# Hartland Landfill
# Greenhouse Gas Emissions Quantification
## (Final Report)

**PREPARED FOR: CAPITAL REGIONAL DISTRICT**

**PREPARED BY: SPERLING HANSEN ASSOCIATES**

**PRJ20007**

**January 2021**

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January 30th, 2021 PRJ20007

Kelly Tradewell, BSc
Environmental Contaminants Officer
Parks & Environmental Services
Capital Regional District

**RE: Hartland Landfill Greenhouse Gas Emissions Quantification – Final Report**

Dear Mrs. Tradewell,

Sperling Hansen Associates (SHA) is pleased to provide you with the final report of the Hartland Landfill Greenhouse Gas (GHG) Emissions Quantification. advanced Landfill Gas (LFG) Generation assessment for the.

SHA conducted comprehensive field investigations and data analysis to quantify fugitive methane emissions from the landfill. Our field investigations and data analyses showed that Hartland Landfill is currently emitting 925 tonnes of $CH_4$ per year, equivalent to 184 scfm of LFG at 50% $CH_4$ content. Therefore, the maximum rate of GHG emissions from Hartland Landfill is estimated to be approximately 23,000 tonnes of CO2-e per year, which accounts for 14% of the generated gas from the landfill in 2020.

Results of this GHG emission quantification study showed that $CH_4$ emission rates at this facility are lower than what is known as industry best engineering practices, indicating a high collection efficiency of the active gas collection system at this site. To our knowledge, this is the highest gas collection efficiency currently achieved in BC. Furthermore, completing a methane mass balance during the two field measurement events showed that UBCiModel©, as a site-specific model, better represents $CH_4$ generation at Hartland Landfill.

If you have any questions about our submission or require any further information, please do not hesitate to contact me.

Yours truly,
**SPERLING HANSEN ASSOCIATES**

A. Ab

Ali R. Abedini, Ph.D.
Senior Environmental Consultant
Landfill Gas Specialist

# HARTLAND LANDFILL

# GREENHOUSE GAS EMISSIONS QUANTIFICATION

**Prepared For:**

CAPITAL REGIONAL DISTRICT

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**January, 2021**

## Table of Content



## List of Appendices

## List of Tables



## List of Figures



## List of Photos

# 1 INTRODUCTION

## 1.1 Background

Hartland Landfill (Landfill) is owned and operated by the Capital Regional District (CRD), located 14 km northwest of Victoria, British Columbia (BC) in the District of Saanich at 1 Hartland Avenue. The landfill occupies a footprint of 33 ha on a property that encompasses 293 Ha. To date, approximately 7,300,000 tonnes of municipal solid waste (MSW) have been landfilled. Hartland Landfill has been developed in two distinct phases. Phase 1 was developed between 1950 and 1996, with a final capping system completed in 1997. Phase 2 has been operational since 1997, with development planned out in six distinct cells. Cells 1 and 2 have been completed to-date and landfilling is currently occurring in Cell 3.

**Photo 1.1 - Hartland Landfill Aerial Photo**

Hartland Landfill is one of the largest landfills in BC and is required to collect and thermally combust generated methane as per the BC Ministry of Environment (ENV) landfill gas regulation (LFG Regulation). This provincial regulation stipulates that landfills generating more than 1,000 tonnes of methane per year are to install and operate an active LFG management system with a minimum gas collection efficiency of 75%. Since 2012, the CRD has been continuously improving and expanding the Hartland Landfill's LFG collection system. As of 2015, the active LFG system has maintained excellent performance with an increasing capture efficiency of the gas throughout the past 5 years.

## 1.2 Landfill Gas Generation and Collection Efficiency at Hartland Landfill

In a recent study, Sperling Hansen Associates (SHA), 2019 conducted a comprehensive LFG generation assessment study for the landfill using three different models: (i) an advanced LFG generation model (UBCiModel©), (ii) ENV's LFG Generation Model (ENV Model), and (iii) ENV Annual Reporting Tool (ENV Annual Tool). This study determined an annual gas capture efficiency of 66% to 80% at this site between 2014 and 2019 based on the UBCiModel©. However, the ENV model and ENV AR Tool showed lower collection efficiencies ranging as low as 59% in 2014 and up to 71% in 2017 (SHA, 2019). More details from results of this study are provided in Section 4.4.

## 1.3 Scope of the Current Study

The CRD retained SHA to complete a full-scale measurement of methane emissions at the Hartland Landfill and to further assess effectiveness of the existing gas collection system. The purpose of the study was to execute the following key tasks.

- Conduct field measurement and quantify fugitive methane emissions from different areas of the landfill.
- Assess LFG management system collection efficiency.
- Identify major emission hot spots and assess potential additional greenhouse gas (GHG) emission reduction that can be achieved through other alternative methodologies such as application of a Biocover system.

# 2 LANDFILL METHANE MASS BALANCE INVESTIGATION

In order to complete a full methane mass balance for a landfill, not only the fugitive methane emissions to the atmosphere need to be quantified, but also methane oxidation by methanotrophic bacteria (naturally existing in landfill cover soil) and methane capture and combustion via active LFG collection and treatment systems must be taken into account. On this basis, Abedini (2014) developed the "METRO equation" which provides a comprehensive mass balance of landfill methane. Detailes of the equation are provided below:

$$G = M + E + T + R + O \qquad \textbf{Equation 1}$$

Where:

G = Generated Methane (theoretical model)
M = Migrated Methane (i.e. offsite lateral migration)
E = Emitted Methane (i.e. atmospheric emissions)
T = Trapped Methane (insignificant in well compacted and active landfills)
R = Recovered Methane (active gas collection system)

O = Oxidized Methane (soil cover or biocover)

The METRO equation considers all possible pathways for the methane generated within a landfill. When offsite lateral migration of methane is not reported and for landfills actively generating methane at high rates, M and T can be removed and the simplified METRO equation can be used as follows (Abedini, 2014):

$$G = E + R + O \qquad \textbf{Equation 2}$$

As mentioned in Section 1.3, the main scope of the current project is to quantify fugitive methane emissions (E) from Hartland Landfill. Section 3 discusses our approach and methodology to fulfill this scope while results of our study are presented and discussed in Section 4. Section 3 also includes information regarding methane recovery data and methane oxidation estimations for the landfill.

# 3 METHANE EMISSIONS MEASUREMENT

There are several methods that can be used to measure fugitive $CH_4$ or LFG emission rate from a variety of landfill covers. The most widely attempted method, and seemingly the more favorable for the purpose of regulatory compliance assessment, is the use of a flux chamber which directly measures $CH_4$ emission flux from the surface of landfills.

In addition to the flux chamber method, other methods such as eddy covariance and co-advected proxy tracer plume measurements and methods relying on remote sensing and plume mapping have been used (Gardiner et al., 2017; Delre et al., 2018; Kormi et al., 2017; Goldsmith et al., 2012; Gollapalli et al., 2018; Monster et al., 2014; Innocenti et al., 2017; Delkash et al., 2016; Allen et al., 2018; Abedini et al., 2019). Many of these methods suffer considerable drawbacks in terms of associated costs, reliability, logistics and compatibility with the typically heterogeneity of landfills and fugitive $CH_4$ emissions.

## 3.1 Technique for Quantification of Fugitive Methane Emissions at Hartland

The technique adopted to quantify the fugitive $CH_4$ emissions in this study is a patented methodology developed through the PhD research of Dr. Ali Abedini at the University of British Columbia (UBC) (Abedini, 2014; Abedini et al., 2019). Abedini's methodology was developed based on comprehensive field investigations completed at the Vancouver Landfill and involves measurement of near-ground surface methane concentrations (SMC) from the area of interest using a flame ionization detector (FID) device.

This method overcomes the major drawbacks of the conventionally acceptable stand alone flux chamber method in terms of detection limit, cost and extensive time required to characterize fugitive emission at a given landfill. Measurement of $CH_4$ concentration at the surface of a landfill is less demanding compared to the flux chamber method and is presumed to lead to more reliable results when the concentration of $CH_4$ at the surface of a landfill is low, as usually happens in cases where there is an active landfill gas collection system or biocover system in place. A reliable correlation between surface concentration of $CH_4$, which can easily be measured, and $CH_4$ emission measured using flux chamber provides a practical method to facilitate $CH_4$ emission rate characterization at a lower cost.

The techniques and procedures used for measuring SMC using a hand-held FID is an approved methodology used across the US, where it is required by the U.S. Environmental Protection Agency's (EPA) new source performance standard (NSPS) regulation. The NSPS requires that all regulated landfills in the US must measure and report $CH_4$ concentrations at the landfill's surface on a quarterly basis. Values registered above the NSPS threshold during the FID scan imply a malfunctioning LFG control system and the landfill owner is then required to implement control measures within a given period of time.

Abedini (2014) developed a correlation between qualitative SMC data and quantitative surface $CH_4$ emission rates (MER). This technique is especially useful when MER levels are very low (e.g. where a geomembrane cap and an active gas collection system are in place) and other measurement techniques such as flux chamber cannot be applied. In June 2020 an SMC scan was completed over the entire landfill footprint where historically waste has been placed. In October of the same year, a second round of SMC measurements were completed over selected areas including areas without permanent closure system in place and where relatively higher emission rates were identified in June. The two rounds of field measurements were intentionally scheduled to be completed in two different climatic conditions (cold and warm seasons) to account for the impact of cold temperature on biological methane oxidation within the landfill's soil cover.

A *Thermo Scientific TVA 2020* FID instrument was used to measure and log $CH_4$ concentrations at the landfill surface. Hartland landfill was divided into 32 scan areas (zones) as shown in Figure 3.1. The areas located on side slopes are tagged as S.x and flat (crest) areas are tagged as C.x. The scanned area also included the exposed top surface of a coarse leachate collection blanket (approximately 2 m x 250 m) located on the west side of C1 area known as Rock Wall, labeled R.W. The surface scan areas had an approximate total footprint of 30 ha. Some minor changes in zones took place between the two rounds of the field work primarily due to the landfill's ongoing waste disposal operations and scheduled development.

Each zone was scanned on approximately 10 m spaced pathways while logging $CH_4$ concentration every 3 seconds. The FID instrument was calibrated using calibration gas tanks before conducting each set of measurements and tested using the same tanks after completion of each survey to detect any calibration drift during the field work.


**Figure 3.1 - Surface Scan Areas at Hartland Landfill (June 2020)**

Photos 3.1a & 3.1b show a TVA 2020 and calibration gases (left) and Dr. Abedini conducting FID measurements on a similar project (right).


**Photo 3.1a & 3.1b - Surface Methane Concentration Scan Using a Portable FID Instrument**

Results of both rounds of field investigations at Hartland Landfill are presented in Section 4.

### 3.1.1 Effect of Barometric Pressure on LFG Emission

A very important aspect of measurement of fugitive methane emissions from landfills is the effect of barometric pressure (BP) on the gas flux intensity. Fluctuation in BP is known to greatly impact LFG atmospheric emissions (Abedini, 2014; Abedini et al., 2019). When the BP is increasing, the increased atmospheric pressure is applied on the ground, restricting natural LFG venting through the landfill surface, or migrating through the soil. Dropping BP reduces the pressure exerted on the ground, enabling LFG to move more freely from the landfill and increasing the potential for gas to escape through the landfill cover or via offsite lateral migration. Abedini's surface scan technique for quantification of methane emissions includes adjustments of methane emission rates (MERs) based on the magnitude and sign of the rate of change in atmospheric pressure (i.e. $\Delta P/t$) at the time of field measurements according to Equation 3 below (Abedini, 2014):

$$MER_a = MER \times (1 + 1.9731 \times |\Delta P/t|)^{\wedge\,(\Delta P/t\,/|\Delta P/t|)} \qquad \textbf{Equation 3}$$

where; $MER_a$ = adjusted methane emission rate (g $CH_4$ $m^2$ $d^{-1}$)
MER = measured methane emission rate (g $CH_4$ $m^2$ $d^{-1}$)
$\Delta P/t$ = rate of change in barometric pressure at the time of field measurement (mbar/hr)

In this equation, ($\Delta P/t\,/|\Delta P/t|$) would be equal to (-1) or (+1), represent the sign of the $\Delta P/t$.

