Operating Criteria and Quantification Methodology for

Green Natural Gas

REVISION

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Protocol Overview

ICF International has been retained by Bullfrog Power to identify the standards that a high-performing Green Natural Gas (biomethane) project should meet, and to describe how a project may result in reduced emissions of greenhouse gases (GHGs). The environmental benefit of using Green Natural Gas is the displacement of fossil-based natural gas, thereby reducing close to 99% of the associated emissions.

This document has three parts and an Appendix:

- **Part 1: Overview of the carbon cycle and Green Natural Gas projects**. The document first explains why Green Natural Gas is biogenic, does not result in an increase of carbon dioxide emissions in the atmosphere, and should be treated as a net zero carbon dioxide emission fuel.
- **Part 2: Direct emissions reductions.** A significant reduction in direct carbon dioxide emissions results when conventional natural gas is substituted with Green Natural Gas. This part of the report establishes a methodology for quantifying direct carbon dioxide emission reductions, which can be applied to any Green Natural Gas project to quantify a consumer's emission reduction.
- **Part 3: Project and annual audit standards as well as Methodology Applicability.** The report then identifies the operating and quality standards that Green Natural Gas facilities should meet and that a regular verification should review. The applicability criteria for applying this methodology to Green Natural Gas projects are also outlined.
- **Appendix: Indirect emissions reductions.** The Appendix describes how the operation of a Green Natural Gas facility also results in indirect emissions reductions (e.g. upstream greenhouse gases, NOx, SO_2, VOCs, particulates). The Appendix provides a more detailed methodology for evaluating both direct and indirect emissions reductions.

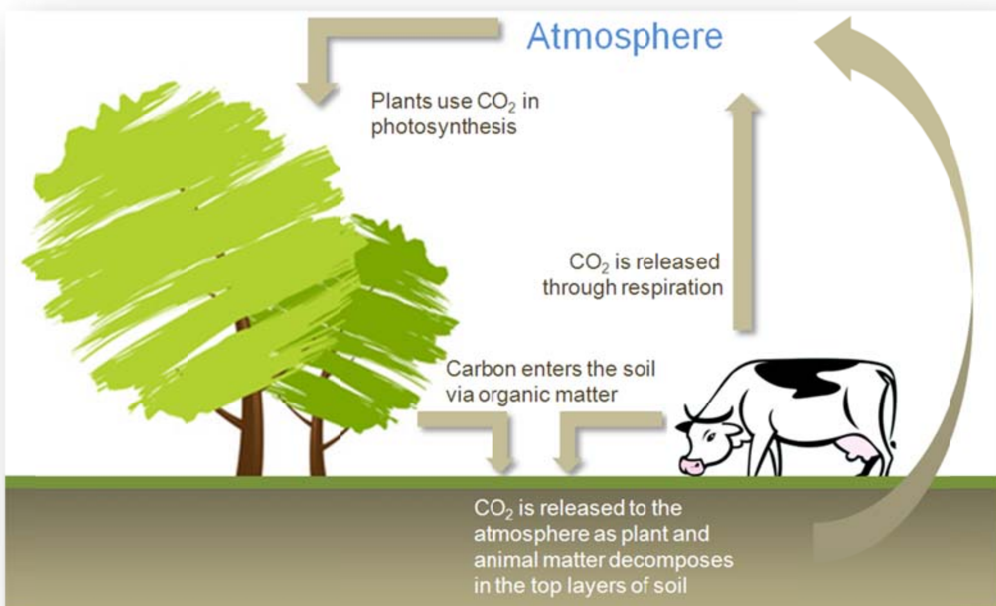
The calculation methodologies provided in this document serve as a guideline for project specific applications and therefore, this document must be uniquely adapted for individual projects. Emission sources relevant for each specific project are identified within a separate site specific Project Document.

Part I: The Carbon Cycle and Green Natural Gas Projects

The Carbon Cycle and Human Activity

Carbon is the foundation of all living organisms and is naturally exchanged between living and decaying organisms, the soil and the atmosphere in the form of carbon dioxide (CO_2) and other carbon based compounds through a continuous cycle known as the carbon cycle that has been in operation since the beginning of life on earth. When plant and animal matter decomposes, some carbon is emitted to the atmosphere as CO_2, while the remaining carbon is stored in the soil. CO_2 that occurs naturally within the carbon cycle as a result of biological processes is known as *biogenic* CO_2. As a result of this natural process, carbon dioxide from the decay of organic matter is recycled in the carbon cycle, and does not increase the amount of carbon in the atmosphere.

Carbon dioxide, as well as other gases including methane (CH_4) and nitrous oxide (N_2O) are GHGs that contribute to global warming. Since the industrial revolution, human activity has dramatically increased concentration of GHGs in the atmosphere (above the naturally occurring level present in the carbon cycle) through the combustion of fossil fuels, land-use changes, and the development of new industrial processes. The combustion of natural gas, for instance, releases carbon into the atmosphere that has been stored below the earth's surface for thousands of years.



Waste Management in a Landfill

The disposal of waste in a landfill is a conventional method of waste management that is very common around the world. Waste is collected at its various sources and transported to landfills where it is spread and covered with alternating layers of waste and cover material, such as soil and sand. As organic waste decomposes in a landfill, landfill gas forms below the surface. Landfill gas naturally migrates towards the surface of the landfill and is emitted into the atmosphere.

