ CH}_4\text{/tonne wood}$$

Assuming only 3% of wood decomposes anaerobically in 25 years (derived from Gardner et. al, 2002), the average methane production from wood is estimated to be on the order of 0.33 m^3/year. This is rounded to 0.3 m^3 methane/year per tonne of wood at 50% moisture content by wet weight.

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