Using Equation 3 and based on the BP variations that were recorded during the scans at Hartland Landfill, the field emission measurement results were adjusted for the rate of change in BP values. The BP data for the three field investigation days were acquired from the closest weather station to the landfill. Additionally, ambient pressure changes were monitored using a portable weather monitor instrument.

The data presented in Figures 3.2 through 3.6 were acquired from the Saanich Airport Weather Station during the days of field investigation on June 17th to 19th, 2020 and October 20th and 21st, 2020. Figures 3.3, 3.5 & 3.6 illustrate BP data from Saanich Airport weather station as well as onsite data measured by a portable weather station during the course of the field work. Comparing the two sets of data showed that even though the BP values measured onsite and at Saanich weather station were slightly different, the rate of change measured at two locations followed the same trend. This comparison confirmed applicability of the BP data that have been historically recorded at Saanich weather station to the emission rate calculations for Hartland Landfill (with a note that Sannich weather station has hourly records for BP).

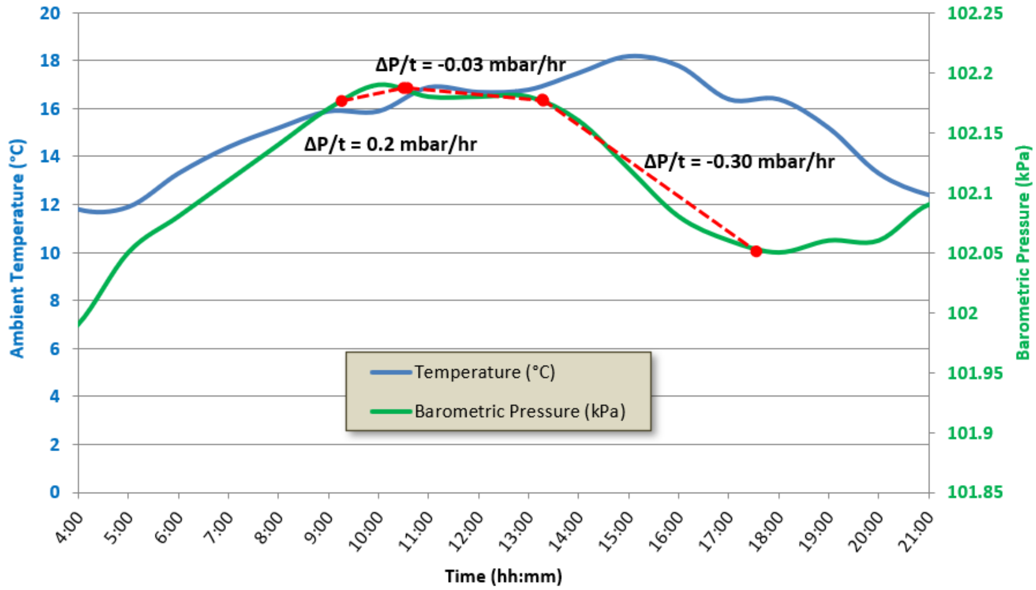


**Figure 3.2 - Atmospheric Pressure & Temperature (Saanich A Weather Station – June 17, 2020)**

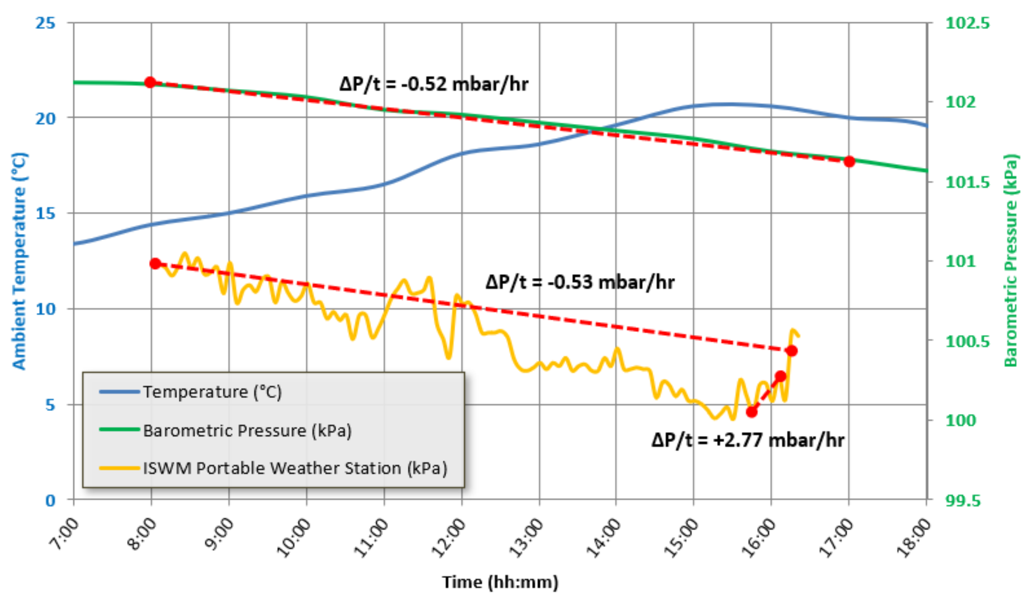


**Figure 3.3 - Atmospheric Pressure & Temp. (Saanich A & Portable Weather Station – June 18, 2020)**

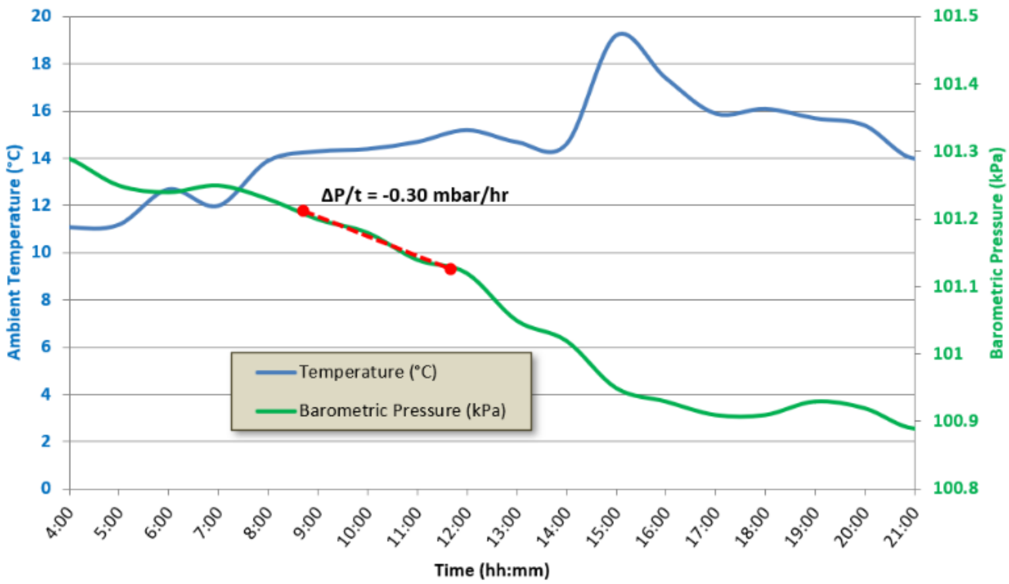


**Figure 3.4 - Atmospheric Pressure & Temperature (Saanich Weather Station – June 19, 2020)**

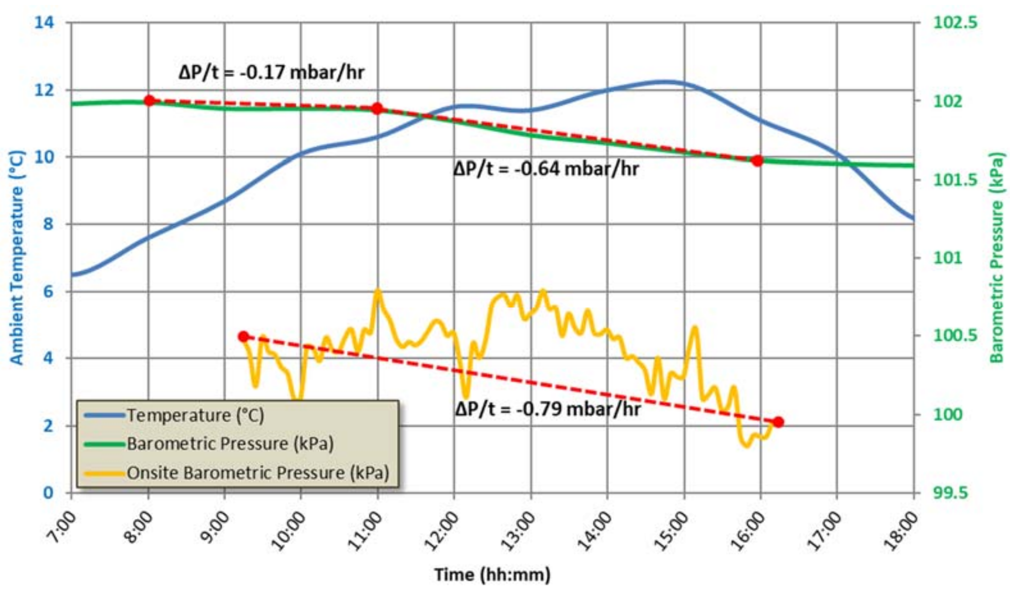


**Figure 3.5 - Atmospheric Pressure & Temperature (Saanich Weather Station – October 20, 2020)**

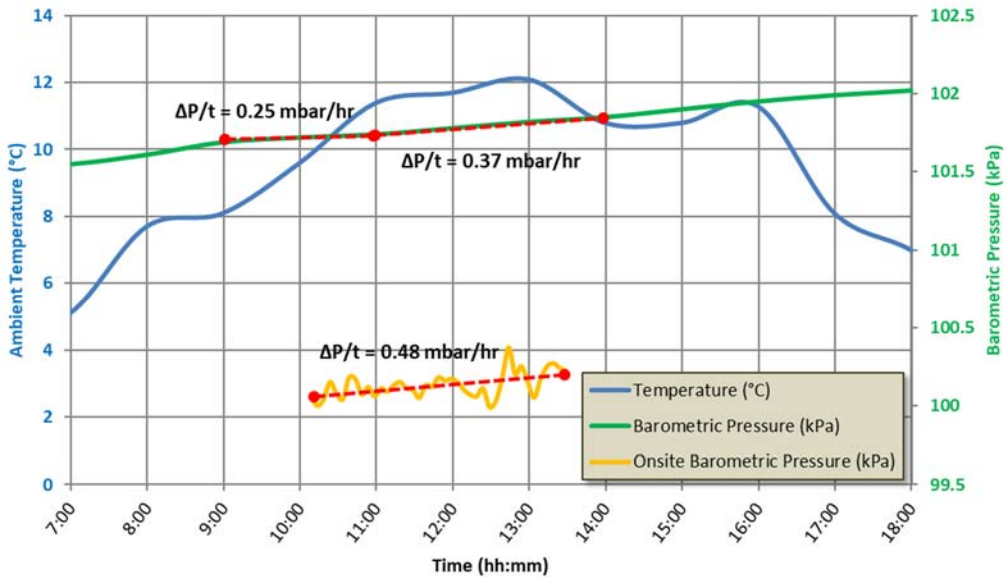


**Figure 3.6 -Atmospheric Pressure & Temperature (Saanich Weather Station – October 21, 2020)**

## 3.2 Gas Collection Rates during June and October 2020 Field Investigations

In order to conduct a system performance review and compare the level of gas emissions with gas capture at Hartland Landfill, SHA collected updated information from the landfill's active gas collection system during the days of field monitoring. Table 3.1 present data regarding the landfill's collected gas quantity and quality during the course of the field investigations for GHG emissions quantification.

