Bioenergy Association of New Zealand

NZ GASEOUS BIOFUELS GHG CARBON INTENSITY METHODOLOGY

Acknowledgements

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Steering Committee

Feedback through the process was gratefully appreciated from all steering group members and industry stakeholders including:

- Beca - Emma Rees, Ulrich Kornmueller, Andrew Wallace.
- Ecogas - Alzbeta Bouskova
- LMS Energy – Jarrod Irving
- Bioceta – Stephan Heubeck
- First Gas – Jesse Shepherd
- Waste Management NZ

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1. SUMMARY

1.1. Purpose

The Bioenergy Association of NZ has engaged Toitū Envirocare to develop a biogas and biomethane greenhouse gas (GHG) accounting methodology for its members and the emerging sector within NZ. This carbon intensity (CI) methodology document covers the three waste-to-energy processes of wastewater treatment, landfill gas capture, and anaerobic digestion (AD) of organic waste to produce biogas and biomethane. Biogas and its refined derivative biomethane are referred to collectively as gaseous biofuels.

The intended use of the CI methodology is to:

1. Provide a publicly available, standardised GHG accounting methodology for evaluating the CI for biogas and biomethane production and use which meets international best practice;
2. Provide the key metrics and measurements required for biogas and biomethane products to satisfy the GHG accounting required for renewable energy certification (REC) schemes;
3. Establish NZ sector requirements for measurement, monitoring, and reporting as it pertains to biogas and biomethane product carbon footprint.

Internationally biogas which is refined and traded through a pipeline network is often referred to as Renewable Natural Gas (RNG). In New Zealand neither the Gas Act 1992 or NZS5442 - Specification for reticulated natural gas refer to RNG. Distributed gas is referred to as biomethane.

1.2. Instructions for Use

This gaseous biofuel carbon footprint methodology is a voluntary guideline. As a voluntary guideline, "should and shall statements" have been included to ensure that there is consistency in approach otherwise the value of the methodology is diminished for everyone if it is too broad and allows too much variation in approach. "Shall" indicates a requirement and "should" indicates a recommendation. Compliance with shall statements are required if an entity seeks compliance with this voluntary standard through verification.

This voluntary guideline does not dictate the requirements of a Renewable Energy Certificate (REC) scheme. This guideline does not mandate the frequency and depth of critical peer review required or verification process which should be outlined within an NZ REC Scheme. However, for alignment with lifecycle assessment (LCA) best practice a critical peer review is recommended in alignment with international standard ISO 14044[1].

1.3. Co-Development and Consultation

The development of this methodology is underpinned by ISO Standards for LCA (ISO 14044[2]) and Product Carbon Footprint (ISO 14067[3]). This methodology uses principles and methodologies from leading international RNG REC schemes, and low carbon/renewable fuel

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[1] ISO 14044: 2006 Environmental management — Life cycle assessment — Requirements and guidelines

[2] ISO 14044:2006, Life cycle assessment — Requirements and guidelines
[3] ISO 14067:2018, Carbon footprint of products — Requirements and guidelines for quantification

standards (LCFS). The list of research documents can be found in the accompanying research paper that underpinned this methodology development.

Methodology development was done in collaboration with the Bioenergy Association of NZ, its sector steering group including engineering firms, energy firms, energy users and government.

This methodology was subject to a public consultation and feedback during February and March 2025.

This methodology was developed by Toitū Envirocare Ltd with a third-party Independent Review from Lifecycles Australia.

1.4. Recommendation Next Steps

Through the development of this methodology, the Bioenergy Association NZ steering group have highlighted the following areas for future development.

1. A Technical Guide showing worked examples of this CI methodology. This could include a sector specific calculator with specific case studies.
2. A Technical Guide for calculating avoided emissions. This is to augment the CI of the biofuel and show the full GHG benefits of the biofuel. Avoided emissions was acknowledged as an important quantification for policy makers, investment decisions and carbon credit generation.
3. An extension of the current report to cover feedstocks from agricultural crops and energy crops.

2. GASEOUS BIOFUEL CARBON INTENSITY METHODOLOGY DEVELOPMENT

This carbon footprint methodology outlines the first New Zealand specific product carbon accounting guideline for biogas and biomethane. This methodology was developed with reference to leading clean fuel standards and biomethane Renewable Energy Certificate (REC) schemes within Canada, USA and Europe. Each international scheme has its own associated methodologies as shown below in the research references and explained further in the associated research document which informed this methodology for NZ. Appendix A contains an overview of international scheme references.

International biomethane carbon footprint methodologies and models inform the CI, the carbon emissions per unit of fuel. International methodologies have variations though all follow a life cycle assessment (LCA) approach. The key areas of variability within the CI models are the allocation method, system boundaries, assumptions, predefined default data, prescribed emission factors and timeframes. A gaseous biofuel CI is producer, scenario and model dependent; the fuel properties change over time depending on the supply chain and process to create the fuel.

This methodology is aligned to principles within many of the international methodologies, augmented with NZ specific requirements, and fully aligned to ISO 14067 product carbon footprint requirements.

This gaseous biofuel product carbon footprint methodology provides guidance for assessing the CI[4] of the product and excludes the assessment of avoided emissions and related carbon credit generation. This complies with requirements of ISO 14067 Carbon Footprint of Products.

2.1. Gaseous Biofuel Overview

Waste-to-energy (WtE) can simply be defined as the conversion of waste into electricity, heat, or biofuels. Many processes are currently being used to convert organic waste or biomass to energy. Anaerobic digestion (AD) has significant potential as a sustainable, circular economy model to support waste reduction and decarbonisation within NZ. A 2021 research document created by Beca, Firstgas Group (now Clarus), Fonterra and EECA outlines the potential of gaseous biofuel in NZ.[5] AD is a sequence of processes whereby micro-organisms break down organic matter in the absence of oxygen to produce a biogas mixture of primarily methane and carbon dioxide, with other trace amounts of gaseous by-products such as H_2S. Typically, the composition of the biogas is 50-70% CH_4 and 30-50% CO_2, with traces of H_2S and NH_3 (1% -5%).Organic waste is defined as waste products containing degradable organic matter. This includes domestic waste, commercial waste, animal manure, wastewater, organic industrial waste (such as sludge from wastewater treatment plants) agriculture waste and municipal solid waste (MSW).

Biogas is generally used directly onsite or supplied by sale to a nearby application. Biogas may also undergo refinement for blending and distribution to purchasers through a gas supply network. When refined for distribution through a pipeline network the refined gas must meet the requirements of NZS 5442(Int):2024 - Specification for reticulated natural gas. In the refining process the methane is separated from carbon dioxide and any other gaseous components such as H2S to produce biomethane. Collectively biogas and biomethane are referred to as gaseous biofuels and Renewable Natural Gas (RNG). Gaseous biofuel can be used as a replacement for fossil-based gas, a source of energy for heating, electricity generation, or as a transportation fuel.

In a controlled AD plant digestion of the feedstock generates slurry/solid residue by-products (digestate and digestate sludge) as well as the gaseous outputs. This digestate residue can be

[4] Carbon Intensity and Product Carbon Footprint are used interchangeably within this document and are intended to mean the same thing.
[5] Biogas and Biomethane in NZ - Unlocking New Zealand's Renewable Natural Gas Potential, 1/07/2021

used as fertiliser, providing a substitute for carbon intensive synthetic fertilisers such as urea, or further treated to create valuable products such as biochar.

Additionally, CO_2 is also a coproduct of the anaerobic digestion of organic residues. “The creation of valuable products like digestate and CO_2 bolster the financial and environmental benefits of RNG production and combined with the capture of biogenic emissions more than double the total emissions avoided throughout the product lifecycle” [5].

2.2. Intended Use and Users

The carbon accounting methodology’s intended use and users within the Bioenergy Sector of NZ was agreed with key sector specialist stakeholders. This information defined the quality requirements and focus areas for the methodology development. Table 1 below was agreed with the Bioenergy Association and its steering group.

- A full list of standards and references can be found in Appendix A.
- Default values can be found in Appendix B.
- Guidance on emission factor selection can be found in Appendix C.
- Acronyms and definitions section can be found at the end of the document.

Table 1: Stakeholders and most relevant standards, GHG accounting typology

Stakeholder Type	Standards / References	GHG Accounting Typology
Certifier / Verifier / Peer Reviewer	14064-1 Organisation GHG; 14067 Product GHG Standard; GHG protocol organisational inventory ISO 14064-3 GHG assurance	Organisational emissions / Product Carbon Footprint
Project Developers / Producers	14064-2 Project GHG accounting; 14067 Product GHG Standard; International REC schemes; International Clean Fuel Standards	biogas /biomethane Carbon Intensity
Biofuel REC Certificate Scheme	European Energy Certificate System (EECS); Green Gas Certification Scheme (GGCS) UK; International REC (I-REC)	biogas /biomethane Carbon Intensity
Clean / Low Carbon Fuels standards	Canada’s Clean Fuel Regulations (CFR); U.S. Renewable Fuel Standard (RFS) California's Low Carbon Fuel Standard (LCFS)	Biomethane Carbon Intensity
Consumers / Organisation GHG	14064-1 Organisation GHG; 14067 Product Standard; PAS 2050;	Organisational emissions / Product Carbon Footprint

2.3. Scope

This methodology covers the below system processes as they relate to gaseous biofuel production and GHG quantification.

1. Collection of organic waste for processing in a purpose built AD plant to gaseous biofuel facility
2. Landfill gas recovery to gaseous biofuel
3. Municipal wastewater treatment plant (WWTP) to gaseous biofuel

The methodology covers the full lifecycle CI of gaseous biofuel and the carbon footprint allocated to the coproducts of CO_2, digestate, heat and electricity. It delineates the key lifecycle stages so they can be used for reporting purposes within an organisational carbon footprint where a renewable gas certificate is used. Measurement and verification best practice is highlighted in alignment with international standards.

This methodology is intended to enable a gaseous biofuel Renewable Energy Certificate (REC) scheme within NZ.

2.4. Carbon Intensity and Functional Unit

Product carbon footprint methods develop a product carbon footprint relative to a functional unit of the product. Some clean fuel standards refer to this as CI.

Product carbon footprint is underpinned by life cycle assessment (LCA). Life Cycle Assessment (LCA) is the compilation and evaluation of the inputs, outputs, and the potential environmental impacts of a product system throughout its life cycle (ISO 14040).

The global standard functional unit for biomethane is MJ or kWh of fuel energy based on the higher heating value (HHV). The carbon emissions per functional unit is typically CO_2e/ energy content of fuel. This is commonly expressed as gCO_2e/MJ, or its equivalent in magnitude $kgCO_2e/GJ$ and is adopted for this methodology.

The energy density, or calorific value, of gaseous biofuels is measured and calculated within this methodology and varies depending on the producer, feedstocks and a range of other producer specific variables.

The energy density of transmission pipeline specification biomethane must meet the NZ Specification for reticulated natural gas (NZS 5442:2024), and its required Wobbe Index (WI) and relative density limits which imply a calorific value range (energy density) of 35.2 MJ/m^3 – 46.5 MJ/m^3.

2.5. Emission factors

A greenhouse gas emission factor (EF) is a co-efficient that describes the mass of a greenhouse gas emitted relative to input or output of a unit process, or a combination of unit processes. Suitable factors need to be selected for this gaseous biofuel CI calculation.

EFs should be full life cycle factors suitable for an ISO 14067 product carbon footprint measurement. Full lifecycle EFs can be accessed from databases such as

Ecoinvent which is the most widely used and comprehensive life cycle inventory databases in the world.

In some instances, emission factors can be sourced from Ministry for the Environment (MFE) latest publicly accessible factors[6]. Caution needs to be applied when using these emission factors within this LCA carbon footprint methodology to ensure that the MFE EFs are applied to cover the lifecycle emissions of the source being quantified. MFE EFs are primarily for organisational carbon footprint which may not include the full lifecycle emissions. Therefore When emissions factors are not full LCA EF's (such as direct emission factor), the value should be supplemented with other relevant supply chain scope 3 emissions factors. Note the MFE EF for AD does not meet the requirements of this methodology for accuracy[7].

All practicable efforts to use the most accurate and representative emissions factors should be applied in alignment with the below hierarchy:

1. Full life cycle supplier specific EFs from the supplier of a product or service.
2. Life cycle emissions factors from Ecoinvent where relevant.
3. Latest NZ MFE EF's where applicable
4. Other government published data for NZ
5. Industry specific studies

More guidance is available in the Toitū explainer on precision and accuracy in Appendix A.

Global Warming Potential (GWP) values from the latest IPCC Assessment Report from the shall be used where possible (currently 6th Assessment Report).

2.6. Treatment of GHG gases and biogenic CO_2

This methodology accounts for all relevant GHGs, including CO_2, methane (CH_4), and nitrous oxide (N_2O) in the emissions assessment. The individual GHGs shall be reported disaggregated prior to aggregating to a CO_2 equivalent. The total carbon footprint of the biofuel is aggregated to a Carbon Dioxide Equivalent. CO_2 equivalent (CO_2e) is a metric used to standardize and quantify the global warming potential (GWP) of different greenhouse gases (GHGs) by expressing them in terms of the warming impact of carbon dioxide (CO_2).

The Global Warming Potential (GWP) is an index, based on radiative properties of GHGs, measuring the radiative forcing following a pulse emission of a unit mass of a given GHG in the present-day atmosphere integrated over a chosen time horizon, relative to that of

[6] MfE Measuring Emissions: A guide for organisations: 2024 detailed guide
[7] MFE Default AD factor is from 2006 IPCC, Ch. 4, Table 4.1. The factor makes assumptions on feedstock, DOC, and fugitives which make it usable for a product LCA.

carbon dioxide (CO_2). The GWP shall be based on a 100-year lifecycle and should be sourced from the latest MFE values AR5 /AR6 or IPCC report AR5/AR6 per Table 2 below.

Table 2: GWP of gaseous biofuel GHGs adapted from the latest IPCC values[8].

Greenhouse Gas	AR5 GWP-100 ($kgCO_2e/kg$)	AR6 GWP-100 ($kgCO_2e/kg$)
CO_2	1	1
CO_2 (biogenic)	0	0
CH_4 (fossil)	30	29.8
CH_4 (biogenic)	28	27.9
N_2O	265	273
Sulphur hexafluoride	23,500	24,300

Organic wastes including food waste, DAF (dissolved air flotation) sludge and wastewater sludge are considered renewable biogenic feedstocks for generating biofuel from biogenic decomposition. Organic waste contains biogenic carbon that is assumed to normally decompose via aerobic or anaerobic decomposition and be released to the atmosphere. Methanogenesis is the final stage of anaerobic digestion, where microorganisms produce methane (CH_4) from intermediate compounds. Gaseous biofuel production collects the CH_4 from the methanogenesis cycle to use for fuel. This guideline treats biogenic CO_2 emissions as zero because it would have been released to atmosphere via natural processes due to decomposition. This aligns to the approach of the IPCC[9] and organizational/ user emissions under ISO14064-1. This carbon neutral approach to gaseous biofuels combustion also aligns with the UK Green Gas Certificate Scheme by which the combustion of biogas and biomethane treat CO_2 emissions as zero. This treatment of directly combusted gaseous biofuels is due to their neutral status in the carbon cycle, as they are part of the biogenic carbon cycle (Figure 1).

Users of gaseous biofuels shall not count the biogenic CO_2 emissions towards the carbon intensity, however it must be accurately calculated and reported separately in the LCA results and organizational inventory. All biogenic emissions other than CO_2, such as biogenic CH_4 and N_2O should be recorded within the carbon footprint of the user and product. This helps stakeholders understand the full scope of emissions associated with a product.

Based on the net zero aspect of biogenic CO_2, switching to gaseous biofuel is a potent emission reduction option for switching from fossil gas. Across the lifecycle biomethane has an 60-65% reduction of emissions relative to fossil gas due to the near zero emissions of biomethane combustion.

[8] Canadian Clean Fuel Regulations: Specification for Fuel LCA Model CI Calculations, V3.0, 2024

[9] 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 3 on Solid Waste Disposal, methane recovery. pg. 3.18

For further reading on the application of biogenic emissions in organisation carbon accounting, see Toitū's explainer[10].

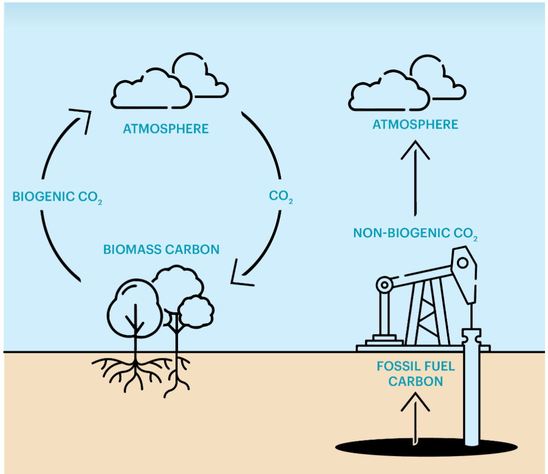

Figure 1 Short Term Biogenic Cycle vs. Long Term Fossil cycle[10]

2.7. Renewable Feedstock

Renewable biofuel is defined as a fuel produced from biomass. No substrate feedstock of fossil origin can be used to produce renewable biofuels. This methodology covers **biogenic waste feedstock** to produce gaseous biofuel and excludes agricultural crops[11] from its scope. Agricultural crops and energy crops are also considered a renewable feedstock however were excluded from the scope of this guidance. Waste is herein defined as a substance which the owner intends or is required to dispose of in alignment with ISO 14067.

The feedstock shall align with the EU RED Cert[12] scheme principles for sustainable biofuels. To ensure the biogenic feedstock is renewable and sustainable it shall meet the definition of biogenic waste as per Figure 2 flowchart (adapted from the EU REDCert).

[10] Explainer Series | Why Biogenic emissions matter | Toitū Envirocare (toitu.co.nz)
[11] Agricultural crops are plants grown for the purpose of producing biofuels.
[12] REDCert, Scheme principles for the production of biomass, biofuels, bioliquids and biomass fuels

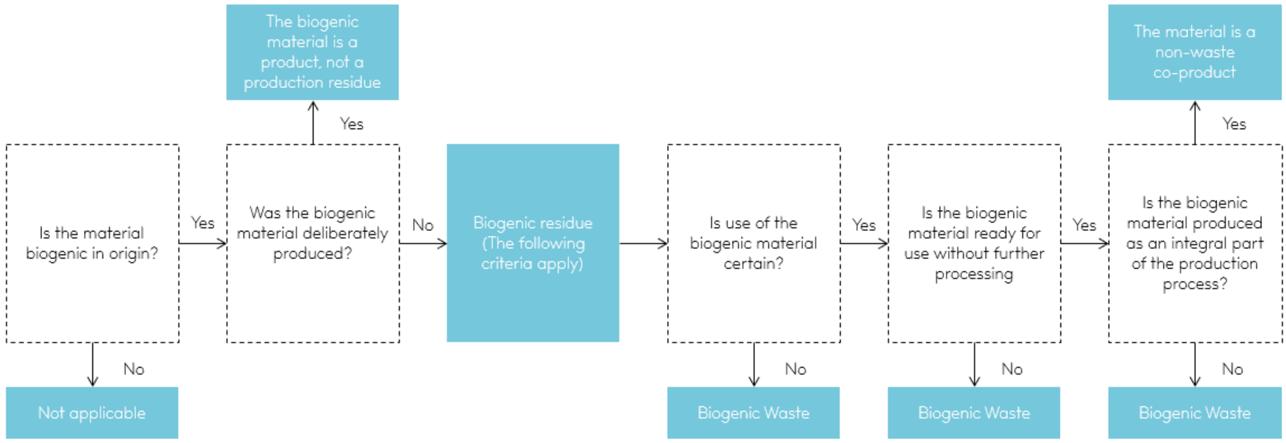

Figure 2: Flowchart to ensure Sustainable Biogenic Waste Feedstock

Renewable organic/biogenic waste feedstocks included in this methodology are:

1. Municipal, industrial and commercial wastewaters or sludges,
2. Organic component of municipal solid waste,
3. Waste from food production and agriculture e.g. crop residues, horticultural waste, agriculture byproducts,
4. Food and beverage processing waste,
5. Food waste from retailers, distributors, consumers (including hospitality, government, institutions, companies etc),
6. Vegetative matter (including garden waste), and timber waste,
7. Animal waste, specifically (but not limited to) agricultural waste.

