Non-Confidential Final Report

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Project Title: Biocovers for Greenhouse Gas Mitigation from Landfills – Demonstration Project

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Executive Summary

In a landfill, waste undergoes anaerobic degradation, producing landfill gas (LFG) that consists mostly of methane (CH_4) and carbon dioxide (CO_2). LFG escapes to the atmosphere through the landfill cover or through gas collection pipe networks that emit LFG at point sources. Sometimes these point sources are flared or used to generate energy.

In 2017, GHG emissions from the waste sector were estimated to contribute 19 megatonnes (MT) of CO_2 equivalent (CO_2e) in Canada (Environment and Climate Change Canada, 2019). Within the waste sector, 79% of GHG emissions are attributable to CH_4 emissions from municipal solid waste (MSW) landfills (Environment and Climate Change Canada, 2019).

The project demonstrated the effectiveness of Evapotranspirative-Landfill Biocover (ETLBC) technology in Alberta, which is a hybrid of landfill biocover (LBC) technology to mitigate fugitive methane emissions from landfills, and evapotranspiration (ET) as an alternative to the traditional approach of using low permeable barrier (clay) covers.

In an ETLBC, evapotranspiration (ET) component is utilized to prevent infiltration of precipitation into underlying waste. As opposed to a conventional clay cover system, which limits infiltration through acting as a low hydraulic conductivity barrier to water, ET covers store water within their soil matrix before slowly releasing it over time through evaporation and transpiration from vegetation. In order to install an ET cover system in Alberta authorization for an alternative to the prescribed clay cover system is required. The project initially received Alberta Environment and Parks (AEP) approval for a pilot demonstration project at the Leduc & District Waste Management Facility, to construct an ET cover system to demonstrate its effectiveness within the Alberta climate.

Based on the results of the pilot scale project, an application for authorization for an alternative cover system was approved by AEP for full scale implementation at the Leduc & District Waste Management Facility. Although a full-scale demonstration project was not completed, based on the modelling exercises performed and in-situ sensor data available, it was concluded that an ET cover system will perform as well, or better, than the prescribed clay cover system for the final closure of the Phase II municipal waste landfill in Leduc.

Although not required for the authorization of an alternative cover system the pilot project was also utilized to demonstrate the effectiveness of methane oxidation in the Alberta climate. In terms of the biocover the pilot demonstration project reported as high as 93% CH_4 methane oxidation efficiency through the ETLBC system.

The development of a quantification protocol for GHG reduction credits through implementation of a landfill biocover was initiated and is ongoing, and the demonstration of a large-scale ETLBC in two other Alberta landfills are also under conceptual design phase. These two landfills have had early engagement with AEP to confirm acceptance of a proposed ETLBC system and confirm the authorization process.

1 Project Description

1.1 Introduction and Background

Landfill biocover (LBC) projects can significantly reduce greenhouse gas (GHG) emissions while providing robust cover systems for municipal solid waste (MSW) landfill cells. LBC systems reduce overall GHG emissions from landfills by converting the methane (CH_4) in fugitive landfill gas (LFG) to biogenic carbon dioxide (CO_2) via microbially mediated oxidation.

In a landfill environment, organic waste undergoes anaerobic decomposition, producing LFG that is comprised primarily of CH_4 and CO_2 at approximately 50% each (volume basis). Without intervention, LFG generated by the decomposing waste escapes into the atmosphere through a landfill final cover system. Thus, landfill sites are known sources of GHG emissions with CH_4 representing a potent GHG that has a global warming potential (GWP) 25 times greater than CO_2 (Government of Canada, 2019).

In 2017, GHG emissions from the waste sector were estimated to contribute 19 megatonnes (MT) of CO_2 equivalent (CO_2e) in Canada (Environment and Climate Change Canada, 2019). Within the waste sector, 79% of GHG emissions are attributable to CH_4 emissions from MSW landfills (Environment and Climate Change Canada, 2019).