**Table 3.1 - Hartland Landfill Active Gas Collection System Data (June & October , 2020)**

| | Daily LFG Flow (scf/day) | LFG Flow Rate (scfm) | $CH_4$ Content (%) | Normalized Flow Rate at 50% [$CH_4$] (scfm) |
|---|---|---|---|---|
| June 17, 2020 | 1,518,828 | 1,054.7 | 50.1 | 1,057.3 |
| June 18, 2020 | 1,559,397 | 1,082.9 | 51.1 | 1,105.7 |
| June 19, 2020 | 1,565,847 | 1,087.4 | 52.5 | 1,141.7 |
| Oct. 19, 2020 | 1,512,416 | 1,050.29 | 52.2 | 1,095.7 |
| Oct. 20, 2020 | 1,548,480 | 1,075.33 | 52.4 | 1,127.6 |
| Oct. 21, 2020 | 1,535,787 | 1,066.52 | 52.1 | 1,110.7 |
| Oct. 22, 2020 | 1,528,443 | 1,061.42 | 51.1 | 1,084.8 |
| **June Average** | **1,548,024** | **1,075.0** | **51.2** | **1,101.6** |
| **Oct. Average** | **1,548,024** | **1,063.4** | **51.9** | **1,104.7** |

scf = standard cubic feet, scfm = standard cubic feet per minute, [$CH_4$] = Methane Concentration

# 4 RESULTS

Results of the surface scan field investigations are presented below in four different sections. One big advantage of the surface scan technique for quantification of methane emissions is identification of methane emission hotspots at the same time. This information allows the landfill owner/ operator to more effectively develop and implement geo-targeted mitigation strategies for reduction of fugitive $CH_4$ emissions (GHG emissions) from the landfill. This information is presented in Section 4.1 below. Section 4.2 presents results of Flux Chamber investigations for development of a site-specific correlation factor between surface methane concentration (SMC) and methane emission rates (MER) and Section 4.3 presents the achieved results for quantification of MER values. Lastly, Section 4.4 reports GHG and LFG emissions rates for the Hartland Landfill in 2020.

## 4.1 Methane Emission Hotspots

There are several types of closure/cover systems that have been applied on various surfaces of Hartland Landfill throughout its lifespan to date. These cover systems include: (i) interim soil cover, (ii) temporary geomembrane cover, (iii) permanent geomembrane cover, and (iv) multi-layer full final closure system including geomembrane liner, drainage layer, sub soil and topsoil cover etc.

**Photo 4.1 - Interim Soil Cover (Area S14)**

**Photo 4.2 - Temporary Woven Liner (Area S10, S11)**

**Photo 4.3 - Textured Geomembrane (Area S1)**

**Photo 4.4 - Final Multilayer Cover (Area S9)**

In general, lower methane emission rates are expected to occur where an impermeable liner is in place and negative pressure is applied to the area through an active gas collection system. However, closure system faults may result in localized (point source) $CH_4$ leaks, known as emission “hotspots”. Typical $CH_4$ emission hotspot locations at landfills include leaking gas pipes, manholes and underground infrastructure connected to the leachate collection system, exposed leachate drainage layer, exposed geomembrane punctures, settlement cracks in compacted clay liner systems and edges of geomembrane closure system if not tied into the bottom liner or no impermeable (clay) plug is used around the edges. Hotspots on the landfill surface are normally predominant on landfill side slopes; however, high emission rates can be observed in crest areas in the case of liner punctures/cracks and in active areas of the landfill where no impermeable liner is in place. Several emission hotspots were identified during the surface scan field works. Major emission hotspots identified during the field works (Rounds 1&2) are shown on Figure 4.1.

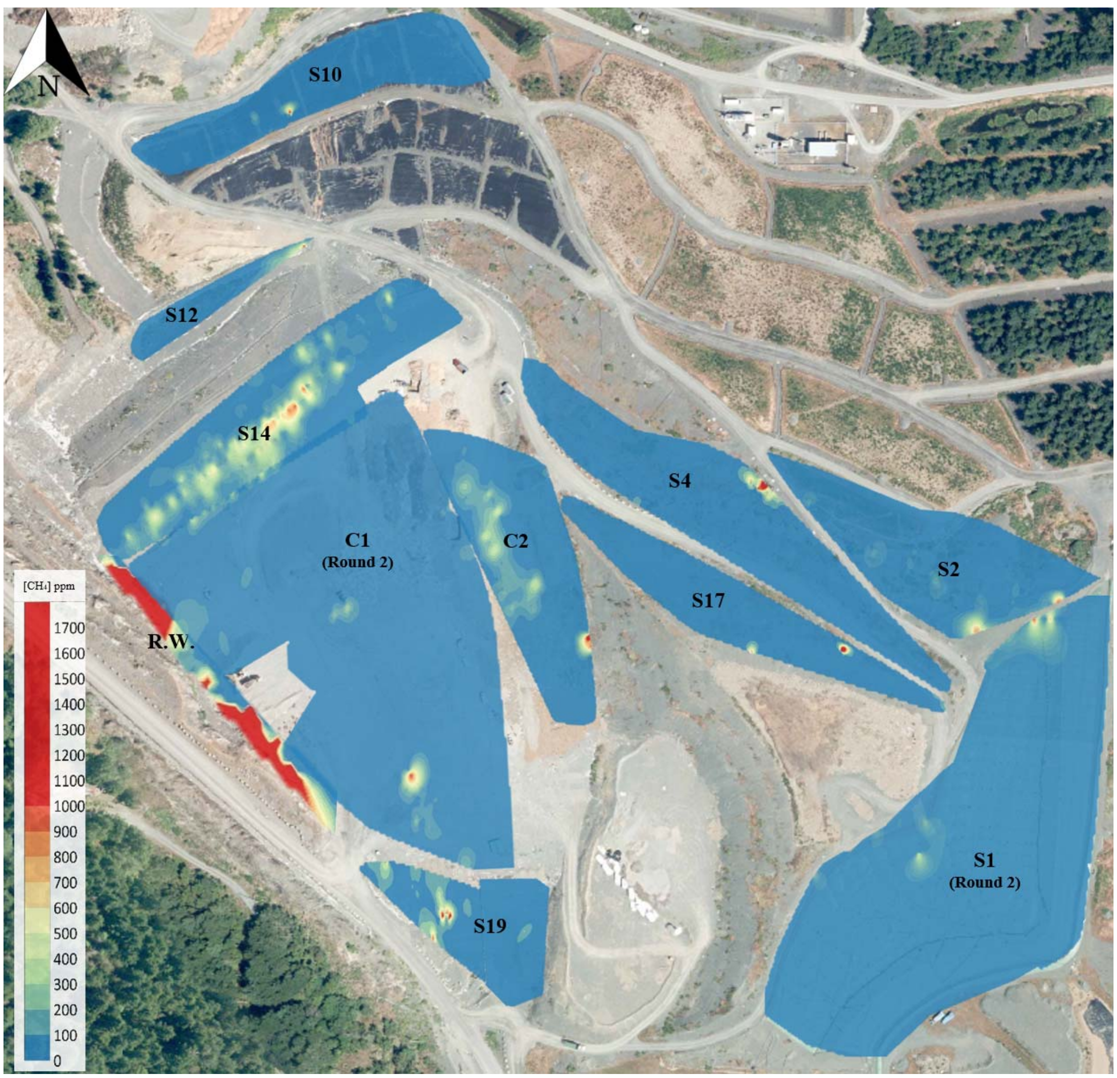


**Figure 4.1 - Major Methane Emission Hotspots at Hartland Landfill (June & October 2020)**

**<u>Phase 2, Cell 3</u>** a major emission hotspot was exposed drainage blanket on the west side of the crest (C1) area. This area, known as the “Rock Wall”, is the interface between the western filling extent of Cell 3 and refuse and creates challenges with respect to gas collection. Soon after round 1 of the surface scan was completed, the Hartland Landfill operations team applied a clay plug over this area and the next lift of waste continued to be placed over top of the clay plug. The second round of the surface scan showed a significant reduction in fugitive methane emissions from the Rock Wall area, however, not having a gas collection system in place at this location, the generated gas started migrating through the drainage blanket towards the north, resulting in a significant increase in $CH_4$ emission from west side of the north slope (marked as S14).

The second round of surface scanning identified this location as a major emission hotspot as illustrated in Figure 4.2. SHA is currently working with CRD to develop a gas collection system for the Rock Wall area. Photos 4.5 and 4.6 below show the clay plug and waste disposal operation at the Rock Wall area during the second round of field works (October 2020).

**Photo 4.5 - Rock Wall Drainage Blanket Clay Plug, October 2020**

**Photo 4.6 - Waste Disposal at West of C1 area Over the Rock Wall Area, October 2020**

North and south slopes (S14 and S19) of this cell (Phase 2, Cell 3) showed relatively high methane emission rates during both sampling rounds. Notably, the horizontal gas collectors that had been installed in the new lifts within this cell were not yet online at the time of the field works (See Photo 4.7).

In addition to S14, the second round of sampling showed higher emission rates from the crest area (C1). Two primary factors causing higher level of emissions from these areas in the second round are (i) blocking the easy pathway for gas emission from the rock wall drainage blanket, and (ii) decomposition of readily degradable organics that had been disposed in this area for the past couple years.

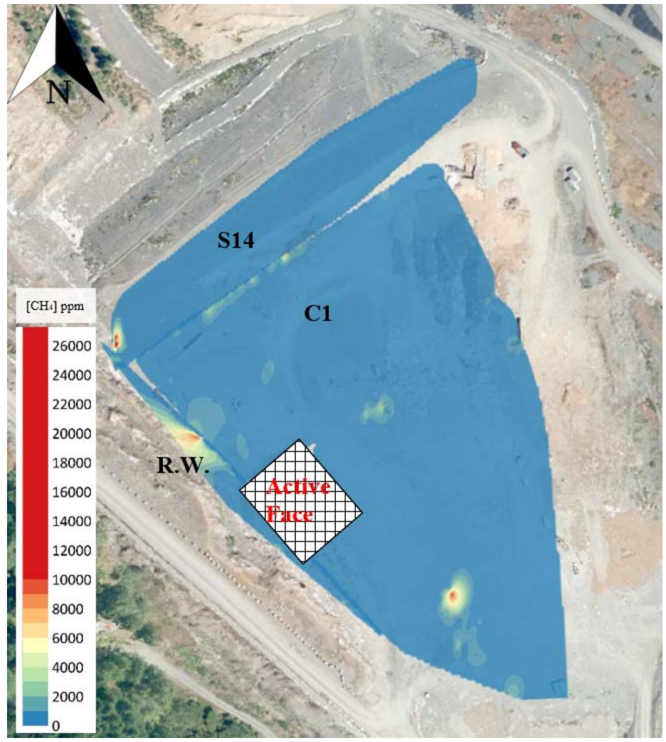


**Figure 4.2 – Cell 3 Methane Emission Hotspots for Round 2 of the Surface Scan (October 2020)**

**Photo 4.7 - New Horizontal Collectors (Area S14)**

**<u>Phase 2, Cell 2</u>** major emission hotspots were detected at the edges of the geomembrane liner. These hotspots were identified during both rounds of field measurements with higher emission rates observed in the second round. Additional hotspots were identified in locations where the geomembrane was damaged. Photos 4.8a to 4.8d show some examples of S1 area emission hotspots.


**Photos 4.8a & 4.8d - Emission Hotspots, Edge of Geomembrane Liner and Damaged Liner (Area S1)**

**<u>Phase 2, Cell 1</u>** temporary liner punctures (Photos 4.9a & 4.9b below) showed relatively high methane leaks during both sampling rounds.

**Photos 4.9a & 4.9b - Temporary Liner Puncture (Area S10)**

## 4.2 Site-Specific Correlation Factor for Hartland Landfill

During the course of the field investigations at Hartland Landfill, thirty five (35) flux chamber measurements were conducted in three (3) zones (Areas S4, S13, and S14) in order to generate a site-specific correlation factor similar to what Dr. Abedini developed for the Vancouver Landfill which were later used as default values in his methodology. Application of flux chambers at landfills to measure fugitive methane emissions from the soil surface through isolating and monitoring the emitting gas from soil is a well-established method. The flux chamber technique includes placing a closed chamber (box) on the landfill's surface and monitoring the change of methane concentration in the box over time. Based on the rate of change in methane concentration in the chamber over time, chamber volume, and area beneath the chamber, the methane flux emitted from landfill's surface can be calculated. The US-EPA guideline, "measurement of gaseous emission rates from land surfaces using an emission isolation flux chamber" (EPA/600/8-86/008), was used to determine the required number of flux chamber tests based on the footprint area of selected zones.