Landfill gas typically contains approximately 40-60% methane, 40-60% carbon dioxide, water vapor and small quantities of other gases and contaminants. The carbon dioxide component of landfill gas is biogenic because it is formed through the natural decomposition of organic material as part of the carbon cycle.

In an oxygen depleted environment, which exists within a landfill, methane is produced as organic material decomposes. The methane contained in landfill gas is not considered to be biogenic. Methane would not form during the natural decomposition of organic material in an oxygen rich environment. However, if landfill gas is collected and the methane is converted to carbon dioxide, the resulting quantity of carbon dioxide is considered biogenic. The volume of carbon dioxide converted from methane is approximately equivalent to the quantity of carbon dioxide that would have been formed through the natural decomposition of the organic material. One of the most effective and productive methods for converting methane to carbon dioxide is through combustion (burning).

Green Natural Gas Opportunity

Most landfill operators either do not collect landfill gas, allowing it to be released into the atmosphere or collect landfill gas and use a simple combustion device, such as a vertical flare stack, to combust the methane and convert it into carbon dioxide. Currently, a number of provinces have regulations requiring new landfills of a certain size to capture and flare landfill gas. While flaring successfully reduces the amount of methane emitted into the atmosphere, it does not utilize the significant energy contained within landfill gas, which is simply lost.

The equipment required to process landfill gas and produce Green Natural Gas is far more complex and capital intensive than flaring. Currently, there are no Canadian jurisdictions that require landfill operators to incur the additional expense of building a Green Natural Gas facility.

Operations of a Green Natural Gas Facility

In both conventional natural gas processing and landfill gas processing, the removal of non-combustible gases and other contaminants produces a high quality gas that is safe for injection into a natural gas pipeline. Typically, landfill gas is dehydrated to remove water vapour and compressed to increase the pressure of the gas. Treatment processes are used to remove trace contaminants such as hydrogen sulphide (H_2S) and ammonia (NH_3). Volatile Organic Compounds (VOCs) and particulate matter (PM, which is essentially very fine dust) are also removed. All of these contaminants must be destroyed or disposed of in a manner meeting provincial regulations. For most of these undesirable gases, this results in a significant reduction of atmospheric emissions when compared to flaring of landfill gas (further information regarding these reductions is set out in the Appendix). Finally, the methane is separated from the carbon dioxide (which is biogenic and released) and other trace gases (such as small amounts of oxygen and nitrogen). The methane is of sufficient quality to be safely injected into the natural gas distribution system to displace conventional natural gas.

Carbon Dioxide Emissions from Green Natural Gas

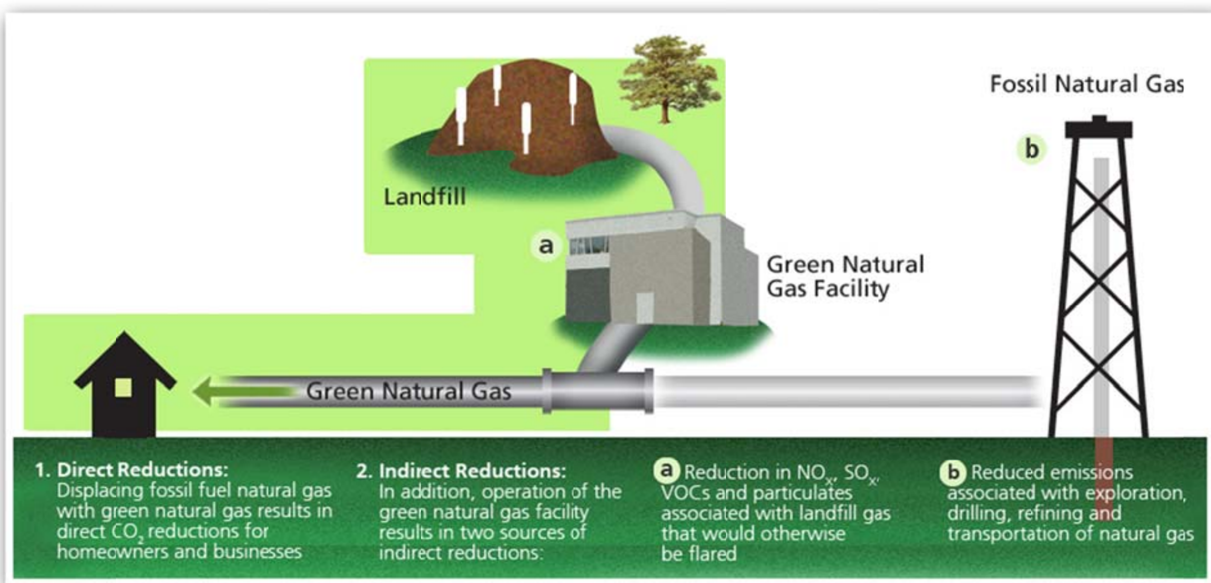
As previously discussed, carbon dioxide resulting from the combustion of Green Natural Gas is considered to be biogenic. Consequently, burning Green Natural Gas does not add incremental carbon dioxide to the atmosphere.

Companies and individuals who are purchasing Green Natural Gas, whether as a bundled product (the environmental attributes bundled with the gas commodity) or as an unbundled product (the environmental attributes unbundled from the commodity) may treat Green Natural Gas as having net zero direct carbon dioxide emissions. For instance, many companies use the World Resources Institute's *Greenhouse Gas Protocol*[1] to calculate their corporate GHG inventory. Under the rules of the Greenhouse Gas Protocol, natural gas that is consumed by a company in a building that the company owns or controls is considered as part of that company's Scope I (direct) emissions. If a company purchases Green Natural Gas, whether bundled with the commodity or unbundled through certificates, the company would report the emissions associated with natural gas consumption as zero. Green Natural Gas effectively displaces all carbon dioxide emissions associated with burning conventional natural gas.