LBC systems present an alternative, and highly effective, method to reduce GHG emissions from waste cells. An LBC system employs a passive process (i.e., it does not require the significant operations and maintenance expenditures typical of an active LFG collection system) which acts to oxidize CH_4 through the establishment of bacteria known as methanotrophs. Methanotrophs oxidize the CH_4 component of LFG to CO_2 as the gas passes through the LBC. These methanotrophs are naturally occurring organisms that grow in CH_4-enriched soils and other media environments that have a continuous supply of CH_4, oxygen, and nutrients. No external seeding is required to stimulate the oxidation process since these organisms are ubiquitous. The by-products of this biological CH_4 oxidation process in LBCs is CO_2 and water vapour which are emitted to the atmosphere and represent a significant reduction in total GHG emissions when compared to the fugitive emissions of CH_4 and CO_2 from anaerobic decomposition of waste without the presence of an LBC system. CH_4 oxidation occurs naturally in soils and other porous media in the presence of oxygen and methanotrophic microbial communities.

Class II Landfills under an Environmental Protection and Enhancement Act (EPEA) approval are prescribed a compacted clay final cover system based upon the Standards for Landfills in Alberta (2010). An alternative final cover system requires authorization from the Alberta Environment and Parks (AEP) Director which would entail proof of concept to the alternative's hydraulic control properties within the Alberta climate. The University of Calgary (U of C) has been extensively studying the application of LBC systems and has proven that, given the semi-arid climate in Alberta, evapotranspiration and storage within the soil matrix can occur that can provide equivalent, if not, better, hydraulic control properties than that of a compacted clay cover system.

The U of C undertook and is conducting ongoing research to develop a surface emissions monitoring methodology that can be representative to the GHG reduction produced by an LBC system while being cost-effective to small landfill owners.

1.2 Detailed Technology Description

Landfills are typically closed by construction of a prescribed compacted clay cover system, upon reaching capacity. Evapotranspiration landfill biocover (ETLBC) systems present an alternative to the standard compacted clay cover system in terms of hydraulic performance while also reducing greenhouse gas (GHG) emissions.

In the application of ETLBC systems, the landfill biocover (LBC) component employs a passive process which acts to oxidize methane (CH_4). Fugitive landfill gas (LFG) emissions escaping through the LBC are oxidized by passing through a porous solid medium that is optimized for the growth of methanotrophs. These methanotrophs are naturally occurring organisms that grow in CH_4-enriched soils and other media environments that have a continuous supply of CH_4, oxygen, and nutrients. The by-products of this biological CH_4 oxidation in LBCs are carbon dioxide (CO_2) and water vapour, emitted to the atmosphere, which represents a significant reduction in total GHG emissions in comparison to the fugitive emissions of CH_4 and CO_2 from anaerobic decomposition of waste without a LBC system. CH_4 oxidation occurs naturally in soils and other porous media in the presence of oxygen and methanotrophic microbial communities.

In an ETLBC, the evapotranspiration (ET) component is utilized to prevent infiltration of precipitation into underlying waste. As opposed to a conventional clay cover system, which limits infiltration through acting as a low hydraulic conductivity barrier to water, ET covers store water within their soil matrix before slowly releasing it over time through evaporation and transpiration from vegetation. The demonstration project showed the applicability of both components of the ETLBC system within the Alberta climate.

Being a natural process, once an ETLBC is in place, there is no requirement for external energy or mechanical equipment contributions other than regular maintenance, as required. The biological oxidation of CH_4 does not produce any harmful by-products, with the end metabolites being composed of biogenic CO_2 and water vapour.

Since the technology is based on natural processes and no mechanical systems are involved, the construction and the operation of ETLBCs are cost effective and considerably cheaper than other systems for controlling GHG emissions from landfills. Additionally, the ET component was also demonstrated to provide equivalent or better infiltration performance when compared to a conventional clay cover.

1.3 Project Objectives

The overall goals of the project were the following:

- Provide proof of concept of ETLBC technology;
- Develop a monitoring and measurement protocol to accurately quantify methane oxidation of the technology to facilitate the creation of greenhouse gas emissions reduction credits; and
- Demonstrate a large-scale evapotranspiration (ET) cover in Alberta.

The final cover system designed, developed, and constructed utilized both the ET and LBC technologies and is referred to as an evapotranspiration landfill biocover (ETLBC).

1.4 Work Scope Overview

The project demonstrated the effectiveness of the ETLBC technology, which is a hybrid of landfill biocover technology to mitigate fugitive CH_4 emissions from landfills and ET-based alternatives to the traditional approach of using low permeable barrier covers (e.g. compacted clay covers).