During these tests at the landfill, methane concentrations inside the chamber were continuously monitored using a Landtec GEM 2000+ gas analyzer. With a maximum flux chamber test duration of approximately 5 to 10 minutes, and the chamber volume of $V = 0.007\ m^3$, as well as the gas analyzer sensitivity of $\pm$ 0.1% $CH_4$, the method overall detection limit was determined to be in the order of 10 to 20 g $CH_4\ m^{-2}\ d^{-1}$. In five (5) locations out of fifteen (15) tested in Area S4, values higher than the instrument detection limit were recorded. However, due to the low methane emission rates in Areas S13 and S14, flux chamber measurements in these two areas did not produce meaningful results. Photos 4.10a and 4.10b below show the flux chamber test setup at Hartland Landfill.

**Photo 4.10a & 4.8b - Flux Chamber Measurement at Hartland Landfill**

The flux chamber test results were graphed and translated to methane emission rates (MER) based on the chamber volume and footprint area. Figures 4.3a and 4.3b show two examples of the graphical illustration of the flux chamber test results.

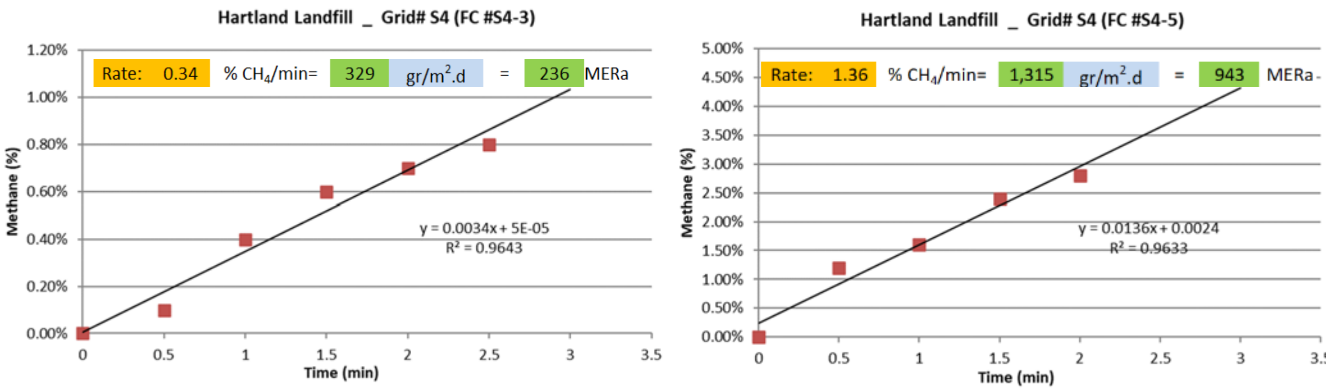


**Figure 4.3a & 4.3b - Flux Chamber Results Graphical illustration (FC# S4-3/15 & FC# S4-5/15)**

The resulting MER from flux chamber tests in Area S4 ranged between zero (non-detectable) to 1,315 g/m$^2$/day (before adjustment for barometric pressure was applied). The averaged result for this area was 14.46 g $CH_4$/m$^2$/day based on the flux chamber measurements.

## 4.3 Methane Emission Rates

The recorded SMC data derived from the first round of surface scan at Hartland Landfill ranged between 0 and 2,167 volumetric parts per million (ppmv) with the majority of high hits (methane emissions hotspots) in areas previously shown on Figure 4.1. The rock wall area showed significantly higher emission rates than all other areas scanned, with SMC values as high as approximately 167,000 ppmv. Further analysis of the results showed significant variation in the level of emission rates from different areas of the Landfill, with the rock wall area being responsible for approximately 18% of the overall GHG emissions from the site during the first round of sampling. Application of a clay plug in this area reduced the maximum SMC value to less than 10,000 ppmv during the follow up measurements in October, however, significant increase in SMC values were observed in western sections of S14 area in this round.

Other areas with relatively high total emissions (i.e. emission rate multiplied by area) identified during the first sampling round were S2, S4, S7, C2, and S19. After completing this round of measurements, the scanned areas were grouped into five (5) categories based on the MER associated with each area. Group 1 (coloured green) with MER less than 2.5 g/m$^2$/day, Group 2 (blue) with MER between 2.5 and 5.0 g/m$^2$/day, Group 3 (yellow) with MER between 5.0 and 10

$g/m^2/day$, Group 4 (orang), with MER between 10 and 15 $g/m^2/day$, and Group 5 (red) with MER higher than 15 $g/m^2/day$.

Detailed assessment of the results indicated that majority the overall emissions were sourced from small portions of the scanned areas, mainly located at the unclosed (active) cell of the landfill (Cell 3). While higher gas emissions from active phases of the landfill are inevitable, identification of major emission hotspots and application of geo-targeted mitigation measures can have a significant impact on further reduction of the overall GHG emissions from the landfill. Figure 4.4 illustrates average $CH_4$ emission rates from each zone. Figure 4.5 shows different scanned areas colour coded based on the associated average MER from each area in first round of surface scan.

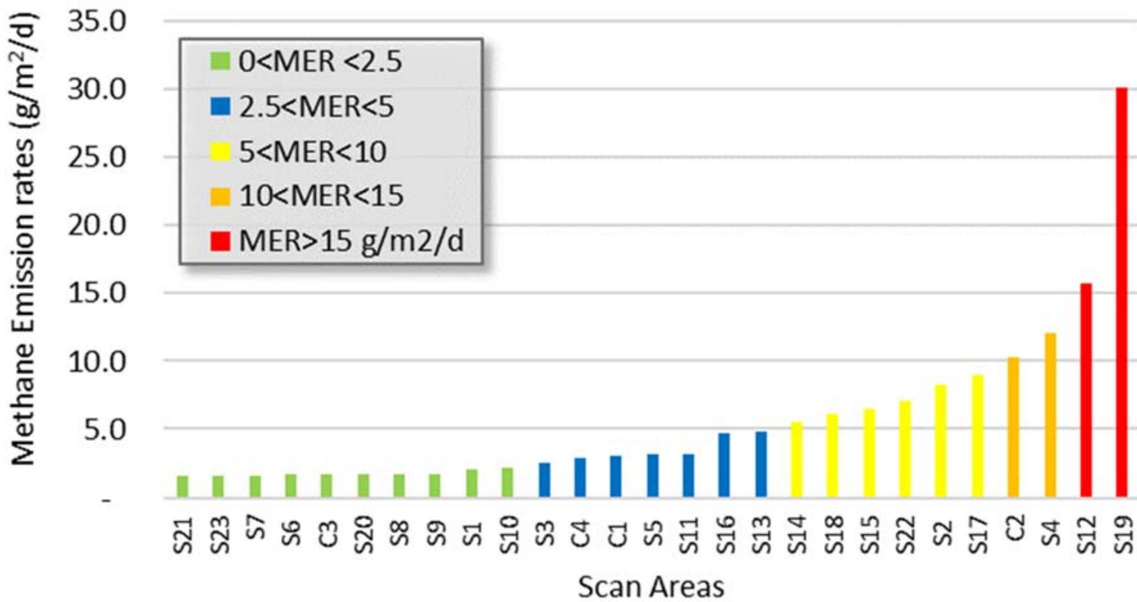


**Figure 4.4 - Average Methane Emission Rates (MER), Hartland Landfill June 2020**

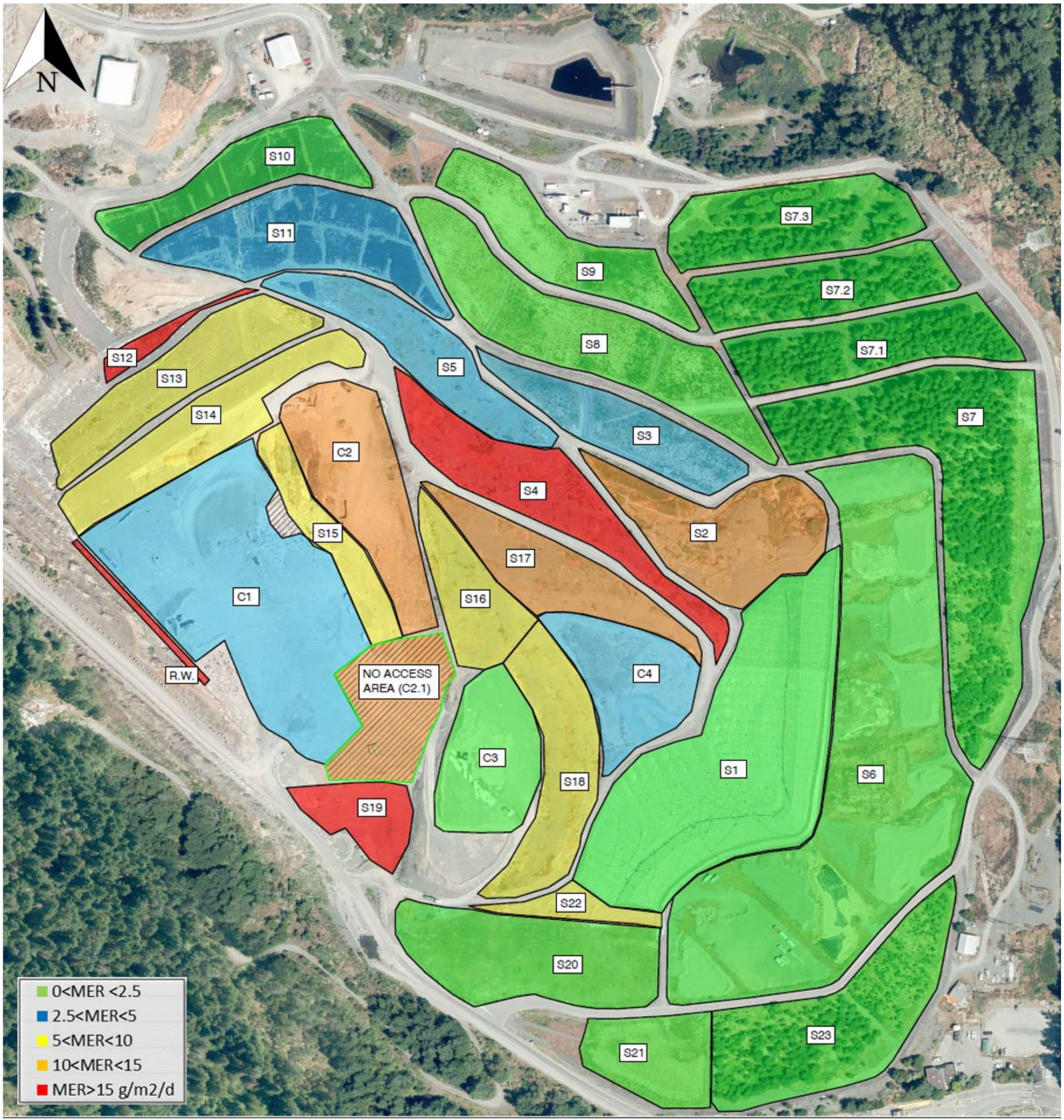


**Figure 4.5 - Grouping the Scan Areas Based on Average Methane Emission Rates**

Based on the default correlation factor, the SMC data was translated to average MER values ranging between 1.6 g $CH_4/m^2/d$ (Area S.21) and 30.1 g $CH_4/m^2/d$ (Area S.19) in the first round. These values in the second round ranged between 1.6 g $CH_4/m^2/d$ (Area S.8) and 34.6 g $CH_4/m^2/d$ (Area S.14). Average MER from the Rock Wall area for Rounds 1 and 2 were 480.6 g $CH_4/m^2/d$ and 190.7 g $CH_4/m^2/d$, respectively. The overall MER for the Hartland landfill for 2020 was calculated to be 17.6 g $CH_4/m^2/d$.

Table 4.1 below presents the results for SMC and MER values for both rounds as well as the site's overall average MER for 2020.