Part II – Quantifying Direct Emissions Reductions from Green Natural Gas

Consumers can achieve significant GHG emissions reductions by replacing conventional natural gas with Green Natural Gas.

The magnitude of the direct GHG emissions reduction is calculated by multiplying the volume of conventional natural gas that is displaced by Green Natural Gas (the end user's consumption) and the natural gas emission factor for carbon dioxide (see Table A3 in Appendix). The emission factor is a standard intensity factor, which provides the carbon dioxide emissions per unit of natural gas burned.



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[1] World Resources Institute, *The Greenhouse Gas Protocol, A Corporate Accounting and Reporting Standard*. Revised Edition. http://www.ghgprotocol.org. 2010.

In 2009, Environment Canada identified that burning 1 cubic metre of natural gas produces approximately 1.9 kg of carbon dioxide.[2] Therefore, displacing 1 cubic metre of conventional natural gas with 1 cubic metre of Green Natural Gas results in a direct emissions reduction equivalent to approximately 1.9 kg of carbon dioxide.

Combusting Green Natural Gas produces very small quantities of methane and nitrous oxide emissions (less than 1% of the total) that are not biogenic. Therefore, switching from conventional natural gas to Green Natural Gas results in a GHG emission reduction in excess of 99%.

The Appendix provides a methodology for quantifying the indirect GHG emissions associated with extracting and processing conventional natural gas and Green Natural Gas.

Part III – Operating/Quality Standards and Methodology Applicability for Green Natural Gas Projects

To meet this standard and to ensure that a Green Natural Gas facility is properly operated and maximizes the environmental benefits of Green Natural Gas, it is key to ensure that a Green Natural Gas facility meets the following operational requirements and applicability criteria:

1) **Waste operations standards:** The landfill and gas collection operations at the Green Natural Gas processing facilities must meet all government environmental and operating requirements.
    a) Landfill installation must be approved for operation by the governing jurisdiction as evidenced by the Installation Report and a current Certificate of Authorization.

2) **Green Gas operations standards:** The Green Natural Gas facility must also meet high operating standards. Demonstrating that the facility is meeting operating standards requires appropriate handling of the contaminants removed from the landfill gas as well as measurement and monitoring of the trace residual contaminants in the Green Natural Gas. In particular, H_2S and NH_3, VOCs and PM must be removed and destroyed or disposed of appropriately, as described in the current Certificate of Authorization.
    a) Green Natural Gas facility installation must be approved for operation by the governing jurisdiction as evidenced by the Installation Report and current Certificate of Authorization;
    b) The operator of a landfill must submit an operations report at a frequency required by Regulation. The operations report must provide monitoring results for contaminant gases required by the Certificate of Authorization;
    c) Levels of H_2S, NH_3, VOCs and PM present in residual gas stream emitted to the atmosphere must not exceed levels prescribed in the Certificate of Authorization;
    d) Annual flare and incinerator volumes must be logged and reported within the Operations Report.

3) **Quality of Green Gas:** The Green Natural Gas being injected into the pipeline system must meet pipeline quality standards. Demonstrating compliance requires monitoring and measurement of the quality of the gas, as well as confirmation of the quality by the pipeline operator.
    a) The volume of Green Natural Gas must be metered using a custody transfer meter, which is calibrated according to the schedule provided by the manufacturer or required by Measurement Canada;

[2] Environment Canada, *Emission Factors from Canada's National Inventory Report, 1990-2009*. http://www.ec.gc.ca (Emission Factors from Canada's GHG Inventory\Fuel Combustion)

b) The gross heating value of the Green Natural Gas injected into the pipeline shall meet a minimum level defined by the local natural gas distribution or transmission operator;
c) The oxygen content of the Green Natural Gas shall not exceed a level defined by the local natural gas distribution or transmission operator;
d) The concentration of hydrogen sulphide in the Green Natural Gas shall not exceed a level defined by the local natural gas distribution or transmission operator;
e) The concentration of volatile organic compounds in the Green Natural Gas shall not exceed a level defined by the local natural gas distribution or transmission operator.

4) **Protocol Applicability:** In addition to the operating and quality standards listed above, the Green Natural Gas facility must demonstrate the following criteria are met.
   a) The Green Natural Gas facility (project) must be additional to all regulatory requirements at the local, regional, provincial, or federal level;
   b) The environmental attributes associated with Green Natural Gas must not be used for regulatory compliance purposes (therefore not used as a feedstock in a GHG-regulated market);
   c) The Green Natural Gas must be transported to market by pipeline.

Appendix

From a consumer's perspective, replacing conventional natural gas with Green Natural Gas (either bundled or unbundled) results in a direct carbon dioxide emissions reduction (Scope I). Processing landfill gas to produce Green Natural Gas also results in two indirect benefits. First, producing Green Natural Gas is less energy intensive than extracting, processing and transporting conventional natural gas, which results in an indirect reduction of GHGs (Scope III emissions). Second, processing landfill gas in the Green Natural Gas facility prevents or removes pollutants that would otherwise have been flared, resulting in the reduction of other emissions (e.g. NOx, SO_2, VOCs, and particulates).