The work scope included a pilot-scale demonstration project of ETLBC technology as proof of concept to obtain AEP authorization, development of a monitoring and measurement protocol to accurately quantify the CH_4 oxidation performance of the technology to facilitate the creation of GHG emissions reduction credits for sale in existing and emerging trading regimes, and the construction of a full-scale ETLBC cover in Alberta.

2 Project Outcomes and Learnings

2.1 Overall Project Achievements

The following were identified to be the project achievements during the project:

Task 0.1 – Formation of Stakeholder/Steering Group

This task was fully executed. The steering committee was created and provided guidance to the project, particularly in the initial stages.

Task 0.2 – Project Initiation

Upon formation of the stakeholder/steering group, the project was initiated with clear delegation on who will be undertaking the work, completing project management, provide technical/academic advise, and overall senior review.

Task 1.1 – Preliminary Design of Landfill Biocover System

A comprehensive literature review took place on LBC and ET cover technologies. The U of C is currently working on publishing a document which shall provide a summary of, but not limited to, the following:

- Engineered bio-based systems for methane oxidation;
- Key design elements of LBCs;
- Material parameters for CH_4 oxidation and ET cover systems;
- Operational and maintenance considerations;
- Construction considerations and methodology;
- Vegetation and effects on methanotrophy;
- Climate and meteorological effects;
- Soil water storage and movement;
- CH_4 oxidation and transport modelling; and
- LFG generation.

Task 1.2 – Identification of LBC Granular Media

The U of C conducted a material selection study based upon locally sourced materials identified by Tetra Tech. The findings were summarized in a report and a recommended mix design for the project was developed.

A summary progress report of the material selection study was prepared by the U of C. The report included analytical testing of organic content, pH, carbon-hydrogen-nitrogen contents, residual moisture content, field capacity, grain size, soil water characteristic curves, and mix design oxidation efficiencies. Initial evaluation of the materials led to the development of the project mix design, which yielded oxidation efficiencies ranging between 75% and 93% (Bartholameuz 2017).

The pilot demonstration stage involved the material supply based upon the material selection study, construction of two test plots at the Leduc landfill, purchase and installation of sensor system, and hydraulic seeding. Additionally, the U of C performed monitoring events at the Leduc landfill to assess fugitive methane emissions on the pilot demonstration project.

Task 1.3 – Determine the Optimum ET-LBC System Design

Documentation on the construction and monitoring of the pilot demonstration stage was completed.

A full design report, for the Leduc landfill on the applicability of an ET cover was developed and submitted to AEP for approval to deviate from the prescribed cover system indicated in the Standards for Landfills in Alberta (AEP 2010). The report was based on data collected from test plot installation in 2016, as indicated in Task 1.2, and hydrological modelling work performed on the pilot-scale cover system. The report demonstrated that the ET cover performed equal to or better than prescribed standard final cover systems in that it maintained lower moisture content, was less likely to fail (traditional clay covers are prone to cracking) and had more robust vegetative growth.

Authorization for the full implementation of the alternative cover system was issued by AEP.

Task 1.4 – Construction of the ETLBC System

In 2019, approximately 50% of the full-scale ETLBC cover, at the Leduc landfill, was constructed with the remaining portion to be constructed during 2020. A small portion of the landfill is expected to remain open for operational activities.

In 2020, it was determined by the Leduc & District Regional Waste Management Authority (LDRWMA) that full closure of the Phase II landfill will not be completed to optimize airspace, and as such, the full implementation of the ETLBC system is on hold.

Task 2.1 – Surface Gas Emissions Measurement

Sensor data provided the significant evidence necessary for the authorization by AEP of the alternative cover system. An augmentation of the sensor system is ongoing and will be installed in the full-scale cover system as ongoing research of temperature and moisture content of the full final ETLBC matrix.

The current sensor system has indicated that media within the test plots have maintained higher temperatures and lower volumetric moisture contents than the surrounding prescribed clay cover system. This is indicative of methanotrophic activity as well as effective evapotranspiration occurring.

Surface emissions measurements were performed at the site by the U of C during intermittent events. This included both surface concentration and flux measurements. Additionally, an on-site weather station was set up to enable accurate meteorological tracking.