2.8. Temporal Boundary

A gaseous biofuel CI is dependent on many variables which change over time depending on the feedstock, transportation, inputs, outputs and process to create the fuel.

All material (significant) activity data relevant to the gaseous biofuel system boundary shall be collected and on an annual basis. Gaseous biofuel CI shall be calculated on an annual basis from the annual historical data relevant to the product LCA.

Verification is the process of evaluating a GHG claim with past historical data to determine it is materially correct and conforms to predetermined criteria. This is typically done annually by international REC schemes and Low Carbon Fuel Standards such as International REC scheme (I-REC), California Low Carbon Fuel Standards and EU RedCert.

This guidance document does not mandate a verification frequency but instead stipulates a critical peer review of the annual LCA report in alignment with ISO 14044.

2.9. System Boundary

The system boundary is a key concept in life cycle assessment (LCA) and associated product carbon footprint. The system boundary is the boundary based on a set of criteria representing which unit processes are a part of the system under study.

Figure 3 shows two system boundaries for this methodology. This methodology provides the system boundary for the **Cradle to Gate** and **Cradle to Grave** CI of the gaseous biofuel product. Cradle-to-gate defines the scope of a carbon LCA which covers all life cycle stages up to the production facility gate. Cradle-to-grave defines the scope of a carbon LCA which covers the full life cycle including end use combustion emissions of the gaseous biofuel.

This methodology covers both system boundaries which aligns with the requirements of many of the biomethane certification schemes internationally. The Canadian Clean Fuel Regulations scheme require reporting of both boundaries, EU REDCert require cradle to grave, and the World Biogas Association require cradle to gate. The system boundary includes upstream inputs of organic waste products and all material activities, inputs and outputs of anaerobic digestion and subsequent refinement of biogas to biomethane. Further details on activities included in the system boundary are found in later sections and Figure 9.

The upstream boundary (“cradle”) is at the point where the biofuel developer/ producer is extracting feedstock to create value/ energy. Exclusions from the upstream boundary are based on negative value/ polluter pays principal (waste management is a cost item/ environmental burden to prior lifecycle of materials being disposed).

Producers of gaseous biofuel shall report the Cradle to Gate product carbon footprint. The LCA gate is at the pipeline network, post biogas scrubbing, compression and injection into the pipeline network. Gate to grave emissions includes transmission and combustion of the gaseous biofuel which happens outside of the control and influence of the producer.

Users of gaseous biofuel require full cradle to gate and gate to grave emissions assessment for an organisational compliant GHG inventory to ISO 14064-1. Cradle to gate emissions satisfies user emissions reporting indirect emissions of the fuel and is often referred to as upstream “well to tank” emissions (GHG Protocol, Scope 3, Category 3)[13].

Gate to grave emissions include direct emissions from combustion of the gaseous biofuel and indirect emissions from transmission and distribution (T&D) losses in the pipeline network (“tank to wheel”). Combustion emissions satisfy user emissions reporting direct emissions (GHG Protocol, Scope 1). T&D emissions satisfy user emissions reporting GHG Protocol, Scope 3, Category 3 indirect emissions.

[13] Corporate Value Chain (Scope 3) Accounting and Reporting Standard

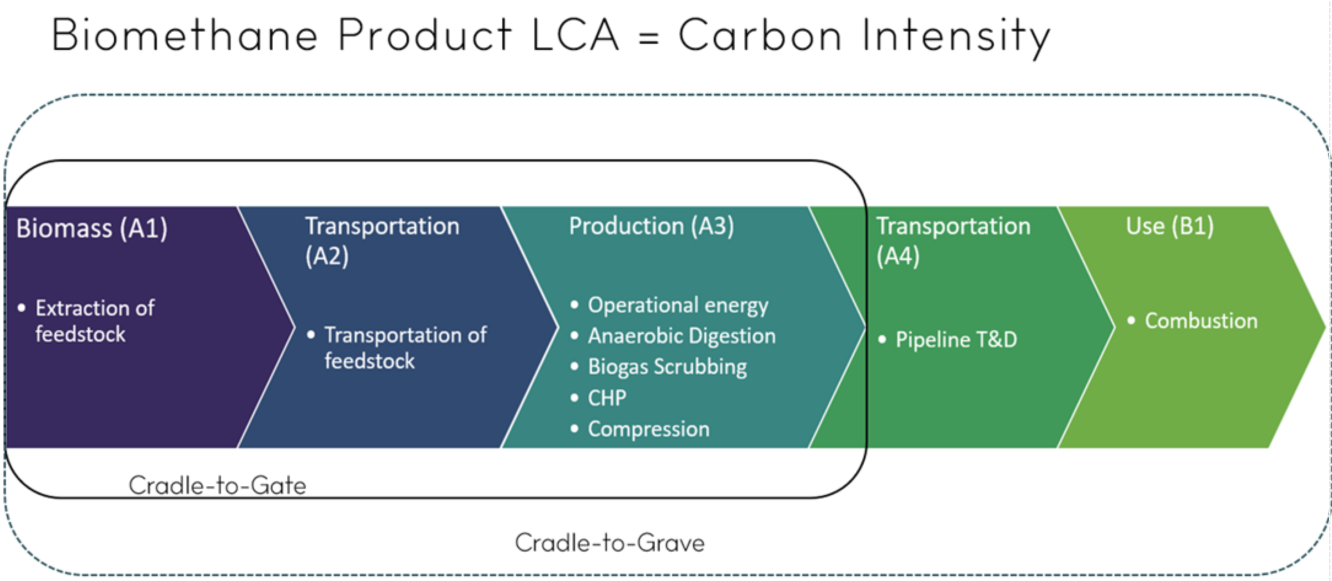

Figure 3 – System boundary, cradle to gate and cradle to grave

2.9.1. Organic Waste to AD Plant - System Boundary

One of the three system processes detailed in this methodology is the organic waste to AD Plant gaseous biofuel project. The AD Plant is purpose built, that uses organic waste as feedstock for gaseous biofuel production within an engineered facility designed to produce biofuels.

The AD Plant biofuel emissions are the GHG emissions that occur within the system boundary of the biofuel production. Figure 4 highlights the upstream boundary of the organic waste to AD Plant treatment process. The dotted lines show the alternative waste treatment process with the solid line showing the AD Plant upstream system boundary. **The upstream boundary is at the point where the biofuel developer/ producer is extracting feedstock to create value/ energy, and this may change depending on the point of extraction.**

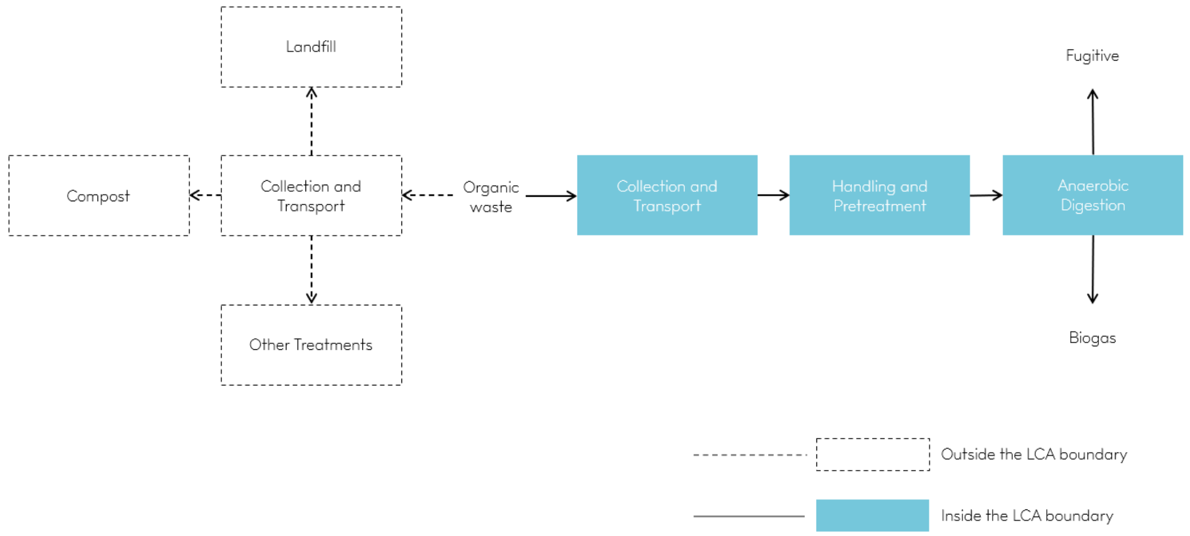

Figure 4: Organic Waste Diversion to AD Plant, Upstream LCA System Boundary[14]

Table 3 below shows the **upstream** sources that would be included/excluded in the gaseous biofuel CI calculation.

[14] Carbon Accounting Methodology for Biogas, American Biogas Council, DRAFT 1.0 — March 8, 2024

Table 3: Upstream GHG Sources, Organic Waste to AD Plant LCA Boundary

Source	Emission Source	Gas	Included/ Excluded	Justification
AD Plant Construction	Embodied Emissions	CO_2, CH_4, N_2O	Excluded	Global Methodologies exclude embodied emissions from plant construction. Deemed outside LCA boundary[15].
Feedstock Production	Fossil fuel, land use, inputs for growing organic material.	CO_2, CH_4, N_2O	Excluded	Feedstock is a waste product and therefore emissions for production are associated to the user of the product and not to the end-of-life recovery / reuse process based on Polluter Pays Principle. [16]
Community Waste Collection	Energy /Fossil fuel Consumption of Waste Collection	CO_2, CH_4, N_2O	Included	Include community kerbside waste collection and transportation to local transfer station in community services.
Feedstock Extraction	Energy /Fossil fuel Consumption, Fugitive emissions	CO_2, CH_4, N_2O	Included	Biofuel LCA starts at the point of Feedstock extraction at the location of waste collection. (i.e. kerbside or commercial site)
Feedstock Transportation	Energy / Fossil fuel consumption	CO_2, CH_4, N_2O	Included	Feedstock Transportation to AD facility.
Feedstock Processing	Facility energy/fossil fuel consumption, fugitive emissions.	CO_2, CH_4, N_2O	Included	Includes all processing emissions for biogas / biomethane. Includes fugitive emissions of the AD and processing.

2.9.2. Landfill Gas System Boundary

The second of the three system processes defined in this methodology is the landfill gas (LFG) to gaseous biofuel project. Landfill gas bioenergy projects are defined as projects that capture LFG from the anaerobic decomposition of municipal solid waste (MSW) and non-municipal landfills. Anaerobic decomposition is delineated from AD plants as it is a passive (uncontrolled) process within the landfill that happens over an extended period of time 20-30 years.

There are three common types of landfills, see Table 4.

[15] World Biogas Association notes that more work and consideration is needed here by certification bodies.
[16] In alignment with the "polluter pays principle" of environmental law.

Table 4: Landfill Types in NZ[17]

Landfill type	Description
Municipal (class 1) lanfills with gas recovery	Municipal, well managed landfill where a landfill gas recovery system is installed. Some of the CH_4 produced during the organic decomposition of waste is captured and destroyed.
Municipal (class 1) landfills without gas recovery	Municipal, well managed landfill where all the CH_4 produced during the organic decomposition of waste escapes into the atmosphere, apart from that which is oxidised inside the landfill.
Non-municipal (class 2-5) landfills	Non-municipal landfills that accept a broader range of wastes where the CH4 produced during organic decomposition of waste escapes into the atmosphere.

Landfills have the highest fugitive emissions of the three waste management processes, and a portion of those emissions shall be allocated to the CI of the biofuel. Upstream transportation for community waste collection should be accounted for from the local transfer station. Commercial waste transportation should be from the location where the waste is extracted to create value/ biofuel. Fugitive emissions created during the conversion of LFG to the gaseous biofuel is within the upstream boundary of the gaseous biofuel CI. Figure 5 and Table 5 below shows the common **upstream** emissions sources within the gaseous biofuel CI calculation for landfills.

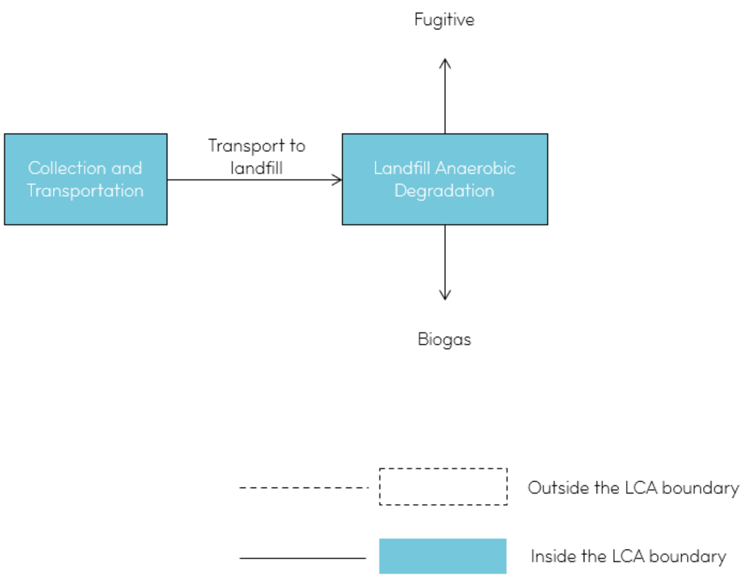

Figure 5: LFG to gaseous biofuel LCA Upstream Boundary

[17] Wasteminz, Technical Guidelines for the Disposal to Land - Project Team Draft - Revised B, MfE comments

Table 5: Upstream GHG Sources, LFG gaseous biofuel LCA Boundary

Source	Emission Source	Gas	Included/ Excluded	Justification
AD Plant Construction	Embodied Emissions	CO_2, CH_4, N_2O	Excluded	Global Methodologies exclude embodied emissions from plant construction. Deemed de minimis and outside LCA boundary[18].
Feedstock Production	Fossil fuel, land use, inputs for growing organic material.	CO_2, CH_4, N_2O	Excluded	Feedstock is a waste product and therefore emissions for production are associated to the user of the product and not to the end-of-life recovery / reuse process based on Polluter Pays Principle. [19]
Community Waste Collection	Energy /Fossil fuel Consumption of Waste Collection	CO_2, CH_4, N_2O	Included	Include community kerbside waste collection and transportation to local transfer station in community services.
Feedstock Extraction	Energy /Fossil fuel Consumption, Fugitive emissions	CO_2, CH_4, N_2O	Included	Biofuel LCA starts at the point of Feedstock extraction of waste collection.
Feedstock Transportation	Fossil fuel consumption	CO_2, CH_4, N_2O	Included	Upstream transportation for community waste collection should be accounted for. Commercial waste transportation should be from the location where the waste is extracted to create value/ biofuel.
LFG Fugitives	Landfill Fugitive emissions & Flaring	CO_2, CH_4, N_2O	Included	Fugitive emissions associated to the landfill are attributed to Gaseous Biofuel (with or without LFG capture).
LFG Processing	Landfill energy consumption, Fugitive emissions	CO_2, CH_4, N_2O	Included	Includes all processing emissions for LFG to biogas / biomethane.

2.9.3. Wastewater Treatment Plant Boundary

The third system processes defined in this methodology is the Wastewater Treatment Plant (WWTP) to gaseous biofuel project. The WWTP to gaseous biofuel project diverts the plants sludge to be processed to gaseous biofuel production in a purpose-built facility at the same geographical site.

On the WWTP, biogenic methane (CH_4) is generated through the conversion of organic matter by the process of methanogenesis. This process can occur in the solids removed from the water supply during water treatment, and from the organic matter found in wastewater and removed in its treatment process. The CI boundary focuses on the sludge

[18] World Biogas Association notes that more work and consideration is needed here by certification bodies.
[19] In alignment with the "polluter pays principle" of environmental law.

treatment to AD, therefore the standard water treatment process is excluded from the upstream boundary of the gaseous biofuel CI.

Biogenic nitrous oxide (N_2O) occurs as the product of denitrification and/or nitrification of the nitrogen compounds found in wastewater by microorganisms, including as part of the treatment process itself. The major sources of biogenic methane and nitrous oxide in the wastewater network are illustrated in Figure 6.

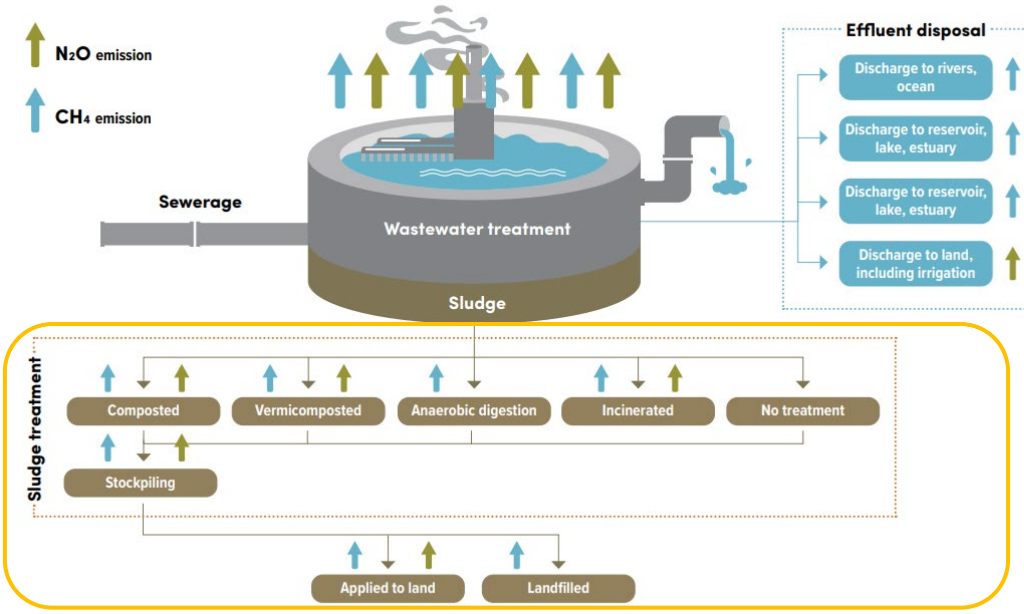

Figure 6: Biogenic methane and nitrous oxide emissions from wastewater treatment, picture credit Navigating to Net Zero, Water NZ, Wastewater emissions[20].