This Appendix provides a framework for calculating direct and indirect emissions in two scenarios: the business as usual, or Baseline scenario, without the Green Natural Gas facility (in which the landfill gas is collected and flared while end use consumers are burning conventional natural gas), and the Project scenario (in which the Green Natural Gas facility is built and the landfill is processing landfill gas and producing Green Natural Gas, which is subsequently burned by end use consumers).

The intent of this Appendix is to serve as a template for project specific applications and therefore, it must be uniquely adapted for individual projects. Emission sources relevant for each specific project should be identified within a separate site specific project document.

The framework analyzes waste management from the curbside through the combustion of gases formed in the landfill for each of the Baseline and Project scenarios. Emission sources that are present in both scenarios are ignored; the focus of this protocol is on the *difference* between the two scenarios identified[3].

This analysis demonstrates that a Green Natural Gas project may result in a reduction in GHG emissions through each stage of the lifecycle (production through consumption). Further, this protocol utilizes the same framework to evaluate the net emissions reductions of other pollutants (including NO_x, SO_2, PM and VOCs) that result from implementing the Project. The quantification of an emissions reduction is accomplished by comparing the emissions in the Baseline scenario to the Project scenario.

The two scenarios are graphically depicted in the figures below. Figure A1 illustrates the process flow of a typical Baseline configuration with a landfill collection and flare system in place. Figure A2 illustrates the process flow in a typical Project scenario in which the landfill continues to operate as it did in the Baseline scenario. The change is that the landfill gas, instead of being flared, is sent to the Green Natural Gas facility for cleaning and injection into the natural gas pipeline system where it displaces conventional natural gas.

The emissions reductions resulting from Green Natural Gas are equal to the difference between the emissions from all sources in the Baseline scenario and the emissions from all sources in the Project scenario. It is not necessary to quantify the emission source if emissions are equivalent in both scenarios for a particular emission source (for example, garbage trucks collecting waste occurs in both scenarios).

Table A1 provides a description of each emission source shown in the process flow diagrams and explains whether each emission source will result in any difference between the Baseline and the Project

[3] In order to yield a net reduction of emissions, the project activity must be additional to federal, provincial and/or regional regulations or binding mandates. Only reductions beyond current regulated levels may be counted as real reductions.

scenarios. If the emission source is not different or material, it is not given further consideration. Table A2 provides basic guidelines for monitoring emission sources at a Green Natural Gas facility.

Figure A1: Baseline Process Flow Diagram – Landfill Gas Collection and Flare System

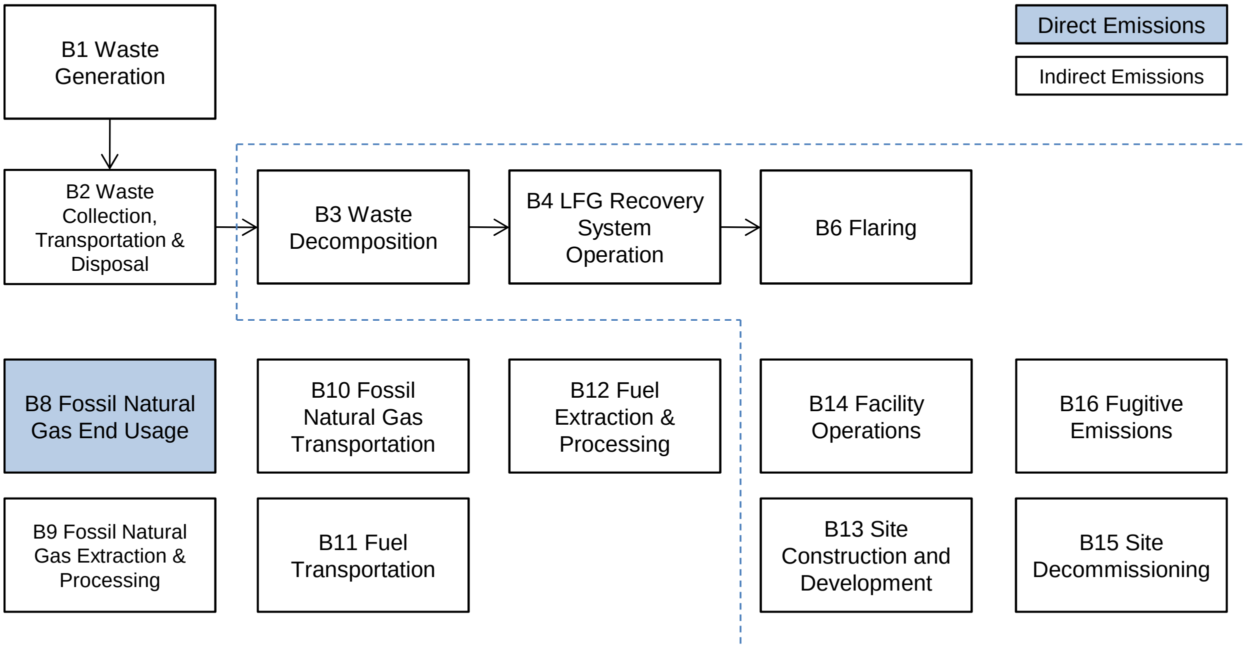

Figure A2: Project Process Flows – Landfill Gas Collection and Processing to Natural Gas Pipeline System