Task 2.2 – Develop the Monitoring and Quantification Protocol

In 2018, the project team submitted an intent to develop an offset protocol to AEP and received approval from AEP to continue with the process. A technical SEED document was developed in 2019, and a technical review team was assembled and approved by AEP in 2020. The technical review team reviewed the SEED document and provided comments.

Task 2.3 – Reporting and Presentation

Design workshops were held during project initiation. Numerous presentations regarding the ETLBC system occurred with the Solid Waste North America (SWANA) Northern Lights Chapter and Waste Reduction Councils. An article was published in the Association of Professional Engineers and Geoscientists in Saskatchewan (APEGS) eEDGE magazine regarding the ETLBC system in Leduc. Additionally, a workshop was provided for landfill operators in 2019.

2.2 Technology Development, Installation, and Commissioning Description

An ETLBC system employs evapotranspiration and soil storage properties of an ET system as a means of reducing infiltration into the landfill waste, as well as biological processes of landfill biocover systems to oxidize the CH_4 component of LFG produced from the decomposition of organic waste. An ETLBC system must be designed to allow a highly porous medium for suitable vegetation to propagate while providing favourable environmental conditions to support a healthy and vigorous population of methanotrophs for effective CH_4 oxidation.

Prior to installation of an ETLBC in Leduc, an assessment of the site's fugitive methane emissions was conducted. This assessment was more qualitative in nature to determine locations of CH_4 hotspots or areas of high CH_4 fluxes and help mitigate the CH_4 hotspots. Mitigation was operational in nature, including increased grading, installation of gas dispersion media, and reseeding, etc. These efforts not only allowed for the dissipation of CH_4 hotspots underneath the installed LBC but also increased overall efficiency of CH_4 oxidation within the LBC material.

A rigorous material selection and screening process was undertaken in order to identify locally available materials that meet the requirements for ETLBC construction. Laboratory testing of available materials was completed to evaluate the application of the ET component of the ETLBC system on site. Mix designs were developed with emphasis on nutrients and water holding capacity to promote growth of methanotrophic communities.

Once installed, the ETLBC system was monitored for optimum moisture content levels, porosity, and soil temperatures. A maintenance program was developed to assess the LBC on a yearly basis. This assessment included inspection of vegetation including appearance and condition, presence of soil erosion, formation of cracks in the cover, changes to slope and settlement of underlying waste, intrusion by animals, as well as compaction of the cover by equipment or other forces. Vegetation appearance may indicate the presence of stresses such as drought or high flux of LFG. Other issues such as cracking or presence of animal burrows may indicate the formation of preferential pathways for fugitive LFG release.

2.3 Experimental Procedures/Methodology

Detailed design and modelling for the ET component of the ETLBC system (herein referred to as ET cover) were conducted using the Hydrological Evaluation for Landfill Performance (HELP) and Vadose/W (Vadose) softwares.

The HELP model is a quasi-two-dimensional hydrologic numerical model for conducting water balance analysis of landfills, cover systems, and other solid waste containment facilities; developed for the United States Environmental Protection Agency (USEPA). HELP is the industry standard for the hydrologic modelling of cover systems in Alberta and is typically included in detailed closure plans for AEP approval.

The numerical modelling package Vadose was selected to perform modelling for detailed design purposes for the ET cover system and cover system sensitivity analysis. In addition, Vadose was also used to model the adjacent conventional clay cover system for comparison purposes.

Vadose is a hydrologic modelling program capable of undertaking the rigorous calculations required to solve unsaturated moisture movement within the vadose zone of a soil matrix. The model simulates water flow under the variably saturated conditions by solving a modified form of the Richards' equation (Benson et al. 2005) using a finite element methodology.

It is noted that Vadose modelling is now performed under the Seep model available from GeoStudio.

2.4 Discussion of any Advancements made toward Commercialization, Commercial Deployment, or Market Adoption

Two landfills in Alberta are currently looking to implement an ET or ETLBC system for closure. Both sites are currently under the conceptual design phase, where on-site stockpiles are being tested for optimal mix design properties. Early engagement with AEP has occurred for both landfills as authorization for an alternative cover system will be required.

In the case of the Leduc landfill, it was demonstrated through test plots, temperature and moisture monitoring, and modelling, that the ET component of the ETLBC system performed equal to or better than prescribed cover systems in that it maintained lower moisture content, was less likely to fail (traditional clay covers are prone to cracking) and had more robust vegetation. As such, authorization for the alternative cover was provided by AEP.