**Table 4.1 - Results of Surface Scan and Methane Emission Quantification for Hartland Landfill**

| Grid Number | Surface Area | | Surface Methane Concentration (SMC, ppm) | | | | | | Methane Emission Rate (MER, $gCH_4/m^2/day$) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Round 1 | Round 2 | Round 1 | | | Round 2 | | | Round 1 | | Round 2 | | 2020 |
| | ($m^2$) | ($m^2$) | MIN | MAX | AVG. | MIN | MAX | AVG. | AVG. | $\pm\delta_{MER}$ | AVG. | $\pm\delta_{MER}$ | Average |
| S1 | 22,600 | 22,600 | 0.7 | 129.4 | 2.3 | - | 1,536.7 | 7.2 | 2.13 | 0.8 | 3.70 | 1.0 | 2.9 |
| S2 | 9,400 | 9,400 | 1.4 | 644.7 | 21.6 | 0.4 | 240.7 | 9.6 | 8.29 | 1.5 | 4.46 | 1.1 | 6.4 |
| S3 | 6,700 | 6,700 | 1.5 | 23.9 | 3.8 | 1.3 | 3.4 | 1.5 | 2.62 | 0.9 | 1.87 | 0.8 | 2.2 |
| S4 | 8,500 | 5,000 | 1.5 | 2,167.0 | 33.2 | 0.3 | 3,017.1 | 43.8 | 12.01 | 1.9 | 15.39 | 2.2 | 13.7 |
| S4.1 | -- | 5,000 | -- | -- | -- | 0.3 | 17.2 | 2.0 | -- | -- | 2.03 | 0.8 | 2.0 |
| S5 | 6,700 | 6,600 | 1.4 | 82.6 | 5.4 | 0.3 | 117.2 | 3.4 | 3.13 | 0.9 | 2.49 | 0.9 | 2.8 |
| S6 | 36,000 | 36,000 | 0.6 | 2.1 | 0.7 | 0.6 | 2.1 | 0.7 | 1.63 | 0.8 | 1.63 | 0.8 | 1.6 |
| S7 | 45,000 | 45,000 | 0.6 | 1.7 | 0.6 | 0.6 | 1.7 | 0.6 | 1.60 | 0.8 | 1.60 | 0.8 | 1.6 |
| S8 | 13,000 | 13,000 | 0.6 | 2.8 | 0.8 | 0.4 | 5.6 | 0.5 | 1.66 | 0.8 | 1.54 | 0.8 | 1.6 |
| S9 | 7,000 | 7,000 | 0.6 | 6.2 | 1.0 | 0.5 | 8.6 | 0.9 | 1.71 | 0.8 | 1.69 | 0.8 | 1.7 |
| S10 | 6,700 | 6,700 | 0.5 | 513.8 | 2.7 | 0.5 | 341.2 | 2.9 | 2.25 | 0.8 | 2.31 | 0.9 | 2.3 |
| S11 | 9,600 | 9,600 | 0.4 | 1,398.3 | 5.5 | 0.5 | 807.4 | 4.6 | 3.16 | 0.9 | 2.86 | 0.9 | 3.0 |
| S12 | 1,400 | 1,400 | 0.5 | 691.5 | 44.7 | 0.6 | 379.5 | 40.0 | 15.70 | 2.3 | 14.19 | 2.1 | 14.9 |
| S13 | 7,500 | 7,500 | 0.5 | 160.9 | 10.8 | 0.6 | 336.5 | 14.6 | 4.86 | 1.1 | 6.06 | 1.3 | 5.5 |
| S14 | 6,300 | 7,700 | 0.7 | 133.8 | 12.5 | - | 10,903.8 | 103.6 | 5.41 | 1.2 | 34.56 | 4.3 | 20.0 |
| S14R | 1,400 | -- | 0.8 | 135.5 | 13.3 | -- | -- | -- | 5.64 | 1.2 | -- | -- | 5.6 |
| S15 | 3,700 | -- | 0.5 | 211.3 | 16.0 | -- | -- | -- | 6.51 | 1.3 | -- | -- | 6.5 |
| S16 | 4,600 | 4,600 | 0.8 | 105.6 | 10.4 | 6.4 | 311.4 | 55.0 | 4.71 | 1.1 | 19.00 | 2.6 | 11.9 |
| S17 | 6,300 | 6,300 | 0.5 | 1,048.4 | 23.5 | 3.1 | 307.9 | 27.3 | 8.92 | 1.6 | 10.14 | 1.7 | 9.5 |
| S18 | 7,500 | 7,500 | 0.5 | 712.7 | 14.8 | 1.5 | 232.9 | 11.9 | 6.14 | 1.3 | 5.20 | 1.2 | 5.7 |
| S19 | 3,200 | 3,200 | 0.9 | 1,386.4 | 89.7 | 2.9 | 595.2 | 55.3 | 30.10 | 3.8 | 19.09 | 2.6 | 24.6 |
| S20 | 10,000 | 10,000 | 0.1 | 21.2 | 0.9 | 2.6 | 57.6 | 17.1 | 1.68 | 0.8 | 6.87 | 1.3 | 4.3 |
| S21 | 5,000 | 5,000 | 0.4 | 5.0 | 0.7 | 0.4 | 5.0 | 0.7 | 1.60 | 0.8 | 1.60 | 0.8 | 1.6 |
| S22 | 1,700 | 1,700 | 0.9 | 264.5 | 17.7 | 7.6 | 745.7 | 42.2 | 7.05 | 1.4 | 14.88 | 2.2 | 11.0 |
| S23 | 12,000 | 12,000 | 0.6 | 1.6 | 0.7 | 0.6 | 1.6 | 0.7 | 1.62 | 0.8 | 1.62 | 0.8 | 1.6 |
| C1 | 22,000 | 24,000 | 0.5 | 122.9 | 5.2 | - | 1,230.5 | 49.5 | 3.05 | 0.9 | 17.23 | 2.4 | 10.1 |
| C2 | 15,000 | 16,000 | 0.5 | 1,392.4 | 27.7 | 2.6 | 638.4 | 42.3 | 10.24 | 1.7 | 14.91 | 2.2 | 12.6 |
| C3 | 6,700 | 6,500 | 0.5 | 8.5 | 0.9 | 0.5 | 8.5 | 0.9 | 1.68 | 0.8 | 1.68 | 0.8 | 1.7 |
| C4 | 6,500 | 6,700 | 0.5 | 45.6 | 4.7 | 0.9 | 50.4 | 7.0 | 2.90 | 0.9 | 3.62 | 1.0 | 3.3 |
| Rock Wall | 500 | 500 | - | 167,456.1 | 1,497.4 | - | 9,980.6 | 591.5 | 480.57 | 51.7 | 190.66 | 20.9 | 335.6 |
| **Average** | | | | | **64.5** | | | **40.6** | **22.0** | ± **2.9** | **14.4** | ± **2.1** | **17.6** |

**S4.1** includes a newly developed slope in north east of C2 area (developed in Aug.- Sep. 2020) and partially overlapping with S4 area
**S14R** includes a smal portion of S14 area that was scanned separatly during round 1 due to instrument reaching memory capacity
**$\pm\delta_{MER}$** values represent range of error of the linear regression developed by Abedini, 2014 determined for 95% confidence limit

| x.x | Data acquired from 1st round of the field work |
|---|---|

Excluding the fugitive $CH_4$ emissions from the rock wall area, Hartland Landfill's average methane emission rate is as low as 6.6 g $CH_4/m^2/d$.

The methane emission rate from the rock wall area was significantly reduced during the second round of field measurement. This reduction was primarily caused by blocking of the methane escape pathway using clay plug and a lift of waste placed over the area between August and October 2020. However, the second round of surface scanning showed higher methane emission rates from slopes just north of the rock wall area (S14). SHA in close collaboration with the CRD engineering team designed a gas emission mitigation system (horizontal gas collector) that will be constructed in the near future.

Round 1 of field measurements, completed in June 2020, showed a total annual $CH_4$ emission rate of 757 ± 179 tonnes of $CH_4$ per year with approximately 50% of the emissions occurring in the unclosed portion of the landfill (Cell #3). The second round that was completed in October of the same year showed an annual $CH_4$ emission rate of 1,069 ± 212 tonnes of $CH_4$ per year with Cell #3 being responsible for 59% of the site's overall emissions. As shown in Table 4.2, these values are equivalent to an average LFG emission rates of 150 scfm and 212 scfm for the first and second round of sampling, respectively.

The site's overall average annual methane emission rate was determined to be 925 tonnes of $CH_4$ per year, equivalent to an LFG emission rate of 183 scfm at 50% methane content. The overall methane emission rate quantified in October was higher than the first round measured in June. Possible reasons for this increase may include (i) seasonal variation in methane emission, (ii) lower oxidation rate of the fugitive methane through the cover soil during colder seasonal temperatures, and (iii) increased gas generation from the active fill area (Cell #3) while no new horizontal gas collectors were brought online between June and October 2020.

Table 4.2 summarizes the annual methane and LFG emission rates for different areas of the landfill and the site's overall average based on the two rounds of GHG measurements completed in June and October of 2020.

**Table 4.2 - Methane and LFG Emission Rates from Different Areas of Hartland Landfill**

| Grid Number | Surface Area | | Annual Methane Emissions (tonnes $CH_4$/year) | | | | | LFG Emission Rates (scfm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Round 1 | Round 2 | Round 1 | | Round 2 | | 2020 | Round 1 | | Round 2 | | 2020 |
| | ($m^2$) | ($m^2$) | AVG. | $\pm\delta_E$ | AVG. | $\pm\delta_E$ | Average | AVG. | $\pm\delta_{LFG}$ | AVG. | $\pm\delta_{LFG}$ | Average |
| **S1** | 22,600 | 22,600 | 26.62 | 10.4 | 46.25 | 12.5 | 36.4 | 5.28 | 2.1 | 9.17 | 2.5 | 7.2 |
| **S2** | 9,400 | 9,400 | 43.08 | 7.7 | 23.17 | 5.6 | 33.1 | 8.55 | 1.5 | 4.59 | 1.1 | 6.6 |
| **S3** | 6,700 | 6,700 | 9.70 | 3.3 | 6.92 | 3.0 | 8.3 | 1.92 | 0.7 | 1.37 | 0.6 | 1.6 |
| **S4** | 8,500 | 5,000 | 56.47 | 8.9 | 42.57 | 6.2 | 49.5 | 11.20 | 1.8 | 8.44 | 1.2 | 9.8 |
| **S4.1** | -- | 5,000 | - | - | 5.61 | 2.3 | 5.6 | - | - | 1.11 | 0.5 | 1.1 |
| **S5** | 6,700 | 6,600 | 11.60 | 3.5 | 9.10 | 3.2 | 10.3 | 2.30 | 0.7 | 1.80 | 0.6 | 2.1 |
| **S6** | 36,000 | 36,000 | 32.37 | 15.5 | 32.37 | 15.5 | 32.4 | 6.42 | 3.1 | 6.42 | 3.1 | 6.4 |
| **S7** | 45,000 | 45,000 | 39.76 | 19.3 | 39.76 | 19.3 | 39.8 | 7.89 | 3.8 | 7.89 | 3.8 | 7.9 |
| **S8** | 13,000 | 13,000 | 11.92 | 5.6 | 11.11 | 5.5 | 11.5 | 2.36 | 1.1 | 2.20 | 1.1 | 2.3 |
| **S9** | 7,000 | 7,000 | 6.62 | 3.1 | 6.53 | 3.0 | 6.6 | 1.31 | 0.6 | 1.29 | 0.6 | 1.3 |
| **S10** | 6,700 | 6,700 | 8.32 | 3.1 | 8.55 | 3.2 | 8.4 | 1.65 | 0.6 | 1.70 | 0.6 | 1.7 |
| **S11** | 9,600 | 9,600 | 16.75 | 5.0 | 15.20 | 4.8 | 16.0 | 3.32 | 1.0 | 3.02 | 1.0 | 3.2 |
| **S12** | 1,400 | 1,400 | 12.15 | 1.8 | 10.98 | 1.6 | 11.6 | 2.41 | 0.3 | 2.18 | 0.3 | 2.3 |
| **S13** | 7,500 | 7,500 | 20.15 | 4.7 | 25.12 | 5.2 | 22.6 | 4.00 | 0.9 | 4.98 | 1.0 | 4.5 |
| **S14** | 6,300 | 7,700 | 18.83 | 4.1 | 147.15 | 18.2 | 83.0 | 3.74 | 0.8 | 29.19 | 3.6 | 16.5 |
| **S14R** | 1,400 | -- | 4.36 | 0.9 | - | - | 4.4 | 0.87 | 0.2 | - | - | 0.9 |
| **S15** | 3,700 | -- | 13.33 | 2.7 | - | - | 13.3 | 2.64 | 0.5 | - | - | 2.6 |
| **S16** | 4,600 | 4,600 | 11.99 | 2.8 | 48.34 | 6.7 | 30.2 | 2.38 | 0.6 | 9.59 | 1.3 | 6.0 |
| **S17** | 6,300 | 6,300 | 31.08 | 5.4 | 35.31 | 5.9 | 33.2 | 6.16 | 1.1 | 7.00 | 1.2 | 6.6 |
| **S18** | 7,500 | 7,500 | 25.47 | 5.2 | 21.55 | 4.8 | 23.5 | 5.05 | 1.0 | 4.27 | 1.0 | 4.7 |
| **S19** | 3,200 | 3,200 | 53.27 | 6.7 | 33.79 | 4.7 | 43.5 | 10.57 | 1.3 | 6.70 | 0.9 | 8.6 |
| **S20** | 10,000 | 10,000 | 9.31 | 4.3 | 38.01 | 7.4 | 23.7 | 1.85 | 0.9 | 7.54 | 1.5 | 4.7 |
| **S21** | 5,000 | 5,000 | 4.42 | 2.1 | 4.42 | 2.1 | 4.4 | 0.88 | 0.4 | 0.88 | 0.4 | 0.9 |
| **S22** | 1,700 | 1,700 | 6.63 | 1.3 | 13.99 | 2.1 | 10.3 | 1.31 | 0.3 | 2.78 | 0.4 | 2.0 |
| **S23** | 12,000 | 12,000 | 10.75 | 5.2 | 10.75 | 5.2 | 10.8 | 2.13 | 1.0 | 2.13 | 1.0 | 2.1 |
| **C1** | 22,000 | 24,000 | 37.17 | 11.3 | 228.67 | 32.4 | 132.9 | 7.37 | 2.2 | 45.36 | 6.4 | 26.4 |
| **C2** | 15,000 | 16,000 | 84.95 | 14.1 | 131.96 | 19.4 | 108.5 | 16.85 | 2.8 | 26.17 | 3.8 | 21.5 |
| **C3** | 6,700 | 6,500 | 6.23 | 2.9 | 6.04 | 2.8 | 6.1 | 1.24 | 0.6 | 1.20 | 0.6 | 1.2 |
| **C4** | 6,500 | 6,700 | 10.41 | 3.3 | 13.41 | 3.7 | 11.9 | 2.06 | 0.7 | 2.66 | 0.7 | 2.4 |
| **Rock Wall** | 500 | 500 | 132.88 | 14.3 | 52.72 | 5.8 | 92.8 | 26.36 | 2.8 | 10.46 | 1.1 | 18.4 |
| **Total** | **292,500** | **293,200** | **757** | **± 179** | **1,069** | **± 212** | **924.6** | **150** | **± 35** | **212** | **± 42** | **183.4** |