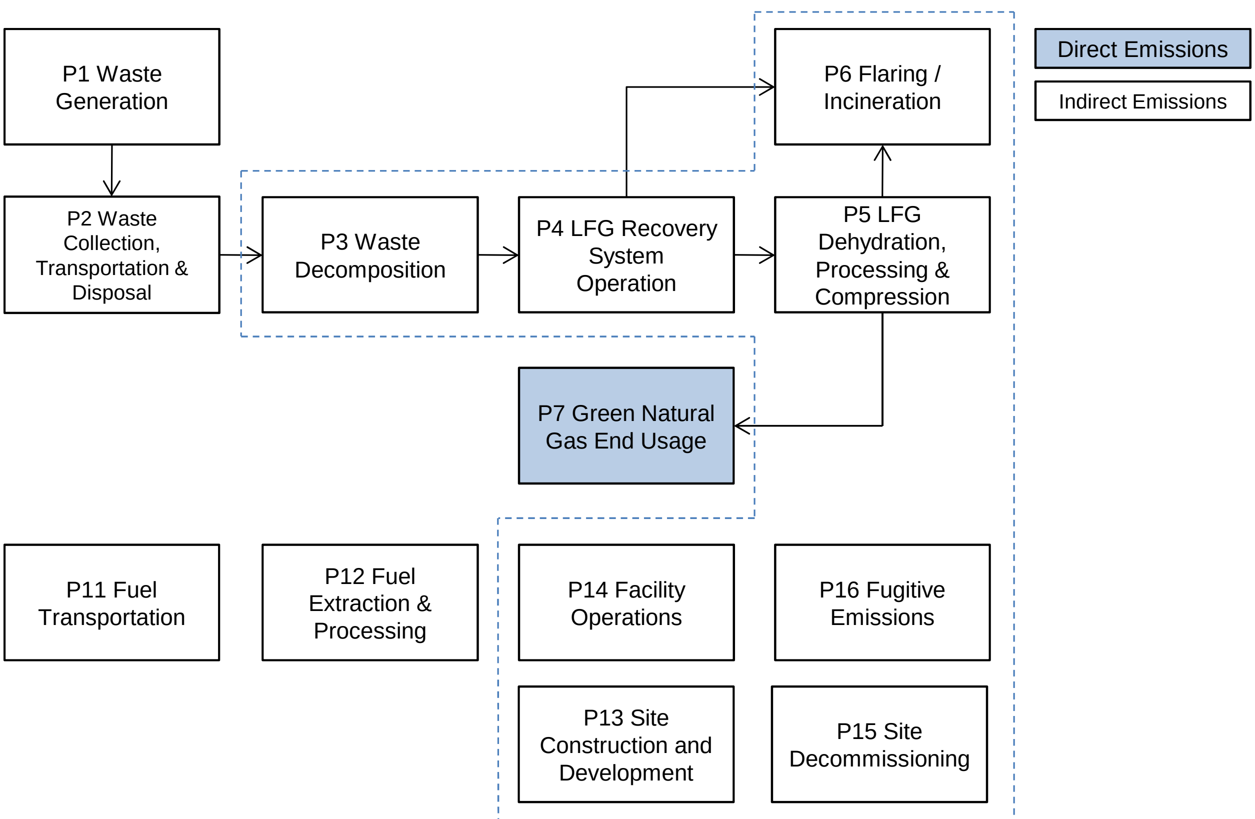

Table A1 -- Identification of Emission Sources

Emission Source (Number)		(Name)	Description	Emission Analysis	Explanation for Exclusion
P1	B1	Waste Generation	Solid waste is produced within the jurisdictions adjacent to the landfill being analyzed.	Excluded	Waste is generated in either scenario; therefore, emissions in the baseline and project scenarios are equivalent.
P2	B2	Waste Collection, Transportation & Disposal	Waste is collected, transported, processed and disposed in the landfill being analyzed.	Excluded	Waste is collected and disposed of in either scenario; therefore, emissions in the baseline and project scenarios are equivalent.
P3	B3	Waste Decomposition	Organic waste decomposes in the landfill and generates LFG, largely comprised of carbon dioxide and methane. A portion of the LFG reaches the surface and is emitted into the atmosphere.	Excluded	Waste decays in the landfill in either scenario; therefore, emissions in the baseline and project scenarios are approximately equivalent. Note: the landfill gas that is collected is described in the following emission source.
P4	B4	LFG Recovery System Operation	Engines drive pumps and blowers used to recover LFG from the landfill through a series of wells and gathering pipelines.	Excluded	Landfill gas is collected in either scenario, either for flaring or converting into Green Natural Gas depending on the scenario. Emissions resulting from the collection of landfill gas in the baseline and project scenarios are equivalent.
P5		LFG Dehydration, Processing & Compression	LFG is dehydrated, compressed and processed through a series of equipment designed to meet commercial natural gas pipeline requirements.	Included: CO_2, CH_4, N_2O	Dehydration and compression does not result in significant emissions of SO_2, NO_x, PM & VOC. *See note below.
P6	B6	Flaring / Incineration	LFG is combusted in a flare stack. A supplemental fuel may be used to ensure more complete combustion. In the project scenario, waste gases may be destroyed in an incinerator or flare. Total LFG volume flaring is used only in upset scenarios or when the Green Natural Gas system is unavailable.	Included: CO_2, CH_4, N_2O, NO_x, SO_2, PM & VOCs	CO_2 emissions resulting from combustion of biogas are excluded because they are considered to be biogenic (part of the natural carbon cycle). CO_2 emissions resulting from the combustion of supplemental fuel (if any) are included.
P7		Green Natural Gas End Usage	Green Natural Gas is combusted in downstream end use equipment.	Included: CH_4, N_2O, NO_x, SO_2, PM & VOCs	CO_2 emissions are excluded because they are considered to be biogenic (part of the natural carbon cycle).
	B8	Fossil Natural Gas End Usage	Conventionally sourced fossil natural gas is combusted in downstream end use equipment.	Included: CO_2, CH_4, N_2O, NO_x, SO_2, PM & VOCs	No exclusions.
	B9	Fossil Natural Gas Extraction & Processing	Conventionally sourced fossil natural gas is extracted and processed by natural gas production companies.	Included: CO_2, CH_4, N_2O	Extraction and processing does not result in significant emissions of SO_2, NO_x, PM & VOC. *See note below.