2.5 Description of Technology Advancement over the Course of the Project

The project acted to demonstrate the applicability of ETLBC technology within the Alberta climate. Through modelling, test plot construction, and sensor monitoring, it was demonstrated that ET technology could outperform conventional clay capping to limit water infiltration at the Leduc site. Additionally, through the design performance, authorization for an alternative cover system was received from AEP to construct a full-scale ETLBC cover. Additionally, the project demonstrated the LBC system had the potential to oxidize 71% to 97% of CH_4 to CO_2 (Bartholameuz 2017) within the first year of implementation, which outperforms the initial assumption of 65%.

The project also acted to evaluate quantification methodologies for methane emissions oxidation by an ETLBC. The findings and quantification methodology developed were included in a carbon offset quantification protocol currently under evaluation by AEP.

2.6 Analysis of Results

From the modelling exercises performed and in-situ sensor data available, it is concluded that the ETLBC cover system will perform as well, or better, than a clay cover system for the final closure of the Phase II municipal waste landfill at Leduc.

Vadose modelling supports the conclusion that the ET cover system will maintain lower moisture contents relative to the conventional clay clover system due to larger pore water pressures present. In addition, due to the greater change in soil water storage, and greater potential to store water, the ET cover system will have a lower chance of failure (percolation through the cover system) than the clay cover system during periods of high precipitation.

The in-situ sensor data gathered in Leduc is supportive of the modelling conclusions. From the data recorded by the test plot field sensors, it is indicative that the ETLBC system is maintaining lower moisture contents than the conventional clay cover system.

Qualitatively, clay soils are often prone to cracking over time, which may lead to the creation of preferential pathways for the infiltration of precipitation into the underlying waste. Because the ETLBC cover system will be made of organic soils, which do not typically crack and can be self-healing due to deep rooting systems, this failure mode is less likely for an ETLBC cover system.

Furthermore, vegetation growth is much more robust in nature for an ETLBC cover system. Potential rooting depths are much higher for loose, topsoil-based mixtures than those constructed of compacted clay materials. The maximum rooting depth for vegetation in a clay cover system can be considered to effectively be 200 mm to the base of the topsoil layer. In an ETLBC cover system, potential rooting depth is the entire thickness of the cover system. The more robust vegetation present in an ETLBC cover system will allow for better performance over time.

Initial evaluation of the materials led to the development of the project mix design, which yielded oxidation efficiencies ranging between 75% and 93% (Bartholameuz 2017). Due to low temperatures and freezing conditions in Canada, it is expected that the CH_4 oxidation rate would decline in the winter; however, test plots in Leduc show that CH_4 oxidation does not completely cease during the winter months due to the exothermic nature of both the anaerobic decomposition process within the landfill and the CH_4 oxidation process in the LBC.

3 Greenhouse Gas Benefits

3.1 Describe how the Completed Project and the Advanced Technology will Result in GHG Reductions in Alberta, and whether the Reductions are Direct and Indirect.

The project will result in GHG emissions reduction in Alberta by both the proof of concept of LBC technology within Alberta, as well as the implementation of the associated offset quantification protocol (if approved). The technology, if widely adopted, is expected to be a viable alternative to prescriptive compacted clay covers as it can be inexpensive, requires less maintenance, and will produce GHG offset credits for project developers. Additionally, the technology represents a much more inexpensive option for GHG mitigation than current technologies such as the LFG capture and utilization.

3.2 Discussion Regarding how the Completed Project will Help Facilitate a Low-Carbon Economy and Secure Alberta's Success in a GHG-constrained Future

The ETLBC technology is expected to reduce CH_4 emissions at sites where it is uneconomical to install and operate an active LFG system. For large landfills (greater than 2 million tonnes of waste in place), installing an active LFG extraction system may be financially and practically viable, but for many smaller and older landfills, it is typically not viable. The ETLBC system can be applicable to smaller landfills where LFG management and GHG mitigation are desired.

Moreover, the ETLBC technology will also eliminate the release of combustion by-products into the atmosphere that would have occurred with the LFG flaring systems.