Figure 7 shows the upstream boundary between the WWTP treatment and an AD plant installed on the same site. In this system process, the gaseous biofuel CI excludes the energy and emissions of the WWTP plant upstream of the AD Plant.

Any additional energy and emissions from the activities at the AD facility to process the gaseous biofuel onsite is within the upstream boundary of the LCA. Table 6 below shows the common upstream emissions sources included within the gaseous biofuel CI calculation.

[20] Water NZ published *Accounting Guidelines for Wastewater Treatment*

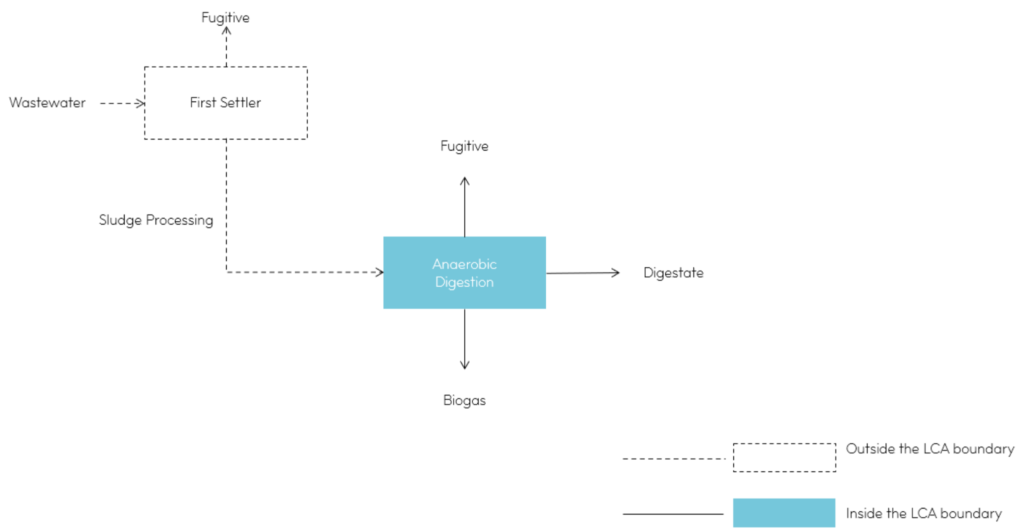

Figure 7: WWTP AD Plant for Treatment of Sludge showing upstream project boundary.

Table 6: Upstream GHG sources, Wastewater to gaseous biofuel LCA

Source	Emission Source	Gas	Included/Excluded	Justification
Embodied	Carbon footprint of building AD Plant.	CO_2e	Excluded	Global Methodologies exclude embodied emissions from plant construction. Deemed outside LCA boundary[21].
Feedstock Production	Fossil fuel Consumption, Fugitive emissions	CO_2, CH_4, N_2O	Excluded	Feedstock is a waste product and therefore emissions for production are associated to the user of the product and not to the end-of-life recovery / reuse process based on Polluter Pays Principle. [22]
Wastewater Processing	Electricity /Fossil fuel Consumption, Fugitive emissions	CO_2, CH_4, N_2O	Excluded	Emissions related to the collection and processing of the wastewater upstream of the AD process are excluded. These emissions are associated to the producer of the wastewater, based on Polluter Pays Principle.
Sludge/ Feedstock Collection for AD	Electricity /Fossil fuel consumption	CO_2, CH_4, N_2O	Included	Emissions related to the collection of the sludge feedstock for AD Plant. e.g. pumps and equipment for sludge processing for AD.
Feedstock Transportation	Fossil fuel consumption	CO_2, CH_4, N_2O	Depends on location of AD	Excluded if wastewater treatment and AD is at the same location. Included if AD is at a different location then wastewater treatment.
Sludge AD Processing	WWTP energy consumption and fugitive emissions.	CO_2, CH_4, N_2O	Included	Includes all processing emissions for sludge to biogas / biomethane. Includes fugitive emissions from the AD process and upgrading including any pretreatment prior to AD for the purpose of increasing energy density of the fuel. E.g. thermal hydrolysis or acid phase digestion.

[21] World Biogas Association notes that more work and consideration is needed here by certification bodies.
[22] In alignment with the "polluter pays principle" of environmental law.

3. PROCESS FLOWS AND ACTIVITY DATA

ISO 14067 requires that the gaseous biofuel CI methodology define consistent criteria for:

1. Which unit processes require a detailed assessment is needed due to an expected significant contribution to the carbon footprint;
2. Which unit processes the quantification of GHG emissions may be based on secondary data if the collection of primary data is not possible or practicable;
3. Which unit processes may be aggregated,

All process flows within the CI system boundary are to be included where they are material.

Within this methodology, materiality is a word to describe if a GHG source or sink is significant enough to include in the gaseous biofuel CI. A source is material if it is of significant magnitude (>1%). An emissions source is also material if it is less than 1% in magnitude and the producer has an ability to measure and influence those emissions. A source or sink can also be material if it is significant to the sector or key stakeholders of the GHG information.

If a GHG source from a process flow can be demonstrated to be immaterial (de minimis) compared to the overall footprint (less than 1% of total[23]), that flow may be excluded. The effect of any exclusions on the outcome of the assessment shall be included in the gaseous biofuel product carbon footprint report. The total of the sources classified as immaterial or de minimis shall not exceed 5% of the total gaseous biofuel carbon footprint.

Figure 8 is an example of the types of process flow inputs and outputs considered and measured as part of the gaseous biofuel system LCA.

[23] ISO 14044 LCA

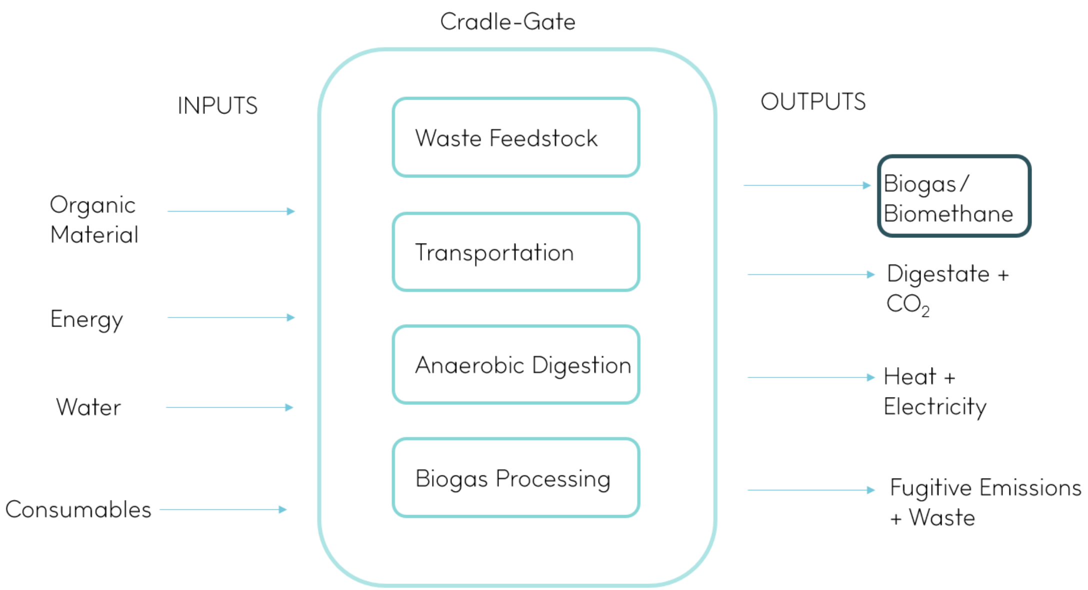

Figure 8: Biogas / Biomethane Process Flows example inputs and outputs.

3.1. Mass Balance

Mass balance is a key concept in gaseous biofuel CI accounting for producers. It ensures accurate tracking and reporting of emissions throughout the production process.

Mass balance is based on the law of conservation of mass; that the mass entering a system must equal the mass leaving the system plus any accumulation within the system over a specified period. This is expressed mathematically as:

$$\text{Mass In} - \text{Mass Out} = \Delta\ \text{Storage}$$

The primary goal of mass balance is to ensure that all material flows are accounted for, providing a check on the validity and completeness of the data. It helps in identifying discrepancies and ensuring that the system is accurately represented.

Producers must collect activity data on all material flows, including biomass inputs, biogas outputs, and any co-products, by-products or waste streams. [24]

The mass balance system must include both,

1. Information on the input/output of raw materials and fuels for which the above sustainability characteristics have been determined (sustainably certified raw materials and fuels), and,
2. Information on the input/output of raw materials and fuels, including fossil fuels, for which no sustainability characteristics have been determined.

[24] REDcert EU - Scheme principles for GHG calculation - Version EU 06, 2023

3.2. Activity Data Requirements

Once the material / mass inputs and outputs to the gaseous biofuel system are defined, key activity data must be measured or estimated in a transparent and comprehensive manner.

Activity data in GHG accounting is defined as the quantity of an emitting activity being measured, for instance the kWh of electricity used to power a process. Activity data quality should always be prioritised for the most material emissions sources within the system boundary.

Activity data is categorised as primary or secondary data as defined below, and primary data should always be prioritised where practicable.

1. **Primary data is defined as the quantified value of a process or an activity obtained from a direct measurement, or a calculation based on direct measurements.** For instance, kWh of electricity purchased, measured at meter.
2. **Secondary data is defined as data which do not fulfil the requirements for primary data. Secondary data can include data obtained from proxy processes or estimates.** For instance, using spend data to estimate emissions of a quantity of purchased consumables or using average sector default values for fugitive emissions.

All material activity data should be peer reviewed.

Key GHG sources, activity data units/metrics and data quality are presented in Table 7, Table 8 and Table 9. Emission Factor sources and defaults are provided through the calculations and summarised in Appendix B.

Table 7: Gaseous biofuel, GHG activity data and data quality

Life cycle stage	Parameter / GHG source	Activity Data unit	Primary or Secondary	Activity Data source	EF source / Default
Waste feedstock extraction	Waste Input per waste type eg. food waste, DAF sludge, WWTP Sludge. Report percentage of degradable organic carbon (DOC) and percentage total solids / dry solids.	kg, DOC, %DS	Primary (based on actual formulation)	Project/ Site specific	DOC Table 5 Calculated
Waste feedstock transportation	Road freight	L fuel / or t.km	Primary / secondary	Freight fuel use; alternatively, Feedstock Weight and distance travel	MFE direct fuel use + WTT indirect emissions [25]
Biogas Processing (Indirect emissions)	Chemicals	kg or $	Primary or Secondary	Site Records or expenditure	Ecoinvent
	Electricity used from grid	kWh	Primary	energy invoices	MFE location-based EF
	Consumables	kg or $	Primary or Secondary	Site Records, expenses	Supplier specific or Ecoinvent, MFE
Biogas Processing (Direct emissions)	Fugitive emissions	m^3 gas	Primary or Secondary		default fugitive emissions or calculate
Biogas Processing (Direct emissions)	Digester Leakage	m^3 gas	Primary or Secondary	Site Measurements preferable	default fugitive emissions or calculate
	Flaring / Combustion	m^3 gas	Primary	Flare Flow control	MFE
	Digestate storage and Lagoons	m^3 CH_4	Primary or Secondary	input rate of volatile solids (VS) measured monthly	Calculated per Equation 15 Default: 0.48 m^3 CH_4/kg VS

[25] Agrilink, NZ Fuel and Electricity – Total Primary Energy and GHG Emission Factors 2022

Life cycle stage	Parameter / GHG source	Activity Data unit	Primary or Secondary	Activity Data source	EF source / Default
	Combined Heat and Power (CHP), heat and electricity cogeneration on production site	GJ fuel, CI fuel, efficiency	Primary	Site specific	Calculated per plant [26] see Equation 8
	Diesel / Fossil Fuels	Litres		Site Records	Ecoinvent / Agrilink

Table 8: GHG activity data and data quality, Waste and Byproducts

Life cycle stage	Parameter / GHG source	Activity Data unit	Primary or Secondary	Activity Data source	EF source / Default
Waste	Waste	kg	Primary	Site Records	MFE waste EFs. Equation 16
CO_2 Gas	Co-product	m^3	Primary	Site Records	Biogenic CO_2 - zero carbon product
Digestate	Co-product	kg	Primary	Site Records	zero carbon product

Table 9: GHG activity data and data quality, Distribution and combustion

Life cycle stage	Parameter / GHG source	Activity Data unit	Primary or Secondary	Activity Data source	EF source / Default
Distribution	Biofuel at pipeline pressure and specification	GJ	Primary	Biofuel volume	MFE T&D loss EF
Combustion	Biogenic combustion	GJ	Primary	user GHG inventory	per ISO 14064-1, MFE, Equation 4 Equation 6

3.3. Exclusions

This methodology prioritises energy and material inputs that are part of the life cycle of a fuel, including the emissions associated with the production and the use of its inputs. From these inputs and emissions, only significant contributors to the CI of fuel are considered.

[26] Environment and Climate Change Canada, Fuel life cycle assessment model methodology, CI of the electricity and thermal energy produced by the CHP system per section A4.

Table 10 contains processes and activities are excluded from the methodology due to their negligible contribution or limitations such as lack of data, methods or high uncertainty or outside of the system boundary.

Table 10: GHG source exclusions for the RNG CI

Exclusion	Justification
Construction and decommissioning of equipment and facilities	Excluded from all the international methodologies researched. Considered non-material while being inside the system boundary.
Indirect land use change from construction of facilities.	Excluded from all the international methodologies researched. Due to exclusion of non-waste feedstocks is assumed to be zero.
The manufacturing of fuel transportation infrastructure (i.e., pipelines, trucks, ships, roads)	Considered non-material while being inside the system boundary.
The manufacturing of fuel combustion infrastructure (i.e., vehicles, boilers)	Considered non-material while being inside the system boundary.
Wastewater treatment processes upstream of the waste diversion to AD Plant.	Outside of system boundary based on polluter pays principal (waste management is a cost item/ environmental burden to prior lifecycle of materials being disposed).
Indirect activities associated with fuel production, such as marketing, accounting, commuting, and legal activities	Considered non-material while being inside the system boundary.
Digestate application to land & CO_2 use	Digestate has positive value and is considered a coproduct and not a waste treatment process. Impacts of application are attributed to the user of the digestate as it provides positive economic and environmental benefits to the users.

4. GASEOUS BIOFUEL CI CALCULATION METHODOLOGY

To calculate the CI of biogas/ biomethane several key activity data metrics are essential as described in previous sections. These metrics help in performing a comprehensive life cycle assessment (LCA) to quantify greenhouse gas (GHG) emissions associated with production to calculate a product carbon footprint. The calculations and metrics for this RNG CI calculation methodology are described below. **Some of the variables will require further detailed calculations to cover the specifics of the system process and variables of the producer. It is the intention that this formula will provide overall coverage of the product emissions sources with detailed nuances to be determined by the producer.**

4.1. Gaseous Biofuel Cradle to Gate Carbon Intensity Calculation

Cradle-to-gate: scope of a CI which covers all life cycle stages up to the production facility gate. Below Equation 3,Equation 4, Equation 5 are adapted from EU REDcert methodology.

Equation 1: $CI_{biofuel} = PE \div (V_{biofuel} \text{ x } Ed_{biofuel})$

CI = Carbon Intensity of gaseous biofuel ($kgCO_2e/GJ$)
PE = Annual total production emissions of gaseous biofuel (Cradle to Gate) ($kgCO_2e$)
$V_{biofuel}$ = Volume of gaseous biofuel produced for the annual period at atmospheric pressure and temperature (m^3)
$Ed_{biofuel}$ = Energy density of gaseous biofuel; (GJ/m^3)
Ed_{biogas} or Ed_{BM} = $\%CH_4$ x 0.0398 (HHV of CH_4, GJ/m^3)

Equation 2: $PE = F + CE + EU + FE_T + CU + W$

PE = Annual total production emissions of gaseous biofuel (Cradle to Gate) ($kgCO_2e$)
F = Feedstock Emissions
CE = Combustion Emissions
EU = Electricity Use Onsite
FE_T = Fugitive Emissions
CU = Consumables Used Onsite
W = Waste Emissions

4.2. Feedstock Emissions (F)

Feedstock emissions are considered those emissions associated to the extraction process and transportation of the feedstock to the gaseous biofuel system. The feedstock of the gaseous biofuel is the renewable organic waste diverted from other processes.

This formula allows for various feedstocks of **x** to be aggregated into an overall feedstock emissions (F).

Equation 3: $F = \sum M_x (E_x + T_x)$

F = Feedstock Emissions ($kgCO_2e$)
M_x = Mass of waste feedstock ***x*** input into biofuel. (kg)
E_x = Emissions from the extraction of the feedstock **x**. ($kgCO_2e/kg$)
T_x = Emissions from transport of feedstock **x** to gaseous biofuel system. ($kgCO_2e/kg$)

4.2.1. Feedstock Transportation (Tx)

Feedstock transportation should be addressed in a consistent manner within the LCA.

Transportation emissions shall include well to tank and tank to wheel emissions assessment. Well to tank emissions are the upstream indirect emissions from fuel extraction, processing, and transport to the fuel tank/pump location. Tank to wheel emissions are the direct emissions from the use of the transportation fuel within the vehicle (e.g., Combustion of fuel or direct use of electricity). The figure below shows this.

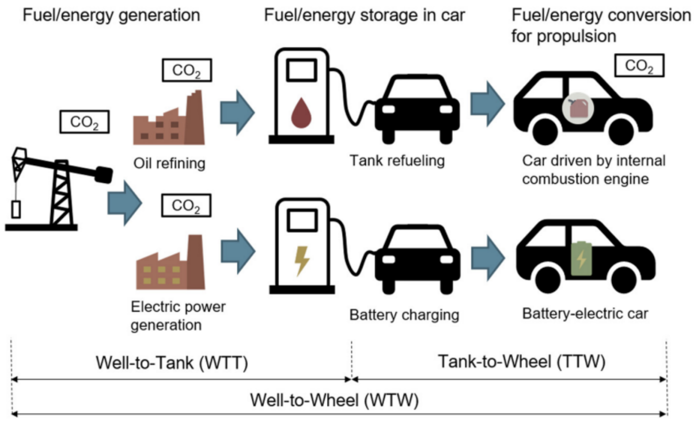

Figure 9: Well to tank vs Well to Wheel emissions[27]

It should be noted that MFE 2024 detailed guide emissions factors do not include well to tank indirect upstream emissions from fuels. For well to tank emissions factors see Appendix B.

Transportation tank-to-wheel emissions can be calculated in multiple ways as listed below in order of highest accuracy,

1. **Fuel-based method (recommended)**: Litres of fuel consumed (by fuel type), for feedstock transportation,
2. **Distance-based method (not recommended)**: requires km or Tonne-km data, by freight mode (road, rail, sea, air) and vehicle type for all freight,
3. **Spend-based method (not acceptable)**: requires spend data by freight mode.

The fuel-based method is most accurate and is the recommended approach of this methodology. Fuel should be measured and allocated by the transportation supplier based on the freight mass and distance travelled. If the transportation supplier is optimizing efficiency and using backloading then applying the fuel method will be most accurate when allocating a discounted portion of the fuel to the backload. In the fuel-based method, the capacity and intensity of fuel consumption of the vehicle may vary based on the loading. Therefore, to determine the amount of fuel used, data can be obtained from fuel purchase records instead of direct fuel measurement.