Emission Source (Number)		(Name)	Description	Emission Analysis	Explanation for Exclusion
	B10	Fossil Natural Gas Transportation	Conventionally sourced fossil natural gas is transported from production regions to distribution regions, which involves compression through the pipeline system.	Included: CO_2, CH_4, N_2O	Fossil natural gas transportation does not result in significant emissions of SO_2, NO_x, PM & VOC. *See note below.
P11	B11	Fuel Transportation	Conventionally sourced fossil natural gas is transported from production regions to the landfill where it may be used to operate landfill equipment, including the pilot light on the flare system. Transportation emissions originate from natural gas compression equipment through the pipeline system or from local deliveries, such as propane trucks.	Included: CO_2, CH_4, N_2O	Fuel transportation does not result in significant emissions of SO_2, NO_x, PM & VOC. See note below. Note: if the landfill processing equipment does not use supplemental fossil fuels, this emission source is excluded.
P12	B12	Fuel Extraction & Processing	Fossil fuels that are combusted in landfill gas processing equipment are processed by natural gas production companies upstream of the site.	Included: CO_2, CH_4, N_2O	Fuel extraction and processing does not result in emissions of SO_2, NO_x, PM & VOC. See note below. Note: if the landfill processing equipment does not use supplemental fossil fuels, this emission source is excluded.
P13	B13	Site Construction & Development	Civil infrastructure and the landfill site are prepared and constructed.	Excluded	Landfill construction and development occurs in both scenarios. Emissions in the baseline and project scenario are similar and small compared to the emissions of the total project when amortized over the project lifetime.
P14	B14	Facility Operations	Facility infrastructure (such as support buildings) are operated including electrical and heating operation.	Excluded	Emissions in the baseline and project scenario are similar and small compared to the emissions of the total project when amortized over the project lifetime.
P15	B15	Site Decommissioning	The landfill site and equipment are disassembled or demolished once the landfill is no longer in operation.	Excluded	Emissions in the baseline and project scenario are similar and small compared to the emissions of the total project when amortized over the project lifetime.
P16	B16	Fugitive Emissions	Unintentional small releases of gas occur throughout Green Natural Gas and conventional Natural gas processing systems and pipelines.	Excluded	Fugitive emissions occur in both scenarios and in most cases will be larger in the baseline. Therefore, it is conservative to exclude this emissions source.

NOTE: Only Flaring/Incineration (B6/P6), Green Natural Gas End Usage (P7) and Fossil Natural Gas End Usage (B8) result in material quantities of SO_2, NO_x, PM & VOC emissions. The other emission sources are negligible and are therefore not considered for the purpose of this analysis.

Table A2: Guidelines for Emission Source Monitoring

Emission Source/ Measurement Parameter	Measurement Procedure	Measurement Frequency (Minimum)	QA/QC Procedures
Heat Content of Green Natural Gas	Gas samples taken and sent to third-party lab; gas chromatograph; or Btu analyzer	Monthly	Sampling by third-party lab or self-calibrating gas analyzing equipment (i.e. chromatograph)
Volume of Green Natural Gas	Metered	Continuously	Meter calibration annually or according to manufacturer specifications
Quantity of Electricity Consumed in Green Natural Gas Processing	Metered	Continuously	Purchase invoices from third-party supplier
Volume of Fuels Consumed for Flaring and Incineration	Inventory based on purchase invoices	Annually	Third-party invoices

Quantification of Greenhouse Gas Emissions Reductions

ICF has developed a Green Natural Gas emissions calculator to help purchasers of Green Natural Gas estimate their impact on GHG emissions from their purchase of Green Natural Gas.

Companies and individuals include the emissions directly associated with the natural gas they consume as part of their greenhouse gas inventory (Scope I emissions in the GHG Protocol). However, the emissions associated with all of the activities required to produce the natural gas are considered Scope III emissions and may optionally be excluded from their emissions inventory. These indirect emissions consist of the emissions resulting from exploration, drilling, refining and transporting natural gas.

Quantification of direct GHG emission reductions is described earlier in this methodology document (see Part II – Quantifying Direct Emissions Reductions from Green Natural Gas). The primary purpose of this section is to prove that the indirect GHG emissions associated with extracting and processing Green Natural Gas are significantly lower than those associated with conventional natural gas.