$\pm\delta_{MER}$ values represent range of error of the linear regression developed by Abedini, 2014 determined for 95% confidence limit

| | |
|---|---|
| x.x | Data acquired from 1st round of the field work |

## 4.4 Methane Mass Balance

### 4.4.1 Modelled Landfill Gas Generation

In 2019, the CRD retained SHA to conduct a comprehensive LFG generation assessment study for the landfill using three different models: (i) an advanced LFG generation model (UBCiModel©), (ii) ENV's LFG Generation Assessment Model (ENV Model), and (iii) ENV Annual Reporting Tool (ENV AR Tool).

The BC LFG Regulation requires that the LFG generation assessment reports be prepared in accordance with the LFG generation assessment procedure guidance (ENV Guidelines) using the ENV Model. ENV AR Tool, is another LFG generation estimation Tool which must be used for annual reporting to assess performance of existing active LFG systems and their methane capture efficiency. The only difference between the ENV Model and the ENV AR Tool is the historical waste disposal tonnages that are considered for gas generation modeling purposes. For the ENV model, historical waste tonnages should cover the period from the first year of landfill operations or thirty years before the year in which the gas generation assessment takes place, whichever is more recent. While for the ENV AR Tool, all waste tonnage data from 1980 to the calendar year prior to the year of assessment are taken into account, resulting in methane generation estimates being usually higher than with the ENV Model. UBCiModel© is a powerful gas generation model that utilizes numerous site-specific input parameters to estimate methane generation rates from the landfill more accurately. Based on a recent comprehensive review on existing gas generation models by Environment and Climate Change Canada (ECCC), the UBCiModel© was ranked among the most accurate models for LFG generation estimation (Jacobs 2020).

A summary of results from SHA, 2019 is provided in Table 4.3 below (SHA, 2019).

**Table 4.3 - LFG Generation Assessment Summary using 3 Models (SHA, 2019)**

| Model | Modelled Methane Generation 2019[1] tonnes $CH_4$/year (scfm LFG) | Modelled Methane Generation 2020[1] tonnes $CH_4$/year (scfm LFG) |
|---|---|---|
| UBCiModel | 6,872 (1,363) | 6,865 (1,362) |
| ENV Model | 6,889 (1,365) | 6,947 (1,376) |
| ENV AR Tool | 7,846 (1,554) | 7,866 (1,558) |

[1] - flows normalized to 50% v/v $CH_4$

Figure 4.6 illustrates a 25-year snapshot of LFG generation comparison between the three models as well as the landfill's LFG recovery data between 2000 and 2020.

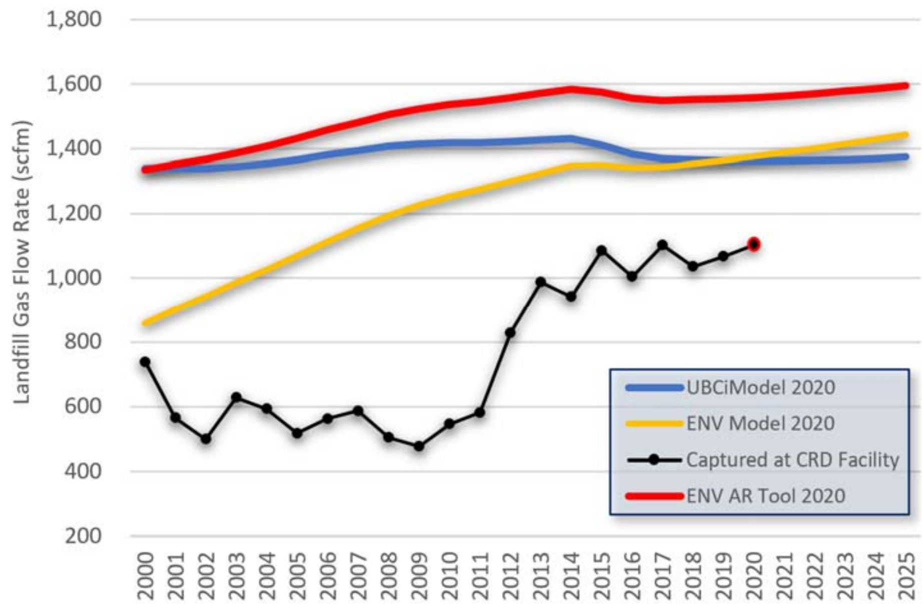


**Figure 4.6 - LFG Generation Estimates for Based on Different Models (2000-2025)**

Given the complexity of the UBCiModel and incorporation of site-specific information as well as the historical and planned organic diversion initiatives, SHA is of the opinion that the UBCiModel predictions provide a better representation of $CH_4$ generation at Hartland Landfill.

Figure 4.7 presents UBCiModel results for LFG generation compared to historical gas collection quantities that was reported by CRD, as well as SHA's estimates for LFG collection rates for landfill's anticipated lifespan including 25 years post closure.

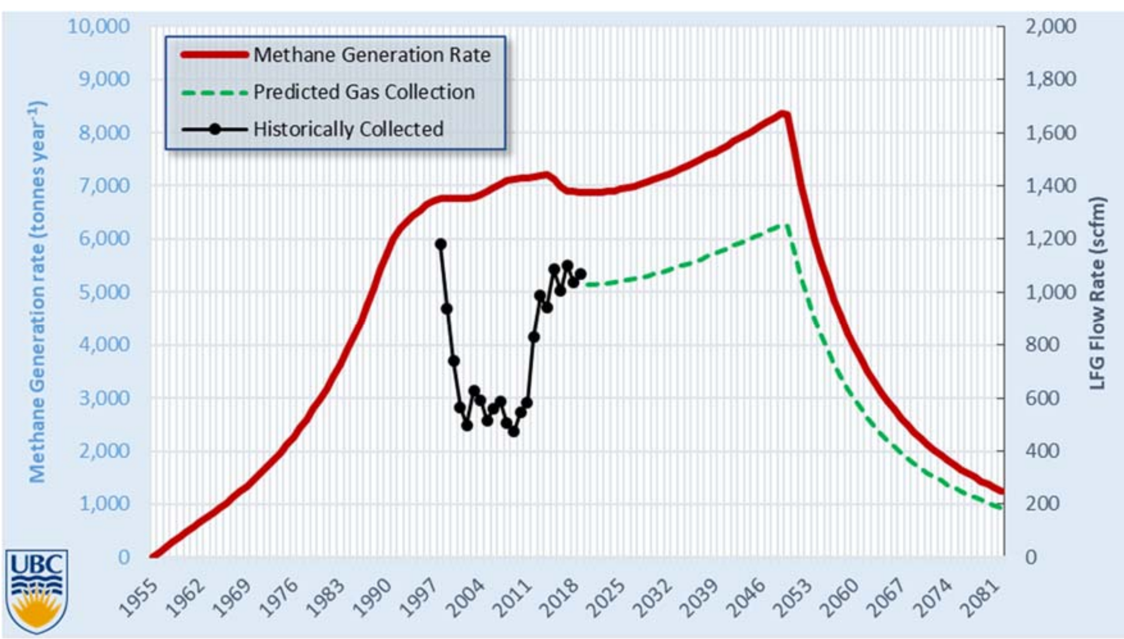


**Figure 4.7 - Predicted LFG Generation and Collection Rates at the Hartland Landfill**

### 4.4.2 Methane Collection Efficiency at Hartland Landfill

Based on the theoretical gas generation modeling and the historical landfill gas flow rate and methane content reported at the gas extraction facility, Table 4.4 below summarizes Hartland Landfill active LFG collection system's efficiency between 2014 and 2019 reported by the three models: UBCiModel©, ENV Model, and the ENV AR Tool.

**Table 4.4 - Hartland Landfill LFG System Capture Efficiency Based on three models**

| Year | Methane Capture Efficiency | | |
|---|---|---|---|
| | UBCiModel | ENV Model* | ENV AR Tool |
| 2014 | 66% | 64% | 59% |
| 2015 | 77% | 75% | 69% |
| 2016 | 73% | 71% | 64% |
| 2017 | 80% | 79% | 71% |
| 2018 | 76% | 75% | 67% |
| 2019 | 78% | 78% | 69% |

* Based on generation estimates made in the year following year of assessment

Based on the results achieved from the UBCiModel©, the current methane generation at Hartland Landfill was estimated to be 1,362 scfm, equivalent to 6,865 tonnes of $CH_4$ per year. Based on the average collected gas flow rate and the average $CH_4$ content previously presented in Table 3.1, the average collected LFG flow rate in June and October of 2020 at the landfill were 1,102 scfm and 1,105 scfm for June and October when normalized to 50% $CH_4$ content. Therefore, the landfill's active gas collection system's average collection efficiency based on the UBCiModel was estimated to be 81% during the field works.

The site investigation showed an average annual methane emission rate of 184 scfm. Therefore, based on results of the field investigations, SHA concluded that approximately 14% of the generated methane from Hartland Landfill is emitted to the atmosphere.

Figure 4.8 illustrates UBCiModel© gas generation estimates, historical gas collection data and gas emission results from the 2020 field investigations.