The distance-based tonne-km method can be estimated based on the mass and distance of the feedstock transportation. MFE provide a long-haul heavy truck ton-kilometer (tkm) emission factor that is NZ specific and includes an industry wide allocation of empty return trips within the emissions factor. This factor is useful when the feedstock is a portion of the freight and there is no fuel data available.

The spend based method shall not be used for the upstream and direct transportation emissions. Spend based method uses $ spend activity data and is an industry average

[27] World Electr. Veh. J. 2022, 13, 61

emissions intensity per $ based on EEIO data (economic environmental input output tables). Spend based method is generally unacceptable for an LCA calculation based on its high level of uncertainty.

4.3. Combustion Emissions (CE)

Direct emissions are created from combustion of fuels onsite to generate heat and power. Combustion of biogas on site for parasitic load [28]can significantly reduce emissions from using fossil gas.

(CE) Combustion Emissions: Emissions from burning biogas or other fuels, measured in kilograms of CO_2 equivalent (CO_2e). Combustion emissions is typically calculated from use of fuel and heat.

1. **Fuel Use**: The quantity of fuels used (e.g., diesel for machinery), measured in litres (l) or kilograms (kg).
2. **Heat Use**: The amount of heat energy used, measured in megajoules (MJ) or gigajoules (GJ).
3. **Fugitive emissions**: from incomplete combustion as explained for CHP below.
4. **Combustion EF**: The emission factor for the combustion of the fuel. See Section 4.4 and 4.5 for Biogas and Biomethane combustion EFs.

4.3.1. Biogas Combustion Emissions (CE_{biogas})

This methodology acknowledges that some producers may utilise and sell biogas to end users without upgrading to biomethane. This calculation acknowledges that Biogas can vary in energy density and carbon emissions from combustion. The biogas properties, such as percentage of methane, temperature and pressure affect the energy density and carbon emissions from the combustion.

Equation 4: $$CE_{biogas} = Ed_{biogas} \times V_{biogas} \times EF_{BM} \ [kg\ CO_2e]$$

CE_{biogas} = Combustion Emissions of biogas
V_{biogas} =Total volume of biogas generated (m^3).
EF_{BM} = Biomethane emissions factor 0.13 Kg CO_2e / GJ (Refer to Table 11)
Ed_{biogas} = Energy density of biogas

Equation 5: $$Ed_{biogas} = \%CH_4 \div 0.99 \times HHV_{BM} \ [GJ / m^3]$$

$\%CH_4$ = Methane Content, the percentage of methane in the biogas,
HHV_{BM} = Biomethane 0.0393 GJ/m^3 (@ 99% CH_4@ 101.3kPa, 15℃)

4.3.2. Biomethane Combustion Emissions (CE_{BM})

[28] Parasitic load refers the amount of electricity consumed by auxiliary equipment that supports the biofuel generation

Biomethane refinement includes scrubbing the gas of contaminants such as H_2S and CO_2 to achieve pipeline specification gas. This calculation acknowledges that Biomethane can vary in energy density and carbon emissions from combustion. Biomethane can be consumed at the production site or by a customer via pipeline. The pressure of the gas affects the energy density and should be converted to standard temp and pressure for comparability 15℃, 101.3kPa. Combustion emissions for Biomethane can be calculated below:

Equation 6: $CE_{BM} = EF_{BM} \times V_{BM} \times Ed_{BM}$ [kg CO_2e]

CE_{BM} = Biomethane Combustion emissions
EF_{BM} = Biomethane emissions factor 0.13 Kg CO_2e / GJ Ref. Table 11
V_{BM} =Total volume of biomethane generated (m^3).
Ed_{BM} = Energy density of biomethane

Equation 7: $Ed_{BM} = \%CH_4 \div 0.99 \times HHV_{BM}$ [GJ / m^3]

$\%CH_4$ = Methane Content, the percentage of methane in the biomethane,
HHV_{BM} = Biomethane 0.0393 GJ/m^3 (@ 99% CH_4@ 101.3kPa, 15℃)

4.3.3. Site generated Combined Heat and Power (CHP)

On site biogas can be used to generate heat and electricity (cogeneration) reducing the overall CI of the biofuel relative to high emissions heat and energy sources. The energy from biogas combustion is converted to mechanical energy by internal combustion engines and / or gas turbines. Electricity is produced, which can be used onsite. Waste heat can be recovered from exhaust gas and engine cooling systems. Factors impacting emissions include the type of CHP system, such as Internal combustions engines or Gas turbine. Along with the fuel content used (i.e., Biogas (50-70% CH_4) and Biomethane (95-99% CH_4) where the calorific value ranges between 35.2 MJ/m^3 – 46.5 MJ/m^3 reflective of CH_4 content).

Equation 8:[29]

$$CHP_{GHG} = \left[\frac{Ed_{biogas} \times V_{biogas} \times EF_{biogas}}{\eta_{elect}}\right] + \left[\frac{Ed_{biogas} \times V_{biogas} \times EF_{biogas}}{\eta_{heat}}\right]$$

CHP_{GHG} = Combined Heat and Power emissions
Ed_{biogas} = Equation 5
HHV_{BM} = Biomethane 0.0393 GJ/m^3 (99% CH_4 @ 101.3kPa, 15℃)
V_{biogas} = Volume of biogas (@ 101.3kPa, 15℃) combusted (m^3)
EF_{biogas} = Combustion Emissions Factor of biogas (kg CO_2/ GJ)

[29] 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2: Energy

Equation 9: $EF_{biogas} = \%CH_4 \div 0.99 \times EF_{BM}$ [kg CO_2/ GJ]

EF_{BM} = 0.13 Kg CO_2e / GJ (HHV_{BM}, 99% CH_4, 101.3kPa, 15℃)
η_{heat} = Heat / Thermal efficiency - %
η_{elect} = Electricity conversion efficiency - %

Key variables that affect the emissions from CHP systems are:

1. Type of CHP system: ICE vs. Gas turbine
2. Fuel: Biogas (50-70% CH_4) and Biomethane (95-99% CH_4) calorific value range of 35.2 MJ/m^3 – 46.5 MJ/m^3 are much lower EF then fossil fuel (see Table 11 below)
3. Efficiency of CHP system: Electric efficiency- $\eta_{elec.}$ (~35%-45%)
   Heat / Thermal efficiency- $\eta_{heat.}$ (~ 40%-50%)

Table 11: Default Combustion Emission Factors of Biomethane and Fossil Gas

Combustion	Biomethane [30]	Fossil Gas [31]
CO_2 (kg CO_2e)	0	53.99
CH_4 (kg CO_2e)	0.1	0.025
N_2O (kg CO_2e)	0.03	0.024
%CH_4	99%	99%
HHV - GJ/m^3	0.0393	0.0358
EF- Kg CO_2e / GJ	0.13	54.035

4.4. Electricity Use Emissions (EU)

Indirect emissions from the use of electricity onsite to produce gaseous biofuel must be calculated.

(EU) Electricity Use Emissions: The amount of electricity consumed in the production process is measured in kilowatt-hours (kWh). Gaseous biofuel production requires electricity, and the next sections details the treatment of electricity in the GHG CI of the production process. AD plants have auxiliary systems such as digester mixers, feedstock pumps and gas compressors which require electricity. The power requirement of these auxiliary systems is referred to as the parasitic load. Electricity for the parasitic load is typically generated on site or used from the grid.

4.4.1. Grid Electricity (location based) Emissions

Location based grid emissions factors can be used per MFEs latest publication relative to the year of production. Emissions factors for electricity grid shall be NZ specific (MFE) and aligned with the closest period for which the annual LCA assessment is completed.

[30] Australia National Greenhouse Accounts Factors 2024 based on HHV / GCV
[31] MFE default for natural gas.

Electricity EFs should be applied on a quarterly basis to acknowledge seasonal fluctuations in the grid as well as in the temporal accuracy of gaseous biofuel production.

4.4.2. Supplier Specific Electricity Emissions (Market-based) - REC's

Gaseous biofuel producers can use Supplier Specific Electricity Emissions where there is an approved contractual instrument in place. Contractual instruments include energy attribute certificates, renewable energy certificates (RECs), guarantee of origin (GOs) or green energy certificates. It is recommended that the product LCA contain dual reporting (both market-based, and location-based) where electricity REC's have been used to reduce the product carbon footprint.

Per ISO 14067, Life cycle data from a supplier-specific electricity product can be used when the supplier is able to guarantee through a contractual instrument that the electricity product meets all the following,

1. Conveys the information associated with the unit of electricity delivered together with the characteristics of the generator,
2. Is assured with a unique claim,
3. Is tracked and redeemed, retired or cancelled by or on behalf of the reporting entity,
4. Is as close as possible (e.g., half hourly) to the period to which the contractual instrument is applied and comprises a corresponding timespan.

4.5. Fugitive Emissions (FE_T)

Fugitive emissions are the direct GHG emissions that escape during the production process, of gaseous biofuel. These direct emissions can occur from the below sources,

1. Anaerobic digester leakage, (FE_{ad})
2. Fugitive emissions during scrubbing biogas and upgrading to biomethane, (FE_{su})
3. Digestate storage, (FE_{ds})
4. Landfill Gas, (FE_{LFG}) – (null if not a landfill gas process)

Equation 10: $$FE_T = FE_{ad} + FE_{su} + FE_{ds} + FE_{LFG}\ (kgCO_2e)$$

Fugitive emissions should be measured and calculated where possible rather than relying on default factors.

4.5.1. Anaerobic Digester Fugitive Emissions (FE_{ad})

An anaerobic digester will leak a portion of the produced biogas and these **digester leakage emissions** (FE_{ad}) must be included in the calculation of the CI of biogas or biomethane for production pathways that involve an anaerobic digester. Fugitive emissions for the AD process can be estimated using a default factor from the US GREET model in Appendix B.

Wastewater Treatment Plant AD fugitive emissions shall be calculated using the Water NZ Carbon Accounting Guidelines[32], section 7.2.

4.5.2. Upgrading to Biomethane Fugitive Emissions (FE_{su})

Fugitive methane emissions occur in the process of upgrading biogas to biomethane and must be accounted for in the biofuel CI value calculations (FE_{su}). Default values from the US GREET model may be used as a starting point however is not recommended for use within the CI due to inaccuracy. (See Appendix B for default values).

Fugitive emissions are sensitive to the assumptions or data used to estimate fugitive emissions impacts. Measuring loss rates of biogas from the system boundary should be a priority to ensure accuracy of the results.

To increase the accuracy of the RNG CI calculation fugitive emissions can be calculated using primary data in alignment with the Canadian Clean Fuel Regulation (CFR) specifications. Landfill gas fugitive emissions should be calculated per Equation 16

Calculating fugitive emissions from scrubbing and upgrading (FE_{su}):

The below equations for calculating fugitive emissions from upgrading are gleaned from the Canadian Clean Fuel Regulations.[33]

There are three alternative methods of calculating FE_{su} pending on available metering. Consequently, if fugitive emissions are captured and directed to destruction equipment, such as a flare, a quantity may be subtracted from the direct emissions.

Equation 11: Gas flow and methane concentration before and after upgrading is metered

$$FE_{su} = \frac{\left(F_{biogas} \times \%CH_{4\,Biogas} - F_{BM} \times \%CH_{4\,BM}\right) \times 0.671 \times 1000}{\text{Total fuel volume}}$$

Equation 12: Biogas flow and methane concentration before upgrading is metered only

$$FE_{su} = \frac{\left(F_{biogas} \times \%CH_{4\,Biogas}\right) \times 0.671 \times 1000 \times ER_{Fugitive}}{\text{Total fuel volume}}$$

Equation 13: Biomethane flow and methane concentration after upgrading is metered only

$$FE_{su} = \frac{\frac{(F_{BM} \times \%CH_{4\,BM} \times 0.671 \times 1000)}{1 - ER_{Fugitive}} - (F_{BM} \times \%CH_{BM} \times 0.671 \times 1000)}{\text{Total fuel volume}}$$

[32] Water NZ, Carbon Accounting guidelines for wastewater treatment, August 2021, V 1.1.
[33] 2024, Environment and Climate Change Canada, Fuel life cycle assessment model methodology

Equation 14: Captured fugitive emissions destroyed

$$FE_{sud} = FE_{su} - FE_{destroyed}$$

$$FE_{distroyed} = \frac{(F_{captured} \times \%CH_{4\,captured}) \times \text{Distruction factor} \times 0.671 \times 1000}{\text{Total fuel volume}}$$

FE_{su} = Upgrading to biomethane
F_{biogas} = flow biogas (m^3/day)
F_{BM} = flow biomethane (m^3/day)
$F_{captured}$ = flow of fugitive emissions captured (m3/day)
$ER_{Fugative}$ = default fugitive emissions rates from Canadian CFR LCA methodology:

- 2% for landfill gas
- 2% for livestock manure
- 1% for municipal solid waste
- 1% for wastewater treatment sludge

4.5.3. Digestate Storage Fugitive Emissions (FE_{ds})

If digestate is not being stored onsite for a period greater than 4 months in an anaerobic condition, then this factor can be omitted[34]. Digestate storage emissions mainly arises from methane produced by remaining volatile solids (VS) within an anaerobic environment.

To accurately calculate Digestate storage emissions, digestate flow, % volatile solids (VS), and biochemical methane potential (BMP) must be measured at the outlet of the digester. There is a significant GHG impact for digesters with a low residence time and high percentage of volatile solids and/or BMP. If digestate is being used as a co-product it is recommended that the producer sample the digestate volatile solids and biochemical methane potential following PAS 110:2014[35].

Emissions vary based on several factors, including duration of storage, temperature, storage conditions, and digestate composition. This methodology uses a formula adapted from IPCC 2019 Guidelines for National Greenhouse Gas Inventories, Ch 6 - Wastewater:

Measuring key parameters:

a. **Storage Duration**: Longer storage times can increase the fugitive emissions.

[34] Delay time in CH4 production for solid waste is 6 months (+/- 2months), based on 2006 IPCC Guidelines for National GHG Inventories, Volume 5, Section 3.2.3
[35] PAS110:2014 Specification for whole digestate, separated liquor and separated fibre derived from the anaerobic digestion of source-segregated biodegradable materials

b. **Storage Conditions**: Covered or uncovered storage impacts fugitive emissions, as does ambient temperature. Below formula assumes that digestate is covered to avoid contamination and dilution from rain[36].

c. **Digestate Characteristics**: BMP = Maximum methane-producing capacity of the digestate (m^3 CH_4/kg VS). BMP default value is 0.48 m^3 CH_4/kg VS.

d. **Volatile Solids (VS) Content**: Indicates the organic matter in digestate that can still degrade and emit methane. (kg)

Equation 15: $FE_{ds} = VS \times BMP \times MCF$

VS = Volatile solids in digestate (kg)
BMP = Maximum methane-producing capacity of the digestate (m^3 CH_4/kg VS)
MCF = Methane correction factor based on storage type and climate

Table 12: Digestate storage defaults[37]

Storage type	Details	MCF	BMP (kg CH_4/kg VS)
Anaerobic shallow lagoon	Depth less than 2 metres, use expert judgment.	0.8	0.48
Anaerobic deep lagoon	Depth more than 2 metres	0.2	0.12

4.5.4. Landfill Fugitive Emissions (FE_{LFG})

Landfills create fugitive emissions from the decomposition of organic waste. A portion of the landfill fugitive emissions shall be attributed to the carbon footprint of the gaseous biofuel.

Fugitive emissions from landfills depends on multiple variables including but not limited to, landfill cover/cap, landfill gas (LFG) capture efficiency, waste composition and the methane generation rate within the landfill.

Landfill gas generation rates decline after an initial peak. This decay is influenced by landfill temperature, moisture content, nutrient availability and pH, among others. Additionally, the biological process of landfill gas generation may be affected by waste composition, waste placement history (depth, age of waste, cover and capping), moisture, pH, temperature and maintenance of the anaerobic environment.

First-Order Decay (FOD) Model: The most widely used landfill gas prediction model is the first-order decay model. The simplest approach is the single stage first-order decay model, which assumes that waste degradation parameters are constant over the analysis period. The model requires two input parameters which are discussed in more detail below:

[36] PAS 110- Covers might influence the impact on digestate of climatic factors, such as rainfall, in the dilution, wetting and slumping of product.
[37] IPCC 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories 6.19, TABLE 6.3 (UPDATED)

- Methane generation potential, Lo in m^3 /tonne;
- Methane generation rate constant, k in 1/yr.

Methane Generation Rate Constant (k) The methane generation rate constant, k, determines how quickly the methane generation rate decreases, once it reaches the peak rate after waste has been placed. The higher the value of k, the faster the methane generation rate from each sub-mass decreases over time. The value of k is a function of the following major factors: Waste moisture content; availability of the nutrients for methanogens; pH; and temperature.

The Potential Methane Generation Capacity (L_o), depends only on the type and composition of waste placed in the landfill. The higher the cellulose content of the waste, the higher the value of L_o. L_o values can be found in Appendix C.

<u>Calculation Methodology:</u>

Landfill fugitive emissions can be estimated from primary or secondary data or a combination of both:

Secondary Data/ Modelling – Relying on estimates of First Order Decay (FOD) models such as IPCC and Scholl Canyon. Using default 10% for surface cap oxidation of LFG CH_4. This is the most common method used and are the basis of the calculations below.

Primary Data/ Measuring – Measuring surface emissions via infrared or other methane detector (e.g. FID Flame Ionization Detector, laser-based analyser). Surface emissions are subtracted from the CH_4 capture and destruction from existing LFG capture system.

There are 2 main options commonly used to calculate landfill emissions within NZ. Option 1 is based on the MFE default factors and Option 2 is to use the methodology within the NZ ETS and Climate Change amendment regulations.

<u>Option 1 - MFE Fugitive LFG Method:</u>

MFE uses a simplified method for organisations to report their GHG emissions from waste to landfill. Fugitive emissions calculation is based on MFE Solid Waste emissions factors and the mass (kg) of waste, its composition, and the landfill type (i.e. with and without landfill gas capture).

The MFE EFs are based on FOD model from IPCC and are therefore secondary data in nature. MFE EF's take a simplified approach to the IPCC FOD model as it ignores the time decay of waste (k) and instead calculates the total emissions that will result in future years from the decomposition of waste attributing these future emissions to the current reporting year. This method aligns to organisational reporting and will ensure that the total future fugitive emissions from the waste feedstock sent to landfill in current reporting year are included in the CI of the biofuel.

Equation 16 is the simplified approach and uses defaults based on national average waste composition and landfill characteristics. Equation 17 has been adapted from IPCC requiring more details on waste composition and landfill characteristics.