The indirect emissions reductions from a Green Natural Gas facility can be expressed as the equation.

$$\boxed{Indirect\ Emission\ Reduction = Indirect\ Emissions_{Baseline} - Indirect\ Emissions_{Project}}$$

The emission sources identified as material to the indirect emissions calculation in Table A1 are included below.

$$\begin{aligned} Indirect\ Emissions\ Baseline &= Emissions_{Flaring} + Emissions_{Fossil\ Natural\ Gas\ Extraction\ \&\ Processing} \\ &+ Emissions_{Fossil\ Natural\ Gas\ Transportation} + Emissions_{Fuel\ \ Transportation} \\ &+ Emissions_{Fuel\ \ Extraction\ \&\ Processing} \end{aligned}$$

$$\begin{aligned} Indirect\ Emissions\ Project &= Emissions_{LFG\ \ Dehydration, Processing\ \&\ Compression} + Emissions_{Flaring\ /Incineration} \\ &+ Emissions_{Fuel\ Transportation} + Emissions_{Fuel\ Extraction\ \&\ Processing} \end{aligned}$$

The formulas on the following page describe the quantification of each indirect emission source. These formulas are used in the calculator to assist purchasers in determining indirect emissions that result from the Green Natural Gas they purchase.

Natural Gas Extraction & Processing (B9, B12, P12)

$$Emissions_{Natural\ Gas\ Extraction\ \&\ Processing} = Emissions_{CO_2} + Emissions_{CH_4} + Emissions_{N_2O}$$

$$Emissions_{CO_2,CH_4,N_2O} = V_{gas} \times EF_{gas}$$

Where:

V_{gas} = Volume of gas
EF_{fuel} = Emission factor for each gas combusted, by gas (see Table A3)

Flaring / Incineration (B6, P6)

$$Emissions_{Flaring} = Emissions_{CO_2,}Emissions_{CH_4}, Emissions_{N_2O}$$

$$Emissions_{CO_2,CH_4,N_2O} = \left(V_{fuel} \times EF_{fuel}\right) + (V_{gas} \times EF_{gas})$$

Where:

V_{fuel} = Volume of fuel used as supplemental or pilot gas for flaring or incinerating
EF_{fuel} = Emission factor of fuel (see Table A3)

V_{gas} = Volume of gas flared or incinerated
EF_{fuel} = Emission factor of gas flared or incinerated (as measured at Green Natural Gas processing facility)

Natural Gas Transportation (B10, B11, P11)

$$Emissions_{Natural\ Gas\ Transportation} = Emissions_{CO_2} + Emissions_{CH_4} + Emissions_{N_2O}$$

$$Emissions_{CO_2,CH_4,N_2O} = V_{natural\ gas} \times Fuel\ Ratio_{delivery\ point} \times EF_{natural\ gas}$$

Where:

V_{Gas} = Volume of gas delivered
$Fuel\ Ratio_{Delivery\ Point}$ = Ratio of gas supplied to gas delivered (see Table A3)
EF_{gas} = Emission factor for natural gas combustion in industrial equipment (see Table A3)

*Note: for fuel transportation other than natural gas, the Fuel Ratio is omitted in the above calculation.

LFG Dehydration, Processing & Compression (P5)

$$Emissions_{LFG\ Dehydration\ \&\ Processing\ System} = Emissions_{CO_2} + Emissions_{CH_4} + Emissions_{N_2O} + Emissions_{ele}$$

$$Emissions_{CO_2,CH_4,N_2O} = V_{fuel} \times EF_{fuel}$$

Where:

V_{fuel} = Volume of fuel
EF_{fuel} = Emission factor for each fuel combusted, by gas (see Table A3)

$$Emissions_{ele} = Q_{ele} \times EF_{ele}$$

Where:

Q_{ele} = Quantity of electricity consumed
EF_{ele} = Electricity emission factor (see Table A3)

Table A3, below, provides GHG emission factors for three different jurisdictions. These emission factors change from time to time; current values are available from the sources referenced below.

Table A3: Sample Greenhouse Gas Emission Factors

Emission Source	Gas	Unit	Factor (Quebec)	Factor (Ontario)	Factor (B.C)
Electricity[4]	CO_2e	kg/kWh	0.003	0.110	0.032
Natural Gas Extraction & Processing[5]	CO_2 CH_4 N_2O	kg/m^3 kg/m^3 kg/m^3	0.133 0.0026 0.000007	0.133 0.0026 0.000007	0.133 0.0026 0.000007
Natural Gas Combustion[6]	CO_2 CH_4 N_2O	kg/m^3 kg/m^3 kg/m^3	1.878 0.000037 0.000035	1.879 0.000037 0.000035	1.916 0.000037 0.000035
Fuel Ratio[7]	N/A	N/A	1.15% (Eastern Zone)	0.97% (Southwestern Zone)	1.0% (Foothills B.C.)

The basic unit of measure used in GHG quantification exercises is mass of CO_2 equivalent (CO_2e). The factors used to convert mass of CH_4 and N_2O to CO_2e for comparison purposes are the following global warming potentials: 21 kg CO_2e/kg CH_4; and 310 kg CO_2e/kg N_2O.[8]

Qualitative Evaluation of Nitrogen Oxides Emissions

Significant reductions in nitrogen oxides (NO_x) can be achieved from the displacement conventional natural gas with Green Natural Gas. The development of NO_x emissions primarily result from the reaction of nitrogen and oxygen in combustion air. The most significant sources of NO_x are *Flaring* (B6) and *Fossil Natural Gas End Usage* (B8) in the baseline scenario and *Flaring / Incineration* (P6) and *Green Natural Gas End Usage* (P9) in the project scenario.