The GHG reduction with an LBC system includes the conversion of CH_4 into biogenic CO_2, which is a less potent GHG. For each unit of CH_4 oxidized in the cover system, the GHG emissions will be reduced by approximately a factor of 25. The GHG mitigation is expected to continue for the entire life of the landfill. Unlike the conventional LFG extraction and utilization/flaring systems, the removal efficiency of the proposed technology is expected to increase in the later stages of landfill life, when LFG generation rates decline.

3.3 Forecast of the Estimated Annual GHG Reductions in Alberta from Commercial Roll out of the Technology in Alberta by the years 2025, 2030, and thereafter

Based on estimated GHG production for an average-sized landfill that could employ the ETLBC technology and a 50% oxidation rate, a landfill could expect to reduce emissions by approximately 86,063 CO_2e over the reporting period (13 years).

4 Economic and Environmental Impacts

4.1 Description of the Projected Economic Impacts in Alberta, Including Revenues, Cost Savings, Job Creation, Investment Attraction, Economic Diversification, Tax Revenue, etc., based on the Outcomes of the Project

It is expected that there will be high uptake of the technology by EPEA-approved landfills that are too small, not geometrically favourable, the landfilled waste is too old, or the site does not have appropriate meteorological conditions to economically implement LFG extraction and utilization. It is currently anticipated that the technology will be considered by between 24-29 of the landfills with EPEA approvals. These landfills would be required to obtain authorization from AEP for the installation of an alternative cover system. There are numerous more landfills in Alberta, operating under an AEP registration, for which ETLBC systems may be viable.

At this time, registered landfills under the Code of Practice in Alberta (2001) will have to apply for an approval in order to install an alternative cover system such as the ETLBC, however, this may not be in the sites best interest as other regulatory requirements might also increase at the site as a result of moving from a registration to an approval. In order to allow for increased uptake of the technology, AEP could amend the Code of Practice in Alberta (2001) to allow for the opportunity to install alternative cover systems at registered sites.

Additionally, it has been noted that the global warming potential value of methane has increased over time. The Intergovernmental Panel on Climate Change (IPCC) has adjusted the global warming potential values for methane from 21 to 25 times that of carbon dioxide from their Second Assessment Report to the Fifth Assessment Report. This increases the potential offset credit value generated for prospective ETLBC projects.

Lastly, the carbon emission pricing has changed in Alberta over the course of the project. The per tonne value of offset credits has increased from $15 per tonne at project initiation to $30 per tonne as of 2017. This is expected to continue to rise over time and will promote the adaptation of the technology to facilitate revenue from GHG mitigation.

4.2 Discussion about the Immediate and Potential Future Environmental Benefits (Including Criteria Air Contaminants, Land Use, Soil, Water Consumption, etc.) Resulting from the Completed Project and Advanced Technology

The various environmental benefits include:

- Reduce fugitive GHG emissions in a landfill through methane oxidation in the LBC material;
- Reduced percolation of precipitation into the waste matrix with an ETLBC system;
- Risk reduction from exposure to harmful compounds in LFG including CH4 and non-methane organic compounds (NMOCs) (Wang et al., 2015; Bogner et al., 2010; Scheutz et, al., 2008);
- Odour reductions; and
- More efficient LFG abatement than compacted clay cover system (abatement can range from 0% to 97% depending on overall emissions and weather conditions).

5 Overall Conclusions

The project presented herein successfully provided a proof of concept that ETLBC systems are applicable in Alberta and are a viable alternative to prescriptive compacted clay covers, passive venting systems, and active LFG collection systems. The ETLBC system is also a proven passive technology that can be applied to small or medium landfills seeking to voluntarily manage LFG and mitigate GHG emissions. It is expected that there will be uptake of the technology by EPEA-approved landfills that are too small to justify the implementation of a LFG collection system to mitigate GHG emissions, or does not have locally-sourced clay material to employ a compacted clay cover system for closure. Furthermore, it is anticipated that uptake will increase when the offsets quantification protocol is approved.

6 Next Steps

6.1 Discussion about the Next Steps for the Technology/Process/Innovation, Including Potential Follow-Up Projects

There are two ongoing ETLBC projects that involve the design, authorization from AEP for an alternative cover system, and construction of the closure works. Ongoing presentations are being completed to encourage the application of an ETLBC system in Alberta. Ongoing development of the proposed Quantification Protocol for a Landfill Biocover System is occurring.

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