Equation 16: $FE_{LFG} = [\sum M_x \times EF_{LFG}] \times (1\text{-}C)$

FE_{LFG} = Landfill Fugitive emissions attributable to the CI of the Biofuel. ($kgCO_2e$)
M_x = Mass of waste (feedstock) ***x***, sent to landfill in the historical reporting year (kg)
EF_{LFG} = Feedstock Landfill Emissions Factor ($kgCO_2e/kg$) – Default MFE factors or Calculate via Equation 17 below.
C = Estimated efficiency of the LFG collection, (typically between 60% and 85%[38] - national default is 0.68)

Equation 17: $EE_{LFG} = DOC \times DOC_f \times F \times MCF \times Conversion \times (1\text{-}Oxidation) \times GWP$

DOC = Degradable organic content (IPCC Default 50%)
DOC_f = Fraction of DOC that can decompose (IPCC default 50%)
F = Fraction (%) of CH_4 in LFG
MCF = Methane correction factor (MFE and EPA default 1 based on ratio of landfill types.)
Conversion = Molecular weight ratio 1.3333 (CH4/C)
Oxidation = Amount of methane oxidised through the landfill cap (default is 10% if capped 0% if uncapped)
GWP = 28 (AR5)

Equation 18 below is used to calculate landfill gas CH_4 destruction efficiency:

Equation 18: $C = D \times Q \div G$

C = Estimated efficiency of the LFG collection and destruction system
D = Destruction factor for the type of destruction equipment in use at the facility as documented in the manufacturer's specifications for the equipment or, if such information is not available,

- Biomethane upgrading = 0.9

G = Estimated gross generation of CH_4 for the year in tonnes calculated in accordance with FOD method
Q = Tonnes of CH_4 conveyed to the destruction equipment in the year

Option 2 - NGER Method[39] (Recommended FOD approach):

It is recommended that where Class 1 landfills use First Order Decay (FOD) GHG models, they should be based on **site specific waste composition and landfill cover**. It is recommended to align with the Australia National Greenhouse and Energy Reporting

[38] 85% cap on LFG capture efficiency is aligned with Australia NGER and US EPA.
[39] Australian Government, Clean Energy Regulator, Estimating emissions and energy from solid waste and landfill biogas management guideline, Aug. 2024

(NGER) method for estimating emissions and energy from solid waste and landfill biogas management guideline, 2024.

This method is deemed to be more accurate than the NZ ETS method above because it caps landfill gas capture efficiency at 85% and requires a calculation of collection efficiency based on landfill cover relative to the landfill area with LFG capture per below equation.

The maximum collection efficiency of landfill gas is calculated using the areas (m^2) for the following categories of landfill capping and gas management per below formula:

$$\text{Equation 19: } C = \frac{[A3 \times 60\% + A4 \times 75\% + A5 \times 95\%]}{[A2 + A3 + A4 + A5]}$$

C = estimated efficiency of the LFG collection and destruction system
A2: areas without active gas collection (m^2).
A3: areas with daily soil cover and active gas collection (m^2).
A4: areas with active gas collection and an intermediate cover in place or a final phytocap (m^2).
A5: areas with active gas collection and final capping in place (excluding phytocaps) (m^2)

Where a landfill operator is unable to specify the areas for the factors A2, A3, A4 and A5, the collection efficiency limit for the landfill shall be 75%.
If and only if landfill GHG fugitive emissions predictions are modelled per above, then then a landfill gas capture efficiency can be reported to a maximum of 85%.

<u>Option 3 - ETS Method (Alternative Less Accurate FOD):</u>

Unique Emission Factors from the Climate Change (Unique Emissions Factors) Amendment Regulations 2024– New Zealand Legislation / EPA are another approach for this calculation, which require IPCC FOD model or alternative FOD model with measured landfill gas destruction efficiency[40]. The key difference for the ETS approach is that it relies on the historical composition data for waste to landfill and uses the time decay of waste (methane generation constant K). ETS approach allows national average landfill compositions for default values and LFG collection efficiency to 90%. For these reasons, it is less accurate to use ETS for this LCA methodology.

Unique Emission Factors (UEF) are calculated by landfills within the ETS based on Unique Emission Factors (UEF) Regulation. 23B relates to waste composition, 23C relates to the use of UEF and LFG collection and destruction system, and 23D relates to waste

[40] Climate Change (Unique Emissions Factors) Amendment Regulations 2024 (SL 2024/202) Contents – New Zealand Legislation

composition and the use of an LFG collection and destruction system. **For more information on ETS method and applicable default factors see Appendix C.**

4.6. Emissions from Consumables Used (CU)

Indirect emissions for the use of consumables (CU) should be calculated based on primary or secondary data. Consumable emissions should include the upfront embodied emissions, raw material supply, transportation of raw material and production of product) and the transportation of the products to the user. These emissions can be found within the EPD (Environmental Product Declaration) of products and EF databases like Ecoinvent. Some consumables may be very small quantities relative to the overall emissions of the biofuel and may be deemed de minimum once they are quantified.

The following are examples of AD consumables:

- Activated carbon filter media, used for biogas cleaning
- Ferric hydroxide or ferric chloride chemical, used for hydrogen sulphide mitigation
- A range of engine/lubrication oils
- Chemicals for pH control i.e. sodium hydroxide or hydrochloric acid
- Chemicals for industrial cleaning i.e. sodium hydroxide “caustic”
- Trace nutrients for feeding the AD biology i.e. trace metals
- Water use, either in process or for wider site, and depending on location, may have an associated carbon impact.

4.7. Waste Emissions (W)

Waste emissions (W) are calculated based on the details of the biofuel production waste products. These production waste streams include digestate, sludge, packaging and any other byproduct of the process. The waste emissions depend on how the waste streams are managed, including any emissions from transportation and offsite waste treatment processes. Ministry for the Environment Measuring Emissions: A guide for organisations provide emission factors for waste disposal.

4.8. Pipeline Transmission and Distribution Emissions (T&D)

Pipeline distribution losses are fugitive emissions which sit beyond the cradle to gate boundary but within the cradle to grave emissions of RNG. Fugitive emissions are based on the overall pipeline network performance. Transmission and Distribution (T&D) losses in the NZ pipeline network can be calculated based on MFE default values per kWh or GJ of pipeline spec RNG added to the network.

If an entity consumes reticulated RNG, related natural gas transmission and distribution losses emissions are categorised under Scope 3, Category 3 based on the GHG Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard.

Table 13[41] details the emission factors for the transmission and distribution losses for reticulated natural gas. These represent an estimate of the average amount of carbon dioxide equivalents emitted from losses associated with the delivery (transmission and distribution) of each unit of gas consumed through local distribution networks in 2022. They are average figures and therefore make no allowance for distance from off-take point, or other factors that may vary between individual consumers.

Table 13: T&D Losses (adapted from MFE GHG measurement guide)

Transmission & Distribution Losses Source	Unit	kg CO_2e/unit	CO2/unit (kg CO_2e)	CH4/unit (kg CO_2e)	N2O/unit (kg CO_2e)
Natural gas used	kWh	0.00723	0.00006	0.00717	n/a
	GJ	2.01	0.0175	1.99	n/a

5. EMISSIONS ALLOCATION TO CO-PRODUCTS

In allocation accounting, the emissions are split between co-products. Co-product allocation is "*partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems*" [ISO 14044: 2006].

Based on ISO 14044, and the GHG Protocol Product Life Cycle Accounting and Reporting Standard allocation approach should be avoided by further sub-dividing the system to isolate co-products. If allocation cannot be avoided, an allocation method should be based on mass, energy content or economic value. [42]

This methodology applies an energy-based allocation to the biomethane product carbon intensity. The main reason for an energy-based allocation is to ensure consistency and comparability of the biomethane CI with other fuels. **In this approach the carbon impacts of the co-products are applied to the gaseous biofuel while the CO_2 and digestate co-products have a zero-emissions carbon intensity.**

Energy-based allocation is required or is default approach for international biomethane REC Schemes such as the European Energy Certificate System (EECS) REDcert methodology, the World Biogas Association CI methodology and aligned with the Canadian Clean Fuel Regulations (CFR).

In alignment with the Canadian CFR, if a production facility produces biomethane or biogas using multiple feedstock types (e.g., wastewater sludge and solid organic wastes), then the gaseous biofuel must first be separated into portions corresponding to each feedstock type to calculate one CI value for each distinct fuel portion produced. In these cases, the allocation procedure must be used to allocate the various inputs to the different portions of biomethane or biogas.

[41] Measuring emissions: A guide for organisations: 2024 detailed guide
[42] ISO 14044 Lifecycle Assessment

5.1. Heat and Electricity Co-products

Heat and electricity are common co-products from the combined heat and power (CHP) produced on the bioenergy production site from combustion of the gaseous biofuel. An energy allocation approach is recommended for the carbon footprint of these co-products.

The combustion emissions factor for biogas depends on the energy density (CH_4/m^3) and the Higher Heating Value (HHV) (GJ/m^3). This can be calculated relative to the published emissions factor for biomethane.

5.1.1. Electricity Co-product Carbon Intensity ($CI_{electricity}$)

Equation 20 $CI_{elect} = CI_{biogas} \times (\eta_{elect} / \eta_{CHP})$ $[kg\ CO_2e/GJ\ of\ electricity]$

CI_{biogas} = Carbon Intensity of Biogas (upstream cradle to gate) - kg CO_2e / GJ

η_{heat} = Heat / Thermal efficiency - %

η_{elect} = Electricity conversion efficiency - %

η_{CHP} = CHP efficiency %

5.1.2. Heat Co-product Carbon Intensity (CI_{heat})

Equation 21: $CI_{heat} = CI_{biogas}\ x\ (\eta_{heat} / \eta_{CHP})$ $[kg\ CO_2e/GJ\ of\ heat]$

CI_{biogas} = Carbon Intensity of Biogas (upstream cradle to gate) - kg CO_2e / GJ

η_{heat} = Heat / Thermal efficiency - %

η_{elect} = Electricity conversion efficiency - %

η_{CHP} = CHP efficiency %

5.2. Digestate application to land

Digestate is the spent contents of an anaerobic digester, which can be used as a fertiliser. Digestate may be liquid, semi-solid or solid. Digestate may be further stabilised aerobically (e.g. composted), applied to land, sent to a solid waste disposal site (SWDS), or kept in a storage or evaporation pond[43]. It contains nutrients and organic matter that can contribute to soil health and soil carbon content. When applied to land, digestate helps build up soil organic carbon (SOC), improving soil structure, fertility, and water retention building climate change resilience on land.

Digestate has positive value and is considered a coproduct and not a waste treatment process. Impacts of application are attributed to the user of the digestate as it provides positive economic and environmental benefits to the users. Digestate application to land is therefore excluded from the Biomethane CI outside the LCA boundary.

Digestate is treated as a zero-carbon co-product in the energy allocation method chosen in this methodology (see section 4). All the emissions to create the digestate are

[43] American Biogas Association; Carbon Accounting Methodology for Biogas, 2024

allocated to the Biomethane CI. The application of digestate to land is therefore outside of the Cradle to Gate LCA boundary of RNG CI measurement.

Digestate application to land often create an avoided emissions relative to synthetic fossil fuel-based fertilisers. The GHG Protocol have draft guidance on accounting land sector application of biogenic fertilisers and SOC [44] which could be useful for future development of an avoided emissions methodology for digestate replacing synthetic fertiliser.

Digestate displacing synthetic fossil-based fertiliser creates avoided emissions and has potential to create carbon credits. See the American Biogas Association carbon accounting methodology and the accompanying research document[45] informing this methodology for more details on avoided emissions.

6. CARBON INTENSITY REPORTING

6.1. Transparency, Assumptions, and Level of Uncertainty

The CI, LCA Report should provide a level of transparency to show what assumptions and variables are "embedded" within the emissions factors, activity data, default values and calculations following this methodology. This should include visibility on how much primary data vs secondary data the calculations rely on. This will help with appreciating the level of uncertainty of the CILCA analysis.

Uncertainty is a measure of any potential inaccuracy, bias, or incompleteness of an emissions factor. Ideally default factors should have low uncertainty. Level of uncertainty should be disclosed within the calculations.

6.2. Project Monitoring Best Practice

The impacts of project activities on relevant emission sources, sinks, and reservoirs (SSR) must be monitored to determine the gaseous biofuel CI. For those purposes, a monitoring plan shall be established for all monitoring and reporting activities associated with gaseous biofuel Producer[46].

The monitoring plan should provide,

1. Parameters to be measured and details (i.e., units, description, acquisition frequency). This is referred to in GHG accounting as Primary data.
2. The frequency of instrument field checks, calibration activities, and data acquisition.
3. The role of individuals performing each specific monitoring activity.

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[44] https://ghgprotocol.org/land-sector-and-removals-guidance
[45] Literature Review – Methods for accounting for the Carbon Intensity of Biomethane
[46] American Biogas Association; Carbon Accounting Methodology for Biogas, 2024

4. The details about the data management system and the flow of raw data to the final report.
5. The process of Biomethane Control System (BCS) activities, digestate separation, and end use.
6. Process Flow Diagram (PFD) showing system boundary, inputs and outputs, and location of meters.
7. The usage of fossil fuels for project activities.
8. Electricity usage.
9. The equipment and frequency of gas generation and methane-content recording.
10. Records of calibration and verification of measurement equipment.
11. The process for recording data and QA/QC procedures for such.

Table 14 provides the list of relevant parameters to be monitored under this methodology in alignment with the American Biogas Association Methodology. Primary data requirements are the measured data (M) and are highlighted.

Table 14: Gaseous Biofuel Plant parameters to be measured and monitored

Parameter	Unit	Description	Frequency	C, Calculated M, Measured R, Reference	Records / Meter Placement
M_F – Mass Feedstock	kg	Mass of Feedstock, % dry solids.	Per Feedstock Type	M + R	Weighbridge mass and % dry solids. DOC can be referenced from Table 18
F_E -Feedstock Energy Density	CH_4/kg,	Calculated from DOC and MCF	Per Feedstock Type	C	Equation 4 – Feedstock Energy.
F_{bg} – Flow Biogas	m^3/day	Biogas flow from AD to refinement	Daily	M	Continuous flow Meter prior to upgrading (@ 101.3kPa, 15°C)
Biogas CH_4 content	% CH_4	Methane content of Biogas flow from AD	Daily	M	Methane Sensor – before upgrading
BG_{CH4} - Biogas Methane Production	m^3 CH_4	Methane Production Emissions	Monthly	C	Calculated from above measurements.
F_{bm} – Flow of RNG	m^3/day	RNG flow	Daily	M	Continuous flow Meters after upgrading and pressurisation to pipeline. (@ 101.3kPa, 15°C).[47]
BM_{CH4} - Biomethane methane content	% CH_4	Methane content of RNG flow downstream of upgrading	Daily	M	Methane Sensor – After upgrading
EU – Electricity Use	kWh	Electricity used on site	Monthly	M	Utility bills Electricity meter . Electricity REC certificates as required.
FU – Fossil Fuel Use	Volume and energy density.	Fossil fuels used	Monthly, per type of fossil fuel.	M	Utility bills and gas meters.
FE – Fugitive Emissions	m^3	Fugitive emissions	Annually or Default /Calculated	M / C	Default per Table 10 or Site assessment (IR camera, methane sensors, LDAR.[48] survey)
VS- Volatile Solids Digestate	kg	Digestate Mass measurement % volatile solids	Annual if Digestate is being stored on site over 4 months.	M	Flowmeter, or Volume, or Mass measurements.
BMP - biochemical methane potential Digestate	BMP	Digestate BMP measurement	Annual if Digestate is being stored on site over 4 months.	M or C	BMP - A default value of 0.48 m^3 CH_4/kg VS

[47] Volumes to be at the standardised temperature and pressure
[48] LDAR is Leak Detection and Repair Survey

Flow meters, sampling devices, and gas analyzers shall be subject to regular maintenance, testing, and calibration to ensure accuracy according to regulatory required frequency and manufacturer's recommendations. Relevant parameters shall be monitored as indicated in Table 14 above.

7. CRITICAL REVIEW AND RECORD KEEPING

A critical peer review of the LCA should be carried out by a suitably qualified person. In such a case, an expert independent of the LCA shall perform the review. The review statement, comments of the LCA practitioner and any response to recommendations made by the LCA reviewer shall be included in the LCA report.[49]

7.1. Mass Balance, Energy Balance & Activity Data

Mass and energy balancing checks are required for many of the international REC schemes to ensure accurate tracking and verification of renewable energy production. These balances help confirm that the reported energy output (electricity, heat, or biomethane) corresponds correctly to the feedstock input and that system losses are accounted for.

An independent critical peer review on data validity should be conducted during the process of data collection to confirm and provide evidence that the data quality requirements specified in Table 7, have been met.

Peer review should involve calculating mass and energy balances with comparative analyses between feedstock energy input and gaseous biofuel energy output. As each unit process obeys the laws of conservation of mass and energy, mass and energy balances provide a useful check on the validity of the description and quantification of a unit process.

The mass balance system must include both information on the input/output of raw materials and fuels for which the above sustainability characteristics have been determined (sustainably certified raw materials and fuels) and information on the input/output of raw materials and fuels, including fossil fuels, for which no sustainability characteristics have been determined. This applies only to raw materials used to produce biofuels, bioliquids and biomass fuels and to finished fuels that can be produced from these raw materials.

7.2. Producer Record-Keeping

For independent critical review and historical documentation, project developers should keep all information outlined in this methodology for 10 years after it is generated. This

[49] ISO 14044:2006 Environmental management — Life cycle assessment — Requirements and guidelines

information will not be publicly available but may be requested for verification. System information the project developer should retain includes:

1. Data inputs for GHG-reduction assessments.
2. Copies of all permits relevant to project activities.
3. Biogas flow meter information, including model number, serial number, calibration procedures, etc.
4. Methane monitoring information.
5. Destruction device monitoring information.
6. Calibration results for all meters.
7. Biogas flow and methane content data.
8. Feedstock data.
9. Results of CO_2e reduction calculations.
10. Initial and subsequent verification records and results.
11. Maintenance records of the Biogas Control System (BCS) and monitoring equipment.

7.3. Energy Balancing

The energy of the biofuel produced comes from the feedstock which is the renewable organic waste diverted from other processes. Energy balance can be assessed by calculating the energy of the feedstock compared to the energy of the biofuel produced. The below data should be recorded to allow for energy balancing of the system.

1. **Type of Feedstock**: Information on the type of waste biomass used (e.g., food waste, agricultural residues, wastewater sludge).
2. **Mass of Feedstock (M_F)**: The amount of each biomass input, shall be measured in kilograms or tonnes. **(%DS)** Total dry solids to be recorded.
3. **Source of Feedstock**: Details and documentation on where the feedstock is sourced from, including transportation distances.
4. **Renewable Feedstock**: Feedstock must meet the requirements of Biogenic Waste outlined in section 2.5.
5. **Degradable organic carbon (DOC).** DOC is the percentage of volatile solids based on the mass of dry solids.
6. **DOC_f-** The fraction of degradable organic carbon that decomposes under anaerobic conditions.
7. **DS Dry Solids (%)**. The percentage of dry solids is the percentage of organic waste mass without water/moisture relative to the mass of the waste with water /moisture content.
8. **Extraction Emissions (E_x):** any energy and emissions associated with extraction of the feedstock within the system boundary.
9. **Determine Feedstock CH_4 Density** (F_{CH4}): CH_4/kg,
10. **Energy Balance Check:** Estimate Feedstock energy from mass input to AD

Mass and Energy Balance Calculation:

To derive the mass and energy balance of an AD facility the CH_4 must be estimated for the biodegradable portion of the feedstock. This should be done via a detailed calculation to estimate the CH_4/kg of feedstock. Alternatively, energy density of the feedstock can be determined via a default table in Appendix.

Default Method:

The default EFs for solid waste come from MFE for waste to landfill without gas recovery. (see Default EFs in Appendix A).

Detailed Method:

The detailed calculation method suggested below is based on the IPCC Guidelines for solid waste disposal[50]. If the variables are unknown / unmeasured then defaults can be chosen as per the below Table and Appendix A.