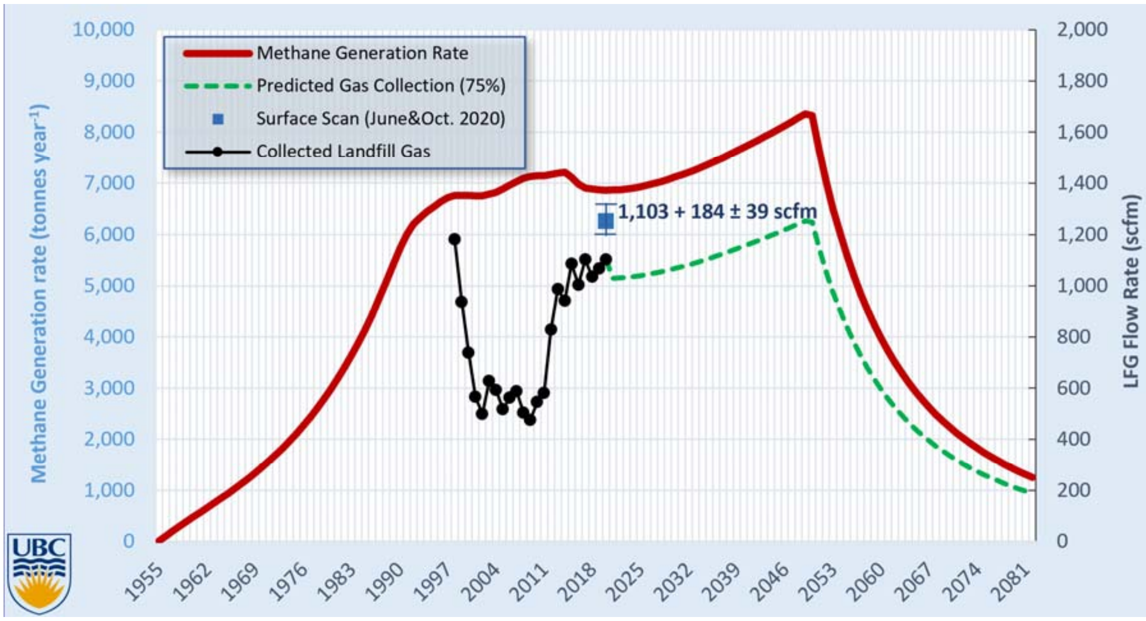


**Figure 4.8 - Landfill Gas Generation, Collection and Emission Rates at Hartland Landfill**

Comparing the $CH_4$ generation estimates for 2020 with the quantity of $CH_4$ collected and emitted this year, shows a difference in results. This value for UBCiModel, ENV Tool and ENV AR Tool was 6%, 7%, and 17% of modelled generated gas, respectively. This difference could be a result of model overestimation and/or the marginal error associated with Abedini's technique linear regression. Moreover, as suggested by the $CH_4$ mass balance METRO equation (described in Section 2), this quantity of "missing" $CH_4$ could be result of methane biological oxidation rates that can vary seasonally.

Table 4.5 shows the $CH_4$ mas balance for Hartland Landfill in 2020 based on the three gas generation models estimations and the two rounds of the fugitive methane emission measurements completed at this site.

**Table 4.5 - Methane Mass Balance at Hartland Landfill in 2020**

| | Modelled LFG Generation Rate | Average LFG Collection Rate | | Average LFG Emission Rate | | Measured LFG (Collected + Emitted) | Difference Between Modelled and Measured Data | |
|---|---|---|---|---|---|---|---|---|
| | (scfm) | (scfm) | % | (scfm) | % | (scfm) | (scfm) | % |
| UBCiModel | 1,362 | 1,103 | 81% | 183 | 13% | 1,287 | 75 | 6% |
| ENV Tool | 1,376 | 1,103 | 80% | 183 | 13% | 1,287 | 90 | 7% |
| ENV AR Tool | 1,558 | 1,103 | 71% | 183 | 12% | 1,287 | 272 | 17% |

## 4.5 Biological Oxidation of Methane

Methane is a potent GHG with a global warming potential (GWP) of 28 to 36 times higher than $CO_2$ in a 100-year timeframe. Therefore, management of LFG and reducing methane emissions from MSW landfills through collection and thermal combustion of methane has become a requirement in many jurisdictions. Another effective method to control $CH_4$ emissions from landfills is biological oxidation. Biological oxidation of methane in landfill cover soil is historically acknowledged by a number of regulatory agencies such as ENV, U.S. Environmental Protection Agency (US EPA), and the International Panel on Climate Change (IPCC).

While landfill cover can be designed to maximize oxidation of $CH_4$ by promoting the growth of methanotrophic bacteria, most regulatory agencies adopted a default value of 10% oxidation rate for any type of soil cover. USEPA (2004) reported an average $CH_4$ oxidation rate (removal efficiency) of 10% to 25% with lower rates for clay cover soil and higher rates for topsoil. However, there are a number of published and peer reviewed scientific research papers that have reported $CH_4$ oxidation rates of 22% to 55% through operational soil cover (Whalen et al., 1990; Chanton et al., 2009; Chanton et al., 2011, Abedini et al. 2016). Abedini et al. (2016) conducted comprehensive investigations and analyses at Vancouver Landfill using stable isotope technique and showed approximately 30% baseline oxidation occurring within cover soils at this site.

Given the site conditions we are of the opinion that the majority of the remaining $CH_4$ mass is biologically oxidized in the landfill soil cover by naturally existing methanotrophic bacteria. The second round of $CH_4$ emissions quantification in October 2020 showed slightly higher emission rates when compared with the rates quantified in June. This could be a result of lower ambient temperature in October slowing down the shallow seated methanotrophic bacteria. Therefore, based on the UBCiModel's $CH_4$ generation estimates, we calculated the total quantity of oxidized $CH_4$ is approximately 29% of the uncollected $CH_4$ travelling through the soil cover in certain areas of the landfill.

Table 4.6 and Figure 4.9 summarize the $CH_4$ mass balance for Hartland Landfill as per the 2020 two rounds of field investigations.

**Table 4.6 - Methane Mass Balance Summary**

| | LFG (scfm) | Methane (tonnes/year) | % of Total LFG Generated | % of LFG Not Collected |
|---|---|---|---|---|
| Gas Generation (Model, 2020) | 1,362 | 6,865 | 100% | -- |
| Average Collection rate | 1,103 | 5,554 | 81% | -- |
| Uncollected Gas | 259 | 1,311 | 19% | -- |
| Average Emission Rate | 184 | 935 | 14% | 71% |
| Balance (Oxidized) | 75 | 376 | 5% | 29% |

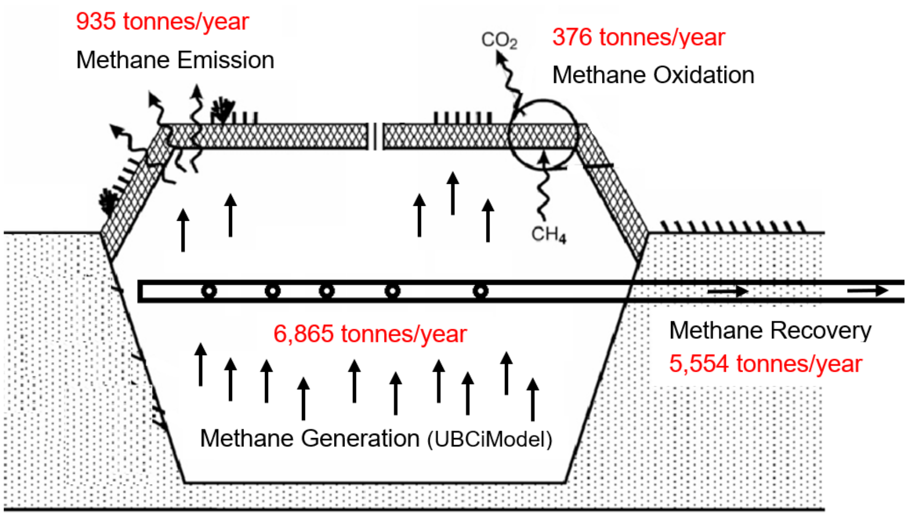


**Figure 4.9 - Hartland Landfill Methane Mass Balance Schematic (2020 Average)**

Figure 4.10 illustrates methane generation and collection data between 2010 and 2030, as well as estimated $CH_4$ emissions and oxidation based on the 2020 field investigations.

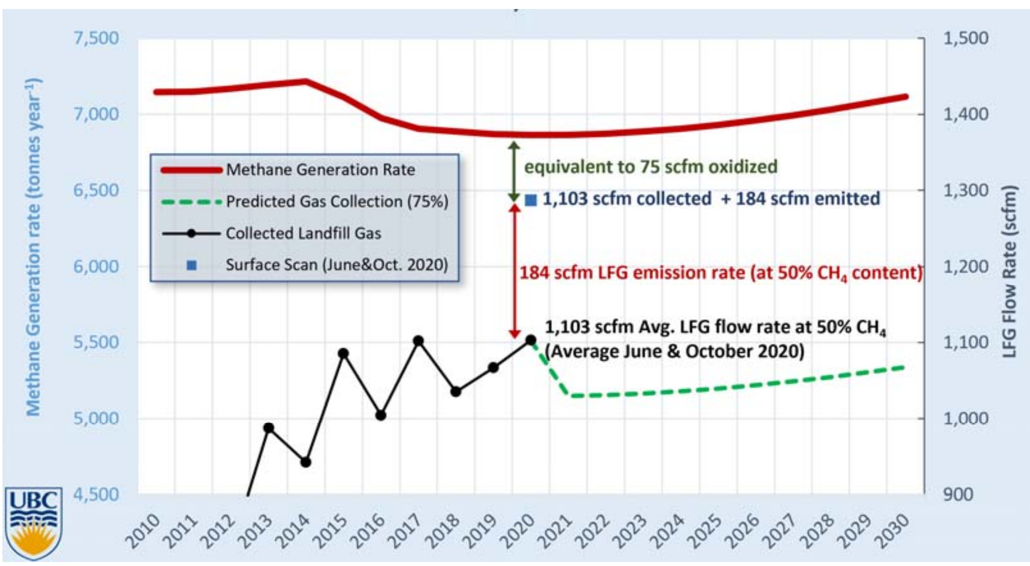


**Figure 4.10 - Illustration of Methane Mass Balance for Hartland Landfill based on 2020 field works**

We anticipate that there is a relatively high seasonal variation in methane oxidation levels in the landfill's soil cover as the media (soil cover) is not engineered to optimize methanotrophic activities. Landfill cover can be designed to maximize $CH_4$ oxidation by promoting the growth of methanotrophic bacteria. Type I and Type II methanotrophs are the primary bacterial populations that utilize $CH_4$ as their source of energy and carbon and convert it to $CO_2$, water and heat. Techniques such as bacterial DNA extraction and stable isotope technique can be used to study methanotrophic abundance and their effectiveness in methane oxidation.

Currently, there are no approved methodologies for assessment of these system's efficiencies in Canada. As a practical approach, SHA has utilized the surface scan technique to measure baseline and post-installation methane emission rates and has successfully quantified several biocover system methane removal efficiencies across BC.

Taking into account the extremely low level of $CH_4$ emission rates at Hartland Landfill (i.e. 6.6 g $CH_4/m^2/day$ excluding the rock wall area), SHA believes that application of a fabricated biocover system on closed surfaces and operational phases of the landfill, in addition to an LFG collection system for the rock wall area, would result in the landfill becoming a near-zero emission facility. General recommendations for fabrication of an optimized biocover system are provided in enclosed Appendix A.

# 5 CONCLUSIONS AND RECOMMENDATIONS

The CRD retained SHA to conduct a full-scale GHG emissions quantification for Hartland Landfill. Site investigations were completed in two rounds of surface emission monitoring in June and October of 2020. Surface emission monitoring includes measurement of near surface methane concentrations which is a standardized methodology in the United States (US) required to assess effectiveness of active gas collection systems in regulated landfills (Reference: California Code of Regulations [CCR] Title 17 Article 4, Sub-article 6, or similarly in the US EPA regulations; 40 Code of Federal Regulations [CFR] Part 60 Subpart XXX).

Quantification of GHG emissions from Hartland Landfill was completed using the surface scan results and a patented technique developed by Dr. Abedini. In this technique, $CH_4$ emission rates are quantified based on landfill's surface methane concentrations and the rate of change in barometric pressure at the time of surface scanning.