There will be significantly less NO_x emitted in the project scenario because:

1. There are fewer NO_x emissions associated with the flare/incinerator in the project scenario because significantly less gas is flared;

2. The principal mechanism of NO_x formation is thermal. Thermal NO_x mechanisms occur through the thermal dissociation and subsequent reaction of nitrogen and oxygen in combustion air[9]. The same volume of NO_x will be formed in end use equipment regardless if the equipment uses fossil natural gas or Green Natural Gas as a fuel source;

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[4] Environment Canada. *Emission Factors from Canada's National Inventory Report 1990-2009*. http://www.ec.gc.ca

[5] Clearstone Engineering Ltd. On behalf of the Canadian Association of Petroleum Producers (CAPP), *A National Inventory of Greenhouse Gas (GHG), Criteria Air Contaminant (CAC) and Hydrogen Sulphide (H_2S) Emission s by the Upstream Oil and Gas Industry.* Calgary. 2004

[6] Environment Canada, *Emission Factors from Canada's National Inventory Report 1990-2009*. http://www.ec.gc.ca (Emission Factors from Canada's GHG Inventory\Fuel Combustion)

[7] TransCanada Pipelines Mainline Average Summer 2012 Fuel Ratios.
http://www.transcanada.com/customerexpress/mainline.html
http://www.transcanada.com/customerexpress/3677.html

[8] Intergovernmental Panel on Climate Change, Climate Change 1995: Second Assessment Report. Available at http://www.ipcc.ch/pdf/climate-changes-1995/ipcc-2nd-assessment/2nd-assessment-en.pdf

[9] USEPA, AP 42, Fifth Edition, Volume I Chapter 1: External Combustion Sources, Section 1.4: Natural Gas Combustion. 1995

3. Prompt NO_x formation, which can occur through the early reaction of nitrogen molecules in the air and hydrocarbon radicals in the fuel, is negligible compared to thermal formation[10]. Therefore it may be excluded from analysis; and

4. Fuel NO_x formation stems from the reaction of fuel bonded nitrogen compounds with oxygen. If Green Natural Gas meets natural gas pipeline specifications, fuel formation of NO_x will be approximately equivalent between the baseline and project scenarios.

Qualitative Evaluation of Sulphur Dioxide Emissions

The Green Natural Gas facility can also achieve a significant reduction in sulphur dioxide emissions. Sulphur dioxide is formed during the combustion of H_2S in the presence of oxygen. H_2S present in landfill gas is chemically converted to SO_2 during combustion.

$$H_2S + O_2 \rightarrow SO_2 + H_2O + Energy$$

During landfill gas processing, H_2S is removed from landfill gas to meet natural gas pipeline specifications. The Green Natural Gas that is produced is essentially free of sulphur and when it is subsequently combusted, it produces almost no SO_2.

In order to substantiate a reduction in SO_2 through the displacement of natural gas with Green Natural Gas, the landfill operator must provide monitored evidence that the Green Natural Gas is essentially free of H_2S as it enters the distribution pipeline than raw Landfill Gas.

Qualitative Evaluation of Volatile Organic Compounds and Particulate Matter Emissions

Volatile Organic Compound emissions refer to a wide range of naturally occurring and human produced organic chemical compounds, which can affect the environment and human health. Emissions are heavily dependent on high temperature combustion with long residence timing[11]. Particulate matter is comprised of solid matter suspended in gas.

The most significant sources of VOC and PM emissions are *Flaring* (B6) and *Fossil Natural Gas End Usage* (B8) in the baseline scenario and *Flaring / Incineration* (P6) *Green Natural Gas End Usage* (P9) in the project scenario. VOC and PM emissions are significantly reduced in the project scenario because processing of Landfill Gas to meet pipeline specification requires the use of carbon beds or other techniques for reducing VOC levels and filters to remove PM in the gas. Unless required by regulation, VOC and PM are not typically removed before flaring, such as in the baseline scenario.

[10] Ibid.
[11] Ibid.

Glossary of Terms & Acronyms

Additional	Extent to which the project produces greater environmental benefit than would have been achieved in the absence of the project. Regulatory additionality specifically addresses the extent to which the project provides greater environmental benefit than is required by law.
Baseline Scenario	The pre-project state, before the construction and operation of the project.
Biogenic CO_2 Emissions	CO_2 emissions resulting from the natural decomposition of organic matter.
CH_4	Methane
CO_2	Carbon Dioxide
Functional Equivalence	A comparison proving that the Project and the Baseline scenarios provide the same function across inputs and outputs (i.e. metered volume of landfill gas). This type of comparison requires a common metric or unit of measurement for comparison between the Project and Baseline activity and emissions profile.
GHG	Greenhouse Gas
H_2S	Hydrogen Sulphide
Landfill	A defined area of land or excavation that receives or has previously received waste.
Landfill Gas (LFG)	Gas resulting from the decomposition of organic waste in a landfill, typically comprised primarily of methane, carbon dioxide and other trace gases. Landfill gas is the byproduct from the natural decomposing organic matter created in an anaerobic condition.
Landfill Gas Project	Installation and operation of infrastructure that collects landfill gas and either combusts the gas locally, or processes the gas to be utilized for local electricity generation or injected into a pipeline as an alternative fuel to natural gas fuel.
NH_3	Ammonia
N_2O	Nitrous Oxide
NO_x	Nitrogen Oxides
PM	Particulate Matter
Project Scenario	The state of the project commencing with construction and continuing with the operation of the project.
SO_2	Sulphur Dioxide
VOC	Volatile Organic Compounds