1. Wastewater feedstock should be recorded by percentage of total solids. (typically, 5% or 30% Total Solids (TS) or Dry Solids (DS))
2. Municipal biogenic and other organic waste should be broken down by category in alignment with MFE (typically, Food, Garden, Paper, Wood (combined), Wood (treated), Wood (untreated), Textile, Nappies, Sludge, Inert)[51]
3. Organic waste degradable organic carbon (DOC) shall be determined

Equation 22:[52] $$\text{Energy Feedstock} = F_{CH4} \times M_F \times HHV_{CH4}\ [MJ]$$ [53]

F_{CH4}= DOC x DOC_f x F x MWR [CH4/kg] - Table 11

MF = Mass of feedstock

HHV_{CH4} = Higher Heating Value - Table 11

[50] IPCC 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Ch. 3, Solid Waste Disposal
[51] MFE, Measuring emissions: A guide for organisations: 2024 detailed guide
[52] Adapted from 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 3 SWD, Equation 3.2 & 3.3

Table 15: Variables for calculating Energy of Feedstock

DOC	Degradable organic content	Value	Source
DOC	Degradable organic content	varies	Table 20 ,Appendix B
DOC_f	fraction of DOC decomposed under anaerobic conditions	50%	IPCC default
F	fraction of gas that is methane	50%	IPCC default
MWR	Molecular Weight Ratio CH_4/C	1.333333	IPCC
GWP_{CH4}	Global Warming Potential biogenic CH_4	28	CO_2e
HHV_{CH4}	Higher Heating Value	0.0398 GJ/m^3	IPCC 2006, Vol. 2, Table 1.2

8. RNG REPORTING WITHIN THE USER GHG INVENTORY

Reporting within the users GHG inventory should be based on ISO 14064-1[54] Organisational GHG reporting standard and / or the GHG Protocol Reporting standard. Currently, the GHG Protocol does not provide explicit guidance on how companies should use RNG REC certificates to account for GHG emissions savings achieved by procuring gaseous biofuels.

This methodology aligns to ISO 14064-1; Direct CO_2 emissions from combustion of biofuel, are quantified and reported separately from anthropogenic emissions and are not aggregated to the total absolute annual emissions. Direct CH_4 and N_2O emissions associated with biofuel combustion should be reported as anthropogenic emissions in the inventory.

This methodology acknowledges a current GHG Protocol work stream “Actions and Market Instruments” that will provide additional guidance on market-based accounting approaches and may effect this guidance document.

This methodology advises reporting in alignment with the latest guidance from the UK Green Gas Certificate Scheme[55]. If a company purchases biogas or RNG through a contractual instrument that meets the GHG Protocol Scope 2 Quality Criteria[56], it can then report Scope 1 emissions for gaseous biofuel using the market-based method and using the product specific Carbon Intensity. The reporting company can report emissions from gaseous biofuel in alignment with the below requirements:

[54] 14064-1:2018, Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals

[55] GGCS Guidance Document 15 Use of Green Gas Certification Scheme within the GHG Protocol Version 1.5 – September 2022

[56] GHG Protocol Scope 2 Criteria required expert interpretation as it is currently written for renewable electricity certificates.

1. Direct Scope 1 biogenic CO_2 emissions linked to the use of gaseous biofuel are zero[57]
2. Direct biogenic emissions from other GHGs (CH_4 and N_2O) still need to be reported as part of Scope 1 emissions.
3. Upstream emissions of gaseous biofuel production and transport must be reported as part of Scope 3 emissions and this data needs to be included on the certificate provided by the certification scheme.
4. Biogenic emissions need to be reported in the organisational GHG Inventory, but separately from the scopes in a memo item.
5. Unlike with Electricity, companies do not need to provide dual reporting for use of gaseous biofuel REC's.

Producers of gaseous biofuel shall report the Cradle to Gate product Carbon Intensity as aligned with the requirements of this methodology. The LCA gate is at the pipeline network, post biogas scrubbing/ upgrading, compression and injection into the pipeline network.

Users of gaseous biofuel require full LCA Cradle to Gate and Gate to Grave emissions to align with Organisational GHG inventory reporting as per Table 16

Table 16: Users Organisational GHG inventory reporting of gaseous biofuel

User Emissions	GHG P Category	Gaseous Biofuel System Boundary	Product LCA
Indirect Upstream emissions (Well to tank)	Scope 3, Cat.3	Upstream = $(CI_{biofuel}) \times V_{biofuel}$	Cradle to Gate
Indirect Upstream Emissions	Scope 3, Cat.3	Downstream = $T\&D_{GHG}$	Gate to Grave
Direct Emissions	Scope 1	Combustion	Gate to Grave

Cradle to Gate emissions satisfies user organisational emissions reporting GHG Protocol, Scope 3, Category 3, Indirect emissions of the fuel and is often referred to as upstream well to tank (WTT)[58]. Well to tank emissions includes the extraction, processing & refining, transportation and distribution of the fuel to the point of consumption/ tank. Well to tank excludes infrastructure emissions embodied within the production plant and pipeline network.

Gate to grave emissions includes Transmission and Distribution (T&D) losses and the combustion of the gaseous biofuel. Combustion emissions satisfy user organisational emissions reporting of direct emissions, GHG Protocol, Scope 1, Category 1. T&D emissions satisfy user emissions reporting GHG Protocol, Scope 3, Category 3 indirect emissions.

[57] Aligned with ISO 14064-1, Direct CO 2 emissions from combustion of biomass and biofuel, as well as composting activities, are quantified and reported separately from anthropogenic emissions. Direct CH4 and N2O emissions associated with biomass combustion should be reported as anthropogenic emissions in the inventory.
[58] Corporate Value Chain (Scope 3) Accounting and Reporting Standard

9. DEFINITIONS

The methodology employs the following definitions:

Activity Data: Greenhouse gas (GHG) activity data is the quantitative measure of activity that results in a greenhouse gas emission or removal.

Allocation: partition of input or output flows of a process between the product system under study and one or more other product systems (ISO 14040).

Anaerobic digester - equipment that is used to generate biogas from liquid or solid waste through anaerobic digestion. The digester is covered or encapsulated to enable biogas capture for flaring, heat and/or power generation or feeding biogas into a natural gas distribution system. In the context of this guidance, this is an engineered system that is designed to produce gaseous biofuels. The following types of digesters are considered:

(i) Covered anaerobic lagoons: anaerobic lagoons that are covered with a flexible membrane to capture methane produced during the digestion process. Covered anaerobic lagoons are typically used for high volume effluent such as animal manure and organic industrial effluent like starch industry effluent;

(ii) Conventional digesters: digesters that are operated like a covered anaerobic lagoon, with no mixing or liquid and biogas recirculation;

(iii) High-rate digesters, such as up-flow anaerobic sludge blanket (UASB) reactors, anaerobic filter bed reactors and fluidized bed reactors;

(iv) Two stage digesters: anaerobic digestion takes place in a two-stage process, solubilization of particulate matter occurs and volatile acids are formed in the first stage digester. The second stage is carried out in a separate digester, at a neutral pH and a longer solid retention time;

Anaerobic digestion (AD)- degradation and stabilization of organic materials by the action of anaerobic bacteria that result in production of methane and carbon dioxide. In the context of this guidance AD is synonymous with Anaerobic digestors and associated plant designed to produce biofuels.

Anaerobic decomposition – the anaerobic process that takes place in landfills which is a passive process of organic decomposition that takes place over an extended period of time (typically 20-30 years).

Biogas - gas generated from a digester via anaerobic digestion. Typically, the composition of the gas is 50-70% CH_4 and 30-50% CO_2, with traces of H_2S and N_2O (1% -5%).

Biomass - biomass is non-fossilized and biodegradable organic material originating from plants, animals and microorganisms. This includes products, by-products, residues and waste from slaughterhouses, cattle-raising, agriculture, forestry and related industries as well as the non-fossilized and biodegradable organic fractions of industrial and municipal wastes. Biomass also includes gases and liquids recovered from the decomposition of non-fossilized and biodegradable organic material;

Biochar - Biochar is produced by pyrolysis, a process that heats biomass (such as wastewater sludge, wood, or agricultural waste) in the absence of oxygen. This process converts organic carbon in the biomass into a stable, solid form of carbon that resists decomposition. Unlike the raw biomass, which would naturally degrade and release CO_2 back into the atmosphere, biochar remains in the soil for hundreds to thousands of years.

Carbon Intensity: in relation to gaseous biofuel fuel, this means the quantity of CO_2e in grams or kilograms that is released during the activities conducted over the fuel's life cycle per megajoule or gigajoule of energy of the fuel. The carbon footprint per unit of energy of the fuel based on the lifecycle stages and specific inputs and outputs of the production.

Carbon Equivalent: A measurement that standardises the climate impacts of different GHGs.

Composting - a process of biodegradation of waste under aerobic (oxygen-rich) conditions. Waste that can be composted must contain solid biodegradable organic material. Composting converts biodegradable organic carbon to mostly carbon dioxide (CO_2) and a residue (compost) that can be used as a fertilizer. Other outputs from composting can include, inter alia, methane (CH_4), nitrous oxide (N_2O), and run-off wastewater (in case of co-composting);

Cradle-to-gate: scope of a CI which covers all life cycle stages up to the production facility gate.

Cradle-to-grave: scope of a CI which covers the full life cycle.

Digestate - spent contents of an anaerobic digester. Digestate may be liquid, semi-solid or solid. Digestate may be further stabilized aerobically (e.g. composted), applied to land, sent to a solid waste disposal site (SWDS), or kept in a storage or evaporation pond;

Digestate to Biochar: The solid fraction of digestate from the AD process can be used as feedstock for biochar production. This converts digestate into a stable carbon-rich material, further sequestering carbon and enhancing the nutrient retention of biochar.

Emission Factor - A coefficient relating GHG activity data with the GHG emission intensity value.

Gaseous Biofuel – Low Carbon clean fuel from organic waste which includes Biogas and Biomethane/ RNG.

Global warming potential - index, based on radiative properties of GHGs, measuring the radiative forcing following a pulse emission of a unit mass of a given GHG in the present-day atmosphere integrated over a chosen time horizon, relative to that of carbon dioxide (CO_2)

Lifecycle Assessment - compilation and evaluation of the inputs, outputs, and the potential environmental impacts of a product system throughout its life cycle (ISO 14040).

Materiality – Within this methodology materiality is a word to describe if a GHG source or sink is significant enough to include in the gaseous biofuel CI. A source is material if it is of significant magnitude (>1% of total) or if the producer has an ability to influence those emissions. A source or sink can also be material if it is significant to the sector or key stakeholders of the GHG information.

Organic waste - waste (fresh waste, animal waste, wastewater) that contains degradable organic matter. This may include, for example, domestic waste, commercial waste, animal manure, wastewater, organic industrial waste (such as sludge from wastewater treatment plants) and MSW;

Solid waste disposal site - designated areas intended as the final storage place for solid waste. Stockpiles are considered a SWDS if: (a) their volume to surface area ratio is 1.5 or larger; and if (b) a visual inspection by the DOE confirms that the material is exposed to anaerobic conditions (i.e. it has a low porosity and is moist);

Upgraded biogas – biogas upgraded to natural gas quality.

Unit process: Smallest divisible activity of a life cycle. It transforms quantities of inputs into quantities of outputs. It can use modelling parameters and background data.

Flow: Material or energy stream entering (input) or leaving (output) a unit process. “Elementary flows” refer to exchanges between a unit process and the environment (i.e. extractions and emissions) while “intermediate flows” refer to exchanges between unit processes (e.g., electricity).

Life cycle stage: Specific part of a life cycle (e.g., feedstock production). Life cycle stages are modelled by a collection of unit processes.

Fuel pathway: Collection of unit processes, modeling parameters, and background data which represents the life cycle of a fuel from a given feedstock. In general, LCA vocabulary, a fuel pathway is called a product system.

System process: Process that contains the lifecycle information of a group of unit processes.

Waste-to-energy: the conversion of waste into power, heat, or biofuels.

Well to tank (WTT): Well to tank emissions are the emissions associated with the production of fuels. WTT includes the extraction, processing, refining, transportation and distribution of the fuel to the point of consumption or “tank”. WTT emissions excludes infrastructure emissions embodied within the production plant and pipeline network.

Verification: The process of evaluating a client claim with past historical data to determine it is materially correct and conforms to predetermined criteria." Footnote: Verification is ISO language and is not used by financial auditors. [Source: Adapted ISO 14064-3]

10. ACRONYMS

The methodology employs the following acronyms.

AD	Anaerobic digestion
BCS	Biogas control system
BMP	Biochemical Methane Potential
CH_4	Methane
CI	Carbon intensity
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
DOC	Degradable organic carbon
EF	GHG emission factor
FOD	First Order Decay (Landfill Gas Generation Model)
GHG	Greenhouse gas
GWP	Global warming potential
LCA	Lifecycle assessment
LCFS	Low carbon fuel standard
LDAR	Leak Detection and Repair (survey)
LFG	Landfill gas
MSW	Municipal solid waste
MCF	Methane Correction Factor
N_2O/NO_X	Nitrous oxide
PE	Production emissions (biogas production stage)
PFD	Process Flow Diagram
QA	Quality assurance
QC	Quality control
RNG	Renewable natural gas (Biomethane)
SOC	Soil organic carbon
SSR	Sources, sinks, and reservoirs
SWDS	Solid waste disposal site
T&D	Transmission and Distribution
VS	Volatile Solids

WWTP	Wastewater treatment plant
WtE	Waste to Energy
WTT	Well to Tank
WTW	Well to Wheel

11. APPENDIX A; REFERENCES

International reference REC/ LCFS schemes and methodologies

Jurisdiction	Scheme Name	CI methodology / model	Functional Unit	System Processes Covered (LFG, WWTP, AD)	System Boundary	Allocation	Verification	Avoided Emissions	Methodology Alignment
Europe	**European Energy Certificate System EECS** EECS | AIB	Renewable Energy Directive II (RED-II). REDcert standards. 2023 Scheme principles for GHG calculation - Version EU 06 Logo REDCERT	grams of CO2 equivalent per MJ of biofuel/bioliquid/ biomass fuel [gCO2eq/MJ]. Use lower heating value (LHV) into the unit gCO2eq/MJ of final fuel	Generic	Cradle to Grave, Feedstock extraction/ transportation to RNG combustion.	Energy Allocation	Annual	Not addressed.	Mass Balance, Sustainable Feedstock, Calculation.
UK	**UK Green Gas Certification Scheme (GGCS)**	2024, Emissions Reporting - Certificates - Green Gas Certification Scheme	gCO2e / MJ (measured as net calorific value / LHV)	Generic	Cradle to Grave; Includes end use combustion	Energy Allocation	Annual	Not addressed.	REC Producer/ User reporting. CI less than = 34.8 kg CO_2e/GJ
Canada	**Canada's Clean Fuel Regulations (CFR)**	2024, Environment and Climate Change Canada, Fuel life cycle assessment model methodology. Fuel Life Cycle	1 MJ of energy content based on the Higher Heating Value (HHV) delivered to the end user and	Generic	Cradle to Grave; Includes end use combustion	Energy Allocation	Annual	Not required. Calculated separate to CI.	Default Values and Fugitive emissions., Exclusions, PDF requirements

Jurisdiction	Scheme Name	CI methodology / model	Functional Unit	System Processes Covered (LFG, WWTP, AD)	System Boundary	Allocation	Verification	Avoided Emissions	Methodology Alignment
		Assessment Model - Canada.ca	used for its energy content.					Optional Reporting.	
USA	American Biogas Association;	2024, Carbon Accounting Methodology for Biogas American biogas council	grams of CO2e per megajoule (MJ) of fuel (LHV) or grams of CO2e per kilowatt hour (kWh) depending on the end-use	Methodologies for WWTP, LFG and Food / Organic to AD.	Cradle to Grave; Includes end use combustion	Energy Allocation (primary); System Expansion (Mass, Economic Value) if can't be avoided.	Annual	Covered	Avoided emissions, Data Quality Measurement requirement, frequency. Upstream boundaries.
World Biogas Association	International Anaerobic Digestion Certification Scheme	2024, International Anaerobic Digestion Certification Scheme, Life Cycle Assessment LCA Guidance for AD	grams of CO2 equivalent per MJ of biofuel/bioliquid/ biomass fuel [gCO2eq/MJ]. Use lower heating value (LHV) into the unit gCO2eq/MJ of final fuel	Generic	Cradle to Gate;	Energy Allocation (primary; secondary use System Expansion (Mass, Economic Value)	Silent	Not covered.	Cradle to Gate Boundary
California	**California's Low Carbon Fuel Standard (LCFS),**	2024 CA-GREET 4.0 (under consultation), CA-GREET 3.0, LCFS Life Cycle Analysis Models and Documentation |	g CO2e / MJ - HHV	Methodologies for WWTP, LFG and Food / Organic to AD.	Cradle to Grave; includes Cradle to Gate, Gate to tank, tank to wheel.	Energy Allocation	Annual	Calculated separate to CI.	Many transportation fuel types. Hydrogen, BioOil to RNG. DOC Default, Well to Wheel LCA, LHV Default.

Jurisdiction	Scheme Name	CI methodology / model	Functional Unit	System Processes Covered (LFG, WWTP, AD)	System Boundary	Allocation	Verification	Avoided Emissions	Methodology Alignment
		California Air Resources Board							
USA	**U.S. Renewable Fuel Standard (RFS)**	GREET T1, US EPA GREET | Department of Energy Renewable Fuel Standard Program | US EPA	g CO_2e / MJ - HHV	Generic.	Cradle to Grave; includes Cradle to Gate, Gate to tank, tank to wheel.	Energy Allocation	Annual	Calculated separate to CI.	Many transportation fuel types. Hydrogen, BioOil to RNG. Well to Wheel LCA, LHV Default.
Australia	**Greenpower Renewable Gas Certification**	2024 - RGGO Scheme – certifier / auditor Renewable Gas Certification - Rules V2.0.pdf	Kg CO_2e / GJ - HHV	"Technology agnostic"	Cradle to Gate	Energy Allocation, Expansion if other products (sold)	Annual	NO	Must use Renewable electricity. REC. Materiality: 1% individual, 5% cumulative.

12. APPENDIX B; DEFAULT FACTORS

Default Factors are provided as a guide at the point in time of this publication (March 2025). Users of the methodology need to ensure the latest and most accurate EFs are chosen as practicable. Users to choose upper value of the default range unless there is a robust justification for a lower factor.