Field investigations and data analyses showed that Hartland Landfill is currently emitting 925 tonnes of $CH_4$ per year, equivalent to 184 scfm of LFG at 50% $CH_4$ content. Therefore, the maximum rate of GHG emissions from Hartland Landfill is estimated to be approximately 23,000 tonnes of $CO_2$-e per year, which accounts for 14% of the generated gas from the landfill. SHA estimated that about 29% of the uncollected $CH_4$ is biologically oxidized by naturally existing methanotrophic bacteria within the soil covers of the landfill. The current methane biological oxidation rate has a significant seasonal variation due to climatic conditions, however; application of an engineered biocover system can maximize the removal efficacy of the fugitive $CH_4$ through biological oxidation.

Hartland Landfill has an active gas collection system that currently collects more than 1,100 scfm of the generated LFG, equivalent to 5,500 tonnes of $CH_4$ per year. Our previous assessments have shown that the site's active LFG system is effectively collecting the generated gas with an approximate capture efficiency of 76% to 80% over the past 3 years. Results of the current GHG emission quantification study confirmed that $CH_4$ emission rates at this facility are lower than what is known as industry best engineering practices, indicating a high collection efficiency of the active gas collection system at this site. To our knowledge, this is the highest gas collection efficiency currently achieved in BC. Furthermore, completing a methane mass balance during the two field measurement events showed that UBCiModel©, as a site-specific model, better represents $CH_4$ generation at Hartland Landfill. We highly recommend that any future feasibility studies and engineering designs for gas collection and/or gas to energy initiatives to be based on more sophisticated models such as UBCiModel©.

Based on our detailed analyses of the field data, we concluded that the majority of the overall $CH_4$ emissions from Hartland Landfill are sourced from the Cell 3 area which is the only area with no permanent or temporary impermeable cap in place. We identified $CH_4$ emission hotspots such as exposed geomembrane liner punctures and tears, edges of geomembrane liner, side slopes of the current filling area and the exposed leachate drainage layer on west of Cell 3 area (rock wall). The level of emissions from north and south slopes of Cell 3 area will be significantly reduced as soon as the recently-installed horizontal gas collectors (lift 167m) in this area are brought online. The rock wall area (located at west of the Cell 3) was identified to be responsible for more than 18% of the site's overall GHG emissions in June 2020. This area was capped later in the summer with an impermeable clay layer and a lift of compacted waste. SHA designed a methane emission mitigation system for this area that will be constructed soon at lift 171m.

Even though the level of GHG emissions from the landfill is well below industry standards and regulatory requirements, additional GHG emission reductions can be achieved at the landfill through application of an engineered biocover system on the closed portions of the landfill, areas such as edges of the geomembrane closure system and areas with no impermeable cap that will not receive new lifts of waste within one year.

Currently, there are no regulations in place in Canada that would encourage application of biological methods to reduce the provincial and/or federal GHG emissions footprint from landfills, nor are there approved methodologies for assessment of these system's efficiencies. Nevertheless, SHA has been using best engineering practices in application of the biocover technology to reduce GHG emissions at a number of smaller landfill sites in BC. We have successfully quantified these biocover methane removal efficiencies through utilization of the surface scan technique.

## 6 STATEMENT OF LIMITATIONS

This report has been prepared by Sperling Hansen Associates (SHA) on behalf of the Capital Regional District in accordance with generally accepted engineering practices to a level of care and skill normally exercised by other members of the engineering and science professions currently practicing under similar conditions in British Columbia, subject to the time limits and financial and physical constraints applicable to the services. The report, which specifically includes all tables and figures, is based on engineering analysis by SHA staff of data compiled during the course of the project. Except where specifically stated to the contrary, the information on which this study is based has been obtained from external sources. This external information has not been independently verified or otherwise examined by Sperling Hansen Associates to determine its accuracy and completeness. Sperling Hansen Associates has relied in good faith on this information and does not accept responsibility of any deficiency, misstatements or inaccuracies contained in the reports as a result of omissions, misinterpretation and/or fraudulent acts of the persons interviewed or contacted, or errors or omissions in the reviewed documentation.

The report is intended solely for the use of the Capital Regional District. Any use which a third party makes of this report, or any reliance on, or decisions to be made based on it, are the responsibilities of such third parties. Sperling Hansen Associates does not accept any responsibility for other uses of the material contained herein nor for damages, if any, suffered by any third party because of decisions made or actions based on this report. Copying of this intellectual property for other purposes is not permitted.

The findings and conclusions of this report are valid only as of the date of this report. The interpretations presented in this report and the conclusions and recommendations that are drawn are based on information that was made available to Sperling Hansen Associates during the course of this project. Should additional new data become available in the future, Sperling Hansen Associates should be requested to re-evaluate the findings of this report and modify the conclusions and recommendations drawn, as required.

Yours truly,
**SPERLING HANSEN ASSOCIATES**

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# Appendix A

## Biocover Design Recommendations

# Biocover Design

Biocover feedstocks may consist of compost, compost and sand or a combination of biosolids, wood chips and sand. The high initial ammonium nitrogen content of fresh biosolids has the potential to negatively impact methanotrophy; however, the effect is short lived and the biocover is designed to assimilate this form of nitrogen to facilitate optimum $CH_4$ consumption. Alternatively, an older source of biosolids or compost can be used. Another alternative is to apply the biocover and allow it to stabilize over time. Under this scenario the biocover will not function optimally until stabilization has occurred. Based on recent research this delay can range from two weeks to a month under laboratory conditions.

**Favorable Conditions for Biocover Performance**

Recently, several approaches have been investigated in industry to exploit the powerful oxidizing ability of methanotrophic bacteria (methanotrophs) and potential uses in industrial processes. Methane reduction in biocover is also accomplished by methanotrophs that utilize methane monooxygenase (MMO) enzyme to oxidize $CH_4$ as a source of energy and carbon. Products of $CH_4$ oxidation are water, carbon dioxide, biomass and heat. Physical and chemical characteristics of the biocover influence the growth and performance of methanotrophs. These include temperature, moisture, organic matter content, carbon to nitrogen ratio (C:N), porosity, structure, and pH.

**Temperature** – The optimal temperature range for $CH_4$ oxidation by methanotrophic bacteria is 15 – 35 °C. Oxidation slows at cooler temperatures, although cold tolerant oxidizers show activity at temperatures as low as 2 – 5 °C (Abedini *et al.*, 2016) and above 40 °C. Oxidation stops at 50 °C (Chris A. Zeiss, 2006).

To optimize the methanotrophic activity in relation to temperature, a key factor to be considered is the depth of the biocover. Biocovers with design depths of 300mm to 600mm are proven to be more effective in methane removal than shallower biocovers. While deep sections of the biocover profile may lack methanotrophic activity due to a lack of oxygen, the mid-sections of the biocover do not experience the severe drop in ambient temperature experienced at surface and are, therefore, capable of hosting and nourishing different types of methanotrophs, and particularly Type 1 methanotrophs. In other words, from a temperature control or cold weather impact perspective, optimization of the biocover performance is achievable through adjusting the depth of a biocover.

**Moisture content** – Moisture in the soil facilitates the transfer of gases allowing $CH_4$ and $O_2$ to reach the methanotrophic bacteria and $CO_2$ to diffuse away. The optimum soil moisture concentration varies for different soils but is in the range of 10 – 30 % although $CH_4$ oxidation can occur in a wider moisture range of 8 – 50 % (Chris A. Zeiss, 2006). Another work suggests that the moisture content should be at least 5 % (Hettiaratchi *et al*., 2007).

**Organic matter** – In general an increase in $CH_4$ oxidation is directly related to an increase in soil organic matter content. Moderate oxidation rates have been demonstrated in soils with an organic matter content of 1 – 10%; soils with an organic matter content of up to 35% show an increased oxidation rate of 10 to 100 times more effective (Chris A. Zeiss, 2006).

It is also important to note that the optimum levels of organic matter and moisture content at which the maximum $CH_4$ oxidation rate ($V_{max}$) is expected are directly related. Figure A.1 below illustrates relation of optimum moisture content to optimum organic matter (Pokhrel et al., 2016).

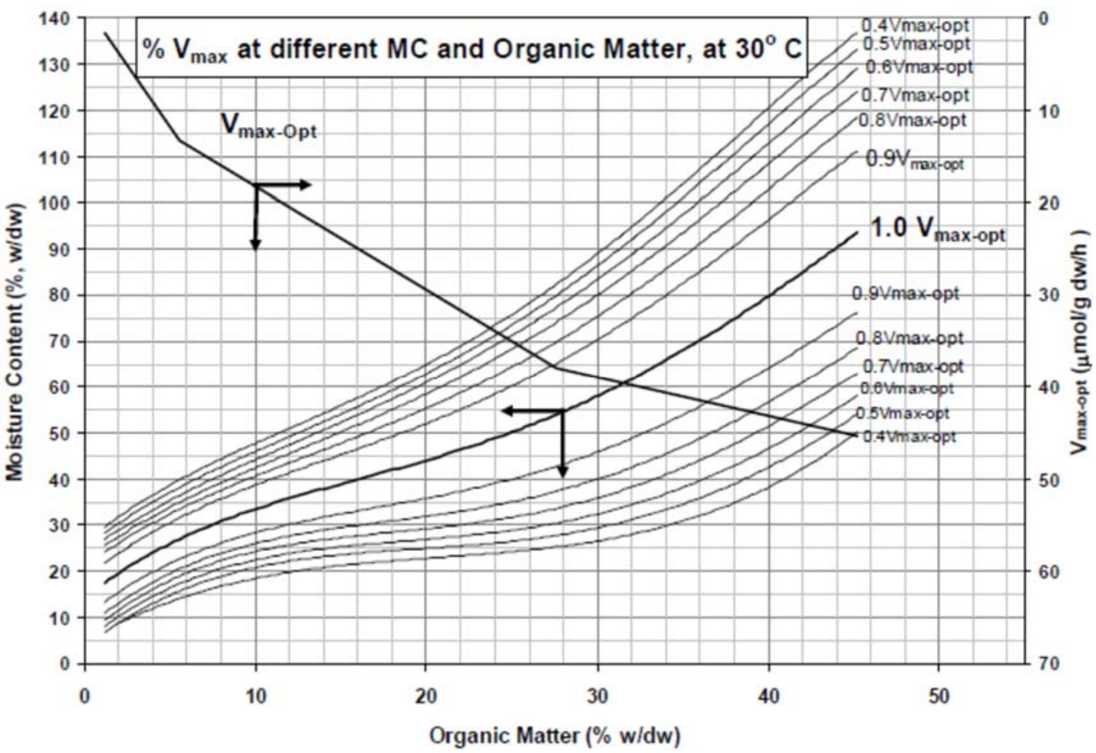


**Figure A.1 - Maximum methane oxidation (Vmax) at different Moisture and Organic Content**

**Carbon to nitrogen ratio (C:N)** – The C:N of the biocover is important as nitrogen, specifically ammonia, can inhibit performance. If the C:N ratio of the soil is lower than 12 the concentration of ammonia can inhibit $CH_4$ oxidation. At C:N ratios of 25 – 97 forms of nitrogen as ammonia are low (Chris A. Zeiss, 2006).

**Porosity and structure** – The ability of oxygen ($O_2$) to enter and move through the soil is vital for $CH_4$ oxidation thus a high porosity (the ratio of the volume of voids to the total volume of the media) is required in the biocover. Increases in bulk density of the medium lead to decreases in porosity and consequently might affect the gas permeability of the biocover. Additionally, the biocover should be structurally stable with minimal settling (Abichou *et a*l, 2004). On the other hand, too porous media allows free movement of gas, not allowing enough retention time for methane within the biocover media. Based on SHA's experience, optimum porosity for biocovers also depends on precipitation levels in the area. Porosities close to coarse sand is usually recommended as minimum value for biocover.

**pH** – Methanotrophs are neutrophilic with an optimal pH range of 6.5 to 8.0. Methane oxidation can occur to a maximum pH range of 8.5 – 9.0. Specific methanotroph species are tolerant of lower pH values down to a pH of 3.0 (Chris A. Zeiss, 2006).

In summary, SHA recommends the following properties to be taken into account for fabrication of a biocover system for the Hartland Landfill.

- moisture: 10 – 30 %, not less than 5%
- organic matter: increasing concentrations up to 35%
- C:N: 25 – 97, not less than 12
- porosity: high (not less than coarse sand porosity)
- pH: 6.5 – 8.0
- thickness of 400mm to 600mm

Once the available feedstock for fabrication of the media is known, lab test on each material shall be conducted and an optimized blend designed.