Table 17: Upstream WTT emission factors for fuels and electricity (New Zealand)

*Source: Agrilink New Zealand fuel and electricity total primary energy and life cycle greenhouse gas emission factors 2022 - July 2022. August 2023 (*Table 2 Summary of fuel energy and life cycle emission factors)

Fuel type	Unit	Fugitive Energy Coefficient	GHG[2] – 2007 (gCO_2e/ unit)	GHG[2] – 2007 (gCO_2e/ unit)[3]	GHG[2] – 2007 (gCO_2e/ unit)
					WTT - Upstream Emissions
			Scope 1 & 3	*Scope* 1	
Diesel	litres	1.21	3,147	2,689	458
Petrol (regular unleaded)	litres	1.21	2,760	2,341	419
Biodiesel (tallow) †	kg	0.50	1,750	-	-
Light fuel oil	litres	1.21	3,415	2,930	485
Marine diesel oil	litres	1.21	3,342	2,879	463
Bunker/Heavy fuel oil	litres	1.21	3,539	3,046	493
Intermediate fuel oil	litres	1.21	3,520	3,030	490
Heavy fuel oil (electricity)	litres	1.21	3,498	3,007	491
Aviation gasoline	litres	1.21	2,634	2,230	404
Natural Gas (Commercial)	MJ	1.13	60.7	53.8	7
LPG	kg	1.13	3,313	2,972	341
Coal (bituminous)	kg	1.02	2,761	2,607	154
Coal (sub-bituminous)	kg	1.02	2,068	1,955	113
Coal (lignite)	kg	1.02	1,512	1,433	79

Table 18: Upstream emissions split by GHG

Upstream emissions split by GHG gas

	Unit	kg CO_2e	CO_2 (kg CO_2)	CH_4 (kg CO_2e)	N_2O (kg CO_2e)
Diesel - Upstream	litre	0.458	0.455255049	0.001750766	0.000994185
Petrol (regular unleaded) - Upstream	litre	0.419	0.401388829	0.005345835	0.012265336
Light fuel oil - Upstream	litre	0.485	0.48224573	0.00175671	0.00099756
Heavy fuel oil - Upstream	litre	0.493	0.490256926	0.001749569	0.000993505
Aviation gasoline - Upstream	litre	0.404	0.400856007	8.09E-05	0.003063081
Natural Gas distributed commercial - Upstream	MJ	0.0069	0.006880901	1.61E-05	3.04E-06
Natural Gas distributed industry - Upstream	MJ	0.0069	0.006893737	3.22E-06	3.05E-06
Coal - Bituminous - Upstream	kg	0.154	0.152895909	0.000456303	0.000647788
Coal - Sub-Bituminous - Upstream	kg	0.113	0.112214868	0.000324483	0.000460649
Coal - Lignite - Upstream	kg	0.079	0.07845766	0.000224141	0.0003182
LPG - Upstream	litre	0.341	0.332583838	0.008104529	0.000311632
LPG stationary commercial - Upstream	kg	0.341	0.340092458	0.000763098	0.000144444
LPG stationary industry - Upstream	kg	0.341	0.340702404	0.000152893	0.000144703
Electricity - Upstream	kWh	0.0073	0.007032144	0.000260243	7.61E-06

Table 19: DOC Degradable Organic Carbon Values (from American Biogas Association Carbon Accounting Methodology for Biogas, 2024)

Landfill Waste Type	DOC (Weight Fraction, Wet Basis)
All bulk waste, unseparated	0.2028
Bulk MSW	0.3
Construction and demolition waste	0.08
Diapers	0.24
Food waste	0.15
Food processing industry waste	0.22
Garden waste	0.2
Inert waste	0
Other industrial solid waste	0.2
Paper waste	0.4
Pulp and paper industry waste	0.2
Sewage sludge	0.05
Textile waste	0.24
Wood and/or straw waste, wood products	0.43

Table 20: MFE 2024 and Australia National Greenhouse Accounts Factors 2024

Emission source		Unit	kg CO_2e	CO_2 (kg CO_2e)	CH_4 (kg CO_2e)	N_2O (kg CO_2e)	Uncertainty	Source
Combustion	Natural Gas	GJ	54.035	53.98607	0.02520	0.02385	CO_2e ± 2.4%, CO_2 ± 2.4%, CH_4 ± 50%, N_2O ± 50%	MFE 2024

Emission source		Unit	kg CO_2e	CO_2 (kg CO_2e)	CH_4 (kg CO_2e)	N_2O (kg CO_2e)	Uncertainty	Source
Combustion	Biomethane (99% CH4 @ 101.1kpa &15C)	GJ	0.130	0	0.1	0.03		Australia 2024

Table 21: MFE 2024 emissions factors, waste to landfill without gas recovery.

Waste to landfill without gas recovery emission factors								
Emission source		**Unit**	**kg CO_2e**	**CO_2 (kg CO_2e)**	**CH_4 (kg CO_2e)**	**N_2O (kg CO_2e)**	**Assumption**	**Uncertainty**
Waste (known composition)	Waste - Food	kg	2.107	n/a	2.107	n/a	N2O and CO2 are excluded	±40%
	Waste - Garden	kg	1.724	n/a	1.724	n/a	N2O and CO2 are excluded	±40%
	Waste - Paper	kg	3.064	n/a	3.064	n/a	N2O and CO2 are excluded	±40%
	Waste - Wood (combined)	kg	1.187	n/a	1.187	n/a	N2O and CO2 are excluded	±40%
	Wood (treated)	kg	0.192	n/a	0.192	n/a	N2O and CO2 are excluded	±40%
	Wood (untreated)	kg	2.681	n/a	2.681	n/a	N2O and CO2 are excluded	±40%
	Waste - Textile	kg	1.532	n/a	1.532	n/a	N2O and CO2 are excluded	±40%
	Waste - Nappies	kg	0.766	n/a	0.766	n/a	N2O and CO2 are excluded	±40%
	Waste - Sludge	kg	0.479	n/a	0.479	n/a	N2O and CO2 are excluded	±40%
	Waste - Other (Inert)	kg	n/a	n/a	n/a	n/a	N2O and CO2 are excluded	±40%
Waste (unknown composition)	General waste	kg	0.724	n/a	0.724	n/a	N2O and CO2 are excluded	Not quantified
	Office waste	kg	2.081	n/a	2.081	n/a	N2O and CO2 are excluded	Not quantified

Table 22: MFE 2024 emissions factors, non-municipal waste, *note N_2O and CO_2 are excluded from these factors*.

Non municipal waste						
Emission source		**Unit**	**kg CO_2e**	**CO_2 (kg CO_2e)**	**CH_4 (kg CO_2e)**	**N_2O (kg CO_2e)**
Waste (known composition)	Biological (sludge)	kg	0.196	n/a	0.196	n/a
	Construction & Demolition	kg	0.157	n/a	0.157	n/a
	Bulk Waste	kg	1.098	n/a	1.098	n/a
	Food	kg	0.588	n/a	0.588	n/a
	Garden	kg	0.784	n/a	0.784	n/a
	Industrial	kg	0.588	n/a	0.588	n/a
	Wood	kg	1.333	n/a	1.333	n/a
	Inert (all other waste)	kg	n/a	n/a	n/a	n/a
	Average for non-municipal solid waste	kg	0.197	n/a	0.197	n/a

This is a simplification of the IPCC FOD model as it ignores the time decay of waste and instead calculates the total emissions that will result — IPCC Waste Emissions Calculation method

Table 23: MFE 2024 emissions factors, transmission and distribution losses

Transmission and distribution losses								
Emission source			**Unit**	**kg CO_2e**	**CO_2 (kg CO_2e)**	**CH_4 (kg CO_2e)**	**N_2O (kg CO_2e)**	**Uncertainty**
Transmission and distribution losses		Natural gas used	kWh	0.007	0.00006	0.00717	n/a	Unknown
		Natural gas used	GJ	2.009	0.01747	1.99160	n/a	Unknown

13. APPENDIX C; LATEST ETS METHOD FOR LANDFILLS

Option 2 for Landfill Gas Fugitive Emissions calculation is from the NZ ETS and associated regulations. Not recommended for this LCA however the defaults below can be useful.

Participants registered for the activity of operating a disposal facility under Part 6 of Schedule 3 of the Climate Change Response Act 2002 are required to calculate their emissions annually and submit an emissions return to the EPA. Regulation 5 of the Climate Change (Waste) Regulations 2010 (**Waste Regulations**) specify the method of calculating emissions for waste and the default emissions factor (**DEF**).

The UEF Regulations have now been amended in 2024, so the same DEF is used in both the Waste and the UEF Regulations. They also replace schedule 3 of the UEF Regulations so that **applicants use the default (historical) waste composition that applied when the waste was disposed, improving the accuracy of the model.** These changes will come into effect on 1 Jan 2026 and apply to 2025 emissions.

The Amendment Regulations: Climate Change (Unique Emissions Factors) Amendment Regulations 2024 (SL 2024/202) Contents – New Zealand Legislation

Latest changes to FOD model parameters in 2024 are:

Schedule
Schedule 3 replaced

r 8

Schedule 3
First-order decay model parameters

r 23C

Waste stream component	Current default waste composition data (SWAP)	Waste composition until 1 January 2023	Waste composition until 1 January 2016	IPCC DOC	Equivalent methane generation potential Lo (m^3 CH_4/tonne)	Decay rate constant k
Food	9.0%	16.8%	0.0%	0.15	75	0.185
Garden	5.7%	8.3%	23.3%	0.20	100	0.100
Nappies and sanitary	2.5%	3.0%	2.7%	0.24	120	0.100
Paper	5.9%	10.7%	14.9%	0.40	200	0.060
Sewage sludge	1.9%	3.9%	0.0%	0.05	25	0.185
Textiles	5.0%	5.6%	3.9%	0.24	120	0.060
Timber	12.6%	11.9%	13.9%	0.43	215	0.030
Inert	57.3%	39.8%	41.3%	0.00	0	0.000

Schedule 2
Destruction factors

r 23C

Destruction equipment	Destruction factor
Open flare	0.5
Enclosed flare	0.9
Internal combustion engines, gas turbines, and boilers	0.9

5 Method of calculating emissions from operating disposal facilities

(1) A waste participant must use the following formula to calculate emissions for each class of waste disposed of at each disposal facility operated by the waste participant in the year:

$$E = (A - B) \times C$$

where—

E is the emissions in tonnes for the class of waste

A is the gross tonnage of the class of waste

B is the diverted tonnage of the class of waste

C is,—

(a) in relation to a class of waste for which no unique emissions factor is approved by the EPA under section 91 of the Act, the default emissions factor of 1.023; and

(b) in relation to a class of waste for which a unique emissions factor is approved by the EPA under section 91 of the Act, the unique emissions factor that the EPA has approved for that class of waste.

(2) An annual emissions return submitted by a waste participant must record the waste participant's total emissions from the activity, calculated by adding together the emissions for each class of waste disposed of at each facility that the waste participant operates.

(3) If a waste participant is required to submit an emissions return for a period other than a year, this regulation applies with any necessary modifications.

23B relates to waste composition:

23B Requirements relating to application for unique emissions factor relating to waste composition

A waste participant who wishes to calculate a unique emissions factor that relates to the composition of a class of waste disposed of at a disposal facility must—

(a) obtain representative data in relation to the composition of the class of waste disposed of at the facility in a year by carrying out at least 2 surveys of 1 or more weeks' duration of the class of waste—

- (i) as it enters the facility; and
- (ii) over a period of 12 months; and
- (iii) at intervals of at least 3 months; and
- (iv) in accordance with Procedure 2 in section 5 of the SWAP; and

(b) record the fractions by weight of each of the following components of the samples of the class of waste taken during each survey period:

- (i) garden waste:
- (ii) nappy and sanitary waste:
- (iii) all putrescible waste other than garden waste:
- (iv) paper waste:
- (v) sewage sludge:
- (vi) timber waste:
- (vii) textile waste:
- (viii) other waste (including plastics, ferrous metals, non-ferrous metals, glass, rubber, rubble, concrete, and potentially hazardous waste); and

(c) calculate a unique emissions factor for the class of waste in accordance with the following formula:

$$UEF = (1.68 \times GW) + (2.016 \times NSW) + (1.26 \times OPW) + (3.36 \times PW) + (0.42 \times SSW) + (3.612 \times TMW) + (2.016 \times TXW)$$

where—

GW is the weighted average fraction of garden waste in the class of waste determined by reference to the results of the surveys

NSW is the weighted average fraction of nappy and sanitary waste in the class of waste determined by reference to the results of the surveys

OPW is the weighted average fraction of putrescible waste other than garden waste in the class of waste determined by reference to the results of the surveys

PW is the weighted average fraction of paper waste in the class of waste determined by reference to the results of the surveys

SSW is the weighted average fraction of sewage sludge in the class of waste determined by reference to the results of the surveys

TMW is the weighted average fraction of timber waste in the class of waste determined by reference to the results of the surveys

TXW is the weighted average fraction of textile waste in the class of waste determined by reference to the results of the surveys

UEF is the unique emissions factor for the class of waste; and

(d) submit the following material to a recognised verifier:

- (i) a record of the surveys undertaken to comply with paragraph (a), including the survey plan for each survey; and
- (ii) the results of the surveys referred to in paragraph (b); and
- (iii) the calculation done under paragraph (c); and

23C relates to the use of an UEF and LFG collection and destruction system:

23C Requirements relating to application for unique emissions factor approval in relation to LFG collection and destruction system

(1) A waste participant who wishes to calculate a unique emissions factor that relates to the use of an LFG collection and destruction system at a disposal facility must,—

(a) using monitoring equipment over the period of 1 year, carry out representative measurements of the volumetric flow rate (in cubic metres per hour) of the LFG collected and conveyed to the destruction equipment; and

(b) obtain representative samples of the LFG collected and conveyed to the destruction equipment over the period of 1 year; and

(c) have tests carried out to measure the CH_4 concentration by volume in each of the samples taken under paragraph (b); and

(d) using the data collected under paragraphs (a) and (b) and the results of the tests done under paragraph (c), calculate the tonnes of CH_4 conveyed to the destruction equipment in the year; and

(e) estimate the gross amount of CH_4 in tonnes that the disposal facility (and any other area from which LFG is conveyed to the destruction equipment) is expected to generate in the year in accordance with subclause (2); and

(f) calculate the estimated efficiency of the LFG collection and destruction system over the year in accordance with the following formula:

$$C = D \times Q \div G$$

where—

C is the estimated efficiency of the LFG collection and destruction system

D is the destruction factor for the type of destruction equipment in use at the facility as documented in the manufacturer's specifications for the equipment or, if such information is not available, the destruction factor in Schedule 2

G is the estimated gross generation of CH_4 for the year in tonnes calculated in accordance with subclause (2)

Q is the tonnes of CH_4 conveyed to the destruction equipment in the year as determined in accordance with paragraph (d); and

(g) calculate a unique emissions factor for the facility in accordance with the following formula:

$$UEF = 0.91 \times (1 - C)$$

where—

C is the lesser of—

(i) 0.9; and

(ii) the figure for the estimated efficiency of the LFG collection and destruction system determined under paragraph (f)

UEF is the unique emissions factor for the facility; and

(h) submit the following material to a recognised verifier:

(i) a record of the measurement, sampling, and testing regime that complies with paragraphs (a) to (c); and

(ii) the calculations done under paragraphs (d), (f), and (g) and subclause (2); and

(iii) any other information required by the recognised verifier as necessary to provide verification of the unique emissions factor under regulation 24.

EPA allows for the use of default emissions factors and in in regulation 23C(1)(g), formula, replace "0.91" with "1.023".

(e) the following inputs must be used to the extent relevant when applying the model:

Parameter	Input
Methane correction factor	1
Fraction of degradable organic carbon (DOC) that degrades to methane	0.5
Fraction of LFG by volume that is methane	0.5
Oxidation factor	10%
Density of methane at normal temperature and pressure	0.668 kg per cubic metre
Equivalent methane generation potential	As per the third or fourth column of Schedule 3
Decay rate constant	As per the fifth column of Schedule 3

23D relates to waste composition and the use of an LFG collection and destruction system:

23D Requirements relating to application for unique emissions factor approval in relation to waste composition and LFG collection and destruction system

A waste participant who wishes to calculate a unique emissions factor for a class of waste disposed of at a disposal facility that relates to waste composition and the use of an LFG collection and destruction system must—

(a) follow the procedure in regulation 23B and calculate a unique emissions factor for waste composition in relation to the class of waste; and

(b) determine the estimated efficiency of the LFG collection and destruction system for the facility by following the procedure in regulation 23C(1)(a) to (f); and

(c) calculate a unique emissions factor for the class of waste in accordance with the following formula:

$$UEF = UEF_{wc} \times (1 - C)$$

where—

C is the lesser of—

(i) 0.9; and

(ii) the figure for the efficiency of the LFG collection and destruction system for the facility determined in accordance with paragraph (b)

UEF is the unique emissions factor for the class of waste

UEF_{wc} is the unique emissions factor relating to waste composition for the class of waste determined in accordance with paragraph (a); and

14. APPENDIX D; PRECISION AND UNCERTAINTY

Precision and uncertainty in emissions calculation models, An Explainer, Toitū

PRECISION AND UNCERTAINTY IN EMISSIONS CALCULATION MODELS

An Explainer

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October 2023

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Contents

Purpose

The purpose of this document is to outline key considerations and differences between financial and carbon auditing. It covers the context and concepts of Greenhouse Gas (GHG) accounting and emission calculation model precision, as well as uncertainty and materiality.

This document is an "Explainer" from Toitū. Each of our Explainers provides an in-depth overview on a topic and will vary on length and detail, but all carry the same intent to inform our members and the public. As such, it reflects on continuous developments in climate science, emissions measurement vs modelled emissions the limitations on modelling, and the overarching value of emissions accounting to inform and drive pollution reduction and practical tips to avoid common mistakes and focus on what is important (also known as Material).

Guidance

Certainty and uncertainty in carbon accounting

Firstly, it is important to define that GHG emissions can be measured or modelled. Measuring uses specific scientific equipment and devices that can determine the exact amount of GHG that have been emitted by that activity (e.g., having a device installed at the exhaustion pipe of a car). Modelling is a quantified representation of the GHG emission source converted into emissions. A model is a simplification of measured physical processes including assumptions, limitations and therefore, uncertainty.

Using a model, rather than measuring emissions is most common practice, due to the availability of data, technical feasibility, and compromise of cost vs accuracy and magnitude of the emission source or emission removal. For most sources and sinks, the model requires a single variable formula activity data x an Emissions Factor (EF) (figure 1), however multivariable models may also be applicable for some scenarios.

Single variable model:

+ Example: Known activity data of litres petrol combusted. User enters litres into a model which converts to emissions using the EF on emissions/litre combusted.

Multivariable model:

+ Example: Known activity data of $spent on petrol, average price per litre. User enters $ AND $/litre into a model. The model converts $spend to litres, then converts litres to emissions using the EF on emissions/litre combusted.

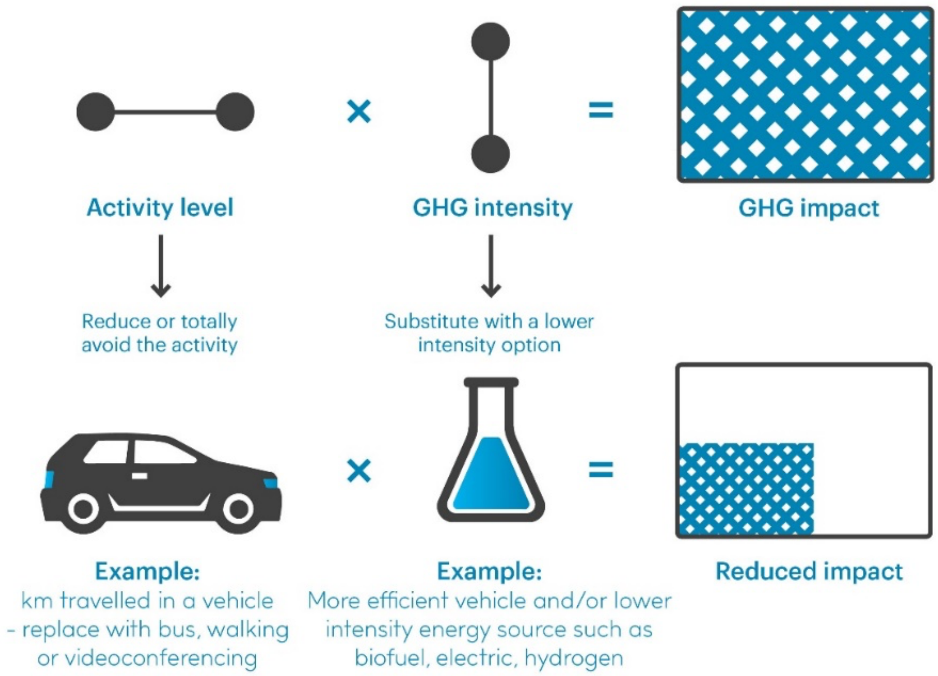

Figure 1: Example of single activity variable model. This visual exemplifies the equation shared above, where Emissions = activity data x emissions factor. In this instance, the activity data is equal to the litres of fuel (such as petrol or diesel) combusted in a vehicle and the GHG intensity refers to the emissions per litre of fuel combusted.

Emission factors help us understand the level of greenhouse gases intensity that occurs from certain activities. Calculated emissions will have a certain level of accuracy and uncertainty, depending on the extent of assumptions and variables in the model. Activity level data refers to the activity performed (e.g., driving a small petrol car for 10km). Emission factors refer to the GHG emissions intensity of a given activity (e.g., emissions per km for a small petrol car).

The discussion of uncertainty in carbon accounting links into several areas. Below we delve into some uncertainty reasoning for each (adapted from the GHG Protocol):

+ Assumptions being used in the calculation of an emission factor; in the various inputs set in the methodology.
    - For example, occupancy rates on aircraft are assumed to be the same for each flight, but in reality they vary per flight throughout the day and year.
+ Average figures are commonly used in the calculation of an emission factor, as opposed to figures being specific to a site, organisation, product or transport movement, etc. The goal for any businesses is to achieve specific figures over time.
    - For example, distance based factors for passenger vehicles within a given size and age category can be based on an average fuel efficiency of tens of thousands of vehicles, and will not reflect the actual fuel efficiency of the vehicle activity emissions are being calculated for.
+ Default data is often used in more complex emission factor calculations, where data parameters are not available locally.

- For example, IPPC defaults (used internationally) are used as part of the NZ waste emission factor calculation.[1]

+ Limited data availability may require extrapolating sample data to represent the whole.
    - For example, commuter rail emission factors are derived using data from one or two regional councils, yet these emission factors are used throughout the country.[2]
+ Activity data that is used in emissions calculations will also have varying degrees of uncertainty.
    - For example, the distance travelled entered for a domestic flight may not be the actual distance travelled, owing to factors such as flight route changes (due to weather conditions), and if circling activity is required during landing (due to airport congestion).

Global Warming Potential (GWP) of greenhouse gases - which is the basis of carbon accounting – also have associated uncertainty, linked to scientific uncertainty. For example, the Global Warming Potential (GWP) of methane (CH4) and nitrous oxide (N2O) have changed with each successive Intergovernmental Panel on Climate Change (IPCC) Assessment Report, as our scientific understanding of the climate impacts of these gases improves.

It's essential to be clear about how certain or uncertain we are when we calculate GHG emissions. National inventory reports require disclosing how accurate carbon accounting is, which is also the best practice recommended by the IPCC, the world's leading climate body. When it comes to the global standard, ISO 14064-1:2018, the rules for measuring and reporting GHG emissions also requires to:

1. Check how sure they are about the methods and data they use to figure out their GHG emissions.
2. Understand and share the level of certainty for different categories of their GHG reports.

If it's too hard or costly for a company to give exact numbers about their level of certainty, they need to explain why and provide a qualitative assessment.

Think of it this way: Carbon accounting isn't as straightforward as financial accounting - it operates in a more unpredictable, dynamic, and complex environment. It's more like navigating a constantly changing and dynamic landscape. Everyone appreciates there's some embedded uncertainty as a known and common part of the practice.

The challenging nature of emission factors

Emissions factors are based on the best information available, which means that they bring the best representation of a conversion rate known to date. By consequence, they aren't always precise. Why? Because they are often calculated based on regional or national average data, so may not exactly reflect the emissions intensity of an activity in a specific location at a particular time.[3] In some cases, when emission factor sets are published, there will be a disclosure of uncertainty. For example, New Zealand's Ministry for the Environment (MfE) gives a range of certainty for their emission factors in their Measuring Emissions Guide. Some are almost spot-on with only 0.1% uncertainty, whilst others can be off by more than 40% uncertainty. When exact numbers aren't provided, the ministry still gives a general idea with a qualitative description of uncertainties included in the guidance.

In some cases, Toitū sources or develops emission factors additional to those published by government agencies. There are several reasons for this, including:

+ There are no published emission factors for a particular activity undertaken by an organisation.
+ A lower uncertainty, more accurate or more applicable emissions factor for the activity is available or can be determined, reducing the inherent uncertainty in emissions calculations.[4]

EFs are developed using underlying GHG emissions information and a suitable functional unit (e.g., tCO2e/litre, tCO2e/kilometre, tCO2e/kilogram, etc). Toitū's process ensures that supplier-specific emission factor calculations are developed based on consistent principles and verified by a party not involved in the emission factors development.

[1] For more on this, refer to pages 22-23: https://environment.govt.nz/assets/publications/Measuring-Emissions-Guidance_DetailedGuide_2023_ME1764.pdf
[2] For more on this, refer to page 66: https://environment.govt.nz/assets/publications/Measuring-Emissions-Guidance_DetailedGuide_2023_ME1764.pdf
[3] Indirect emissions sources, such as scope 2 (electricity) and scope 3 (value chain) are generally calculated using average data, etc.
[4] An in-depth example is provided on page 7.

Choosing the right emission factor can be a difficult task. What's 'right and wrong' can be blurry and often dependant on external factors. We recommend following the approach described below, when assessing your emissions factor selection.

When selecting an emission factor, you should consider:

+ what is the most appropriate emission factor.
+ Consider the available activity data; is it the most granular available?
+ Assess the source and activity level data that makes up the emission factor.
+ The specific details and scope of the factor such as, 'direct combustion of petrol' vs 'direct combustion and upstream 'Well-to-Tank' production of the petrol'.

The accuracy and specificity. At Toitū our process ensures that supplier-specific emission factor calculations are based on key inventory quality principles such as relevance, completeness, and accuracy.[5]

From Toitū carbon programme experience, selection of emission factors should be conducted firstly by a publication (or equivalent) search, following a search hierarchy as shown in Figure 2.

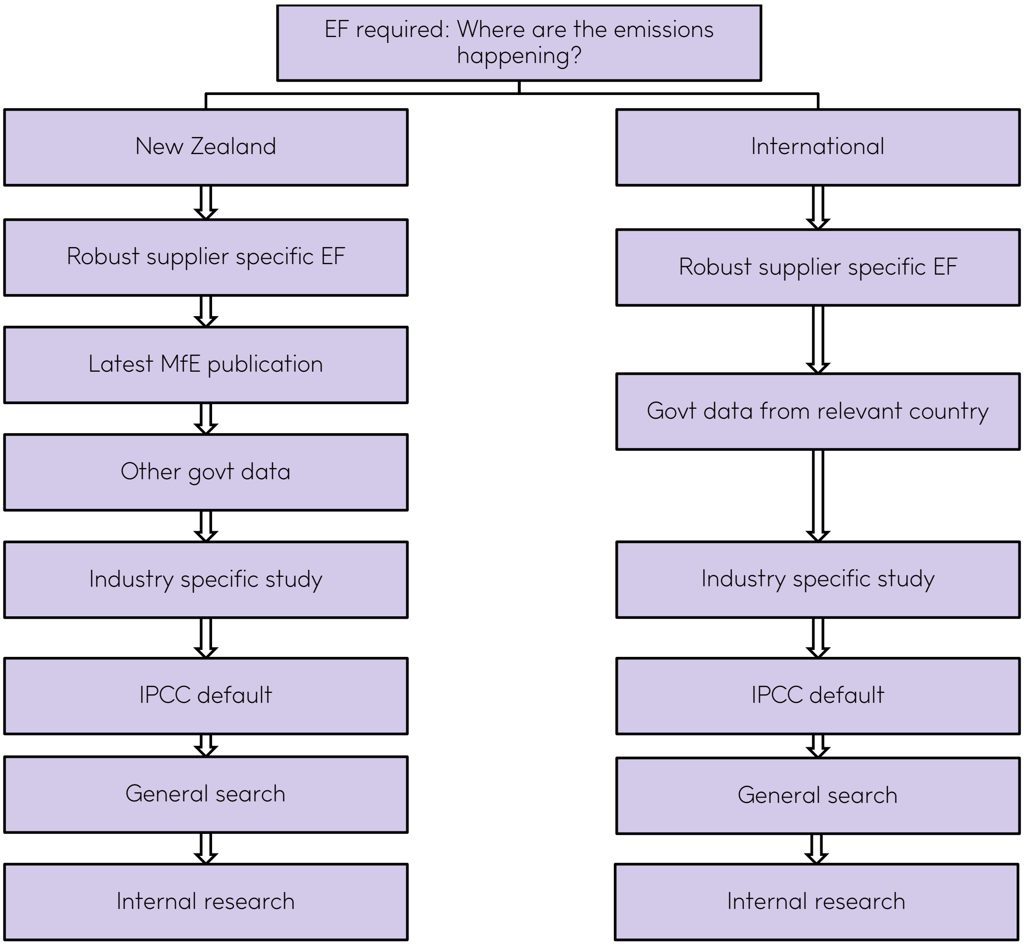

Figure 2: Recommended approach to sourcing an emission factor in a publication search hierarchy.

The level of the search (figure 2) will not always reflect the highest quality. For example, a robust industry specific study may be more accurate than a more general government published factor. So, it's essential to evaluate all emission factors you use to ensure they are the best option for your emissions source. Here are our recommendation components to check for factor quality:

[5] For more on definitions of Relevance, Completeness, Accuracy, and others; refer to page 9 of GHG Protocol Corporate Standard

- Geographic suitability - ideally the data should reflect the country or region that the emissions calculation is associated with.
- Time period - ideally the data should reflect the time period that the emissions calculation is associated with.
- Multiple gases - Whether it covers just one gas or multiple gases (e.g., CO_2, CH_4, N_2O, etc.)
- Peer review - Whether some or all the data has been peer reviewed and/or third party verified.
- Version of publication - Is the publication the most recent version?
- Applicability - What typical emission source activities are anticipated for the factor, and will these be an appropriate match?
- Updates – Are there likely to be version updates? (i.e., will there be a need to monitor for new publications?)
- Scope (Lifecycle) - Are the factors aligned to organisation or product/service measurements e.g., Tank to Wheel vs Well to Wheel.
- Transparency and number of assumptions and/or variables "embedded" within the factor.
- Level of visibility the factor enables, for identifying opportunities to reduce the emissions.

Applying the principles of the search hierarchy and quality checking your identified options can help prioritise what's right.

Example: Choosing the right emission factor based on factor quality and publication search hierarchy

Company A includes freight in its operations, which is transported by heavy goods vehicles (HGVs). They use Company B as their freight supplier. Company B has calculated the GHG emissions associated with fuel use in its vehicles and has calculated supplier specific emission factors, both based on their overall fleet and for individual vehicle types. There are several emission factors that could be determined and used by a company that uses Company B as a freight provider, with varying inherent uncertainty levels. Listed below are a range of emission factors which all relate to freighting of goods:

Published by MfE:

- Road Freight All trucks (kg CO_2e/tonne.km[6]): Calculated over the whole NZ HGV fleet, typically used when details of vehicle type and urban/rural split are unknown.
- Urban delivery heavy truck or Long-haul heavy truck (kg CO_2e/tonne.km): Calculated for HGVs that are used for either long-haul or urban activities, typically used where the types of deliveries are known, but not the type or size of vehicles.
- HGV by fuel, size, and age (kg per CO_2e km travelled by the HGV): Calculated using typical real world fuel efficiency of different segments of the NZ HGV fleet, does not allow for the weight of goods being transported, so assumes the entire vehicle is allocated to the load being reported.

Supplier Specific:

- Average emissions for the Company B fleet: Average fuel use per km travelled for the entire Company B fleet, considering the actual fuel use, rather than whole NZ HGV fleet.
- Emissions for Company B vehicles by vehicle type and size: calculated for different sizes of vehicles in the Company B fleet using fuel card information for specific vehicles and collated by vehicle type.

In this example, any of the emission factors are suitable for calculating emissions from the freight activity, provided input parameters are appropriate and there are no errors in the calculation. However, the supplier specific factors should provide lower uncertainty than the MfE factors, because they are calculated based on underlying data that is more specific (Specificity) to the vehicles being used for freighting the specific goods, and more accurate (Accuracy) because it is based on the fuel used by the specific freight company (Company B) used by the organisation (Company A). Supplier specific factors should also provide greater visibility for Company A to identify opportunities to reduce their freight emissions.

[6] Tonne.km = # of tonnes x km travelled

Where Toitū develops emission factors, or where emission factors are sourced from other references, wherever available Toitū includes an uncertainty estimate in the emissions factor database alongside the emissions factor, based on quantitative or qualitative assessment of inherent uncertainty in underlying data.

Understanding Materiality and Verification of a GHG inventory

Greenhouse Gas verification evaluates historical data and information to determine if the statement is materially correct and conforms to set criteria. At Toitū Envirocare we go by the globally recognised verification standard, ISO 14064-3:2019 which is deemed the most accurate and science-based auditing criteria. The term 'materially correct' is a key concept as it relates to the concept of materiality, which involves determining what's truly significant in a GHG inventory. Relevant materiality definitions in ISO 14063-3:2019 include[7]:

+ Material: information capable of influencing the decisions of intended users.
+ Materiality: concept that individual misstatements or the aggregation of misstatements could influence the intended users' decisions.
+ Intended user: means the individual or organisation that will rely on the GHG information to make decisions.
+ Intended use: means the main purpose set by the organisation or the GHG Programme to determine its GHG emissions, aligned with the needs of the interested user of the GHG information. Example of intended uses could include informing the Board or stakeholders, minimising emissions, managing risk or informing the organisation.

For example, if Company A is an exporter and heavily rely on freight as part of their regular activities and has investors as intended users, excluding freight from their GHG inventory is material and it could influence the decision of those investors (Intended user).

As part of the audit process, verifiers confirm the materiality threshold (%) required by the intended users. If no materiality threshold has been specified by intended users, the verifier/validator shall set (a) materiality threshold(s) and communicate them to the company.

According to ISO 14064-3:2019, GHG programmes can determine a materiality threshold. At Toitū, our default materiality threshold on our Carbon Certification Programme is 5%. This means that misstatements over 1% (including exclusions), that when added together produce less than 5%, are deemed not to influence the intended users' decisions. While 5% is a common materiality threshold used in GHG audits, we at Toitū check for discrepancies and communicate with companies where any unusual uncertainty circumstances are identified.

It is not possible to give absolute assurance over GHG emissions inventories, largely due to inherent uncertainties. Assurance refers to the degree of confidence in the GHG statement and information provided in the audit process. A level of assurance is agreed prior to commencing a GHG verification process. There are two common types of assurances used:

+ Reasonable assurance: is a level of assurance where the nature and extent of the verification activities have been planned to provide a high but not absolute level of assurance on historical data and information.
+ Limited assurance: is a level of assurance where the nature and extent of the verification activities have been designed to provide an initial level of assurance on historical data and information (ISO 14064-3:2019).

Materiality of differences in emission factors compared to uncertainty

Another difference between financial and carbon accounting is the number of decimal places and precision used in calculations. Financial accounting uses two decimal places, like in dollars and cents. In contrast, carbon accounting often goes deeper, sometimes using ten or more decimal places. This precision is seen especially in emission factors, which are typically calculated as tonnes CO_2e for organisation inventories.

[7] Toitū carbon programme Organisation Technical Requirements, also referenced in ISO14064-1:2018

If an emission factor is published using several significant figures, any change to the third significant figure or beyond, will have an immaterial change to a carbon inventory. This is because it will not have an impact greater than the 5% level of materiality, regardless of the level of activity data entered or the GWP of the emission factor being applied.

For example, the table below illustrates the impact on the carbon footprint for a given activity, when the emission factor value changes. There are three scenarios outlined where an emission factor value changes at the second, third and fourth significant figure. A change at the second significant figure does make a material difference (8.9%), while a change in the third and fourth significant figure falls below the 5% materiality threshold, typically used by Toitū and commonly used in GHG verification engagements. Therefore, if there are small rounding differences between published and reported emission factors, these may not be identified as non-conformities in a GHG audit process as they are not material in the context of the GHG inventory.

Considering the uncertainties described, and the immaterial impact that changes beyond the third significant figure make to a carbon inventory, it becomes clear that any changes at the fourth decimal place and beyond are clearly immaterial.

Unrounded EF	Rounded EF (to nearest number)	Difference introduced	EF rounded up	Difference introduced
1.123456789	1	10.989%		
2 significant figures	1.1	2.088%		
3 significant figures	1.12	0.308%	1.13	-0.582%
4 significant figures	1.123	0.041%	1.124	-0.048%
5 significant figures	1.1234	0.005%	1.1235	-0.004%

Table 1: The table compares the difference between the EF original value and the rounded number across difference significant figures. It shows that with 3 significant values, 1.12 or 1.13, the difference introduced is less than 1%, making it minimal or immaterial, when applying materiality concept explained above. Columns 2 and 3 bring the EF rounded to the closest number and difference introduced between the rounded value and original value, respectively. Columns 4 and 5 bring the EF rounded up and difference introduced between the rounded value and original value, respectively.

Conclusion

Carbon accounting is based on science, which is constantly evolving and while it carries a level of uncertainty, its power lies in its ability to illuminate. It might not give a precise representation of greenhouse gases being emitted, but it does equip organisations with vital insights into their climate impact and areas of influence. It is a model instead of direct measurement. Make no mistake though, this helps empower businesses to understand how they can shift their impact from negative to positive; to make informed decisions on how to actively manage and reduce their environmental footprint.

There is a value when companies can say, "We have reduced 20% of our electricity emissions" or "We have reduced our electricity consumption kWh by 20%". Our recommended approach is to set reduction targets on a percentage basis (as opposed to tonnes of emissions), or even defaulting back to activity data variation in a period. This future-proofs updates as emission factors evolve that can impact the total carbon footprint value.

There might be uncertainties where it is not possible or practicable to fully overcome. But with advancements in science and more precise emission factors, uncertainty gap narrows further. Simply starting to reduce the uncertainty by the selection of more accurate emission factors (e.g., emissions per litre of fuel used has a lower inherent uncertainty than emissions per km travelled) or improving activity data quality is a step forward in becoming more certain about our carbon impact. Remember, every bit counts and if don't measure it, you can't manage it. As philosopher Thomas Carlyle said:

"Go as far as you can see. When you get there, you'll be able to see further."
Thomas Carlyle

As the science underlying carbon accounting becomes better understood, we expect methodologies to reduce the level of uncertainties in the process. The path may be challenging as legislation and best practice evolve, but the most crucial action is for countries and organisations to continue leading positive change. Businesses must continue meeting legislation and working towards authentic action; so that investors and consumers can make an informed choice about products and services they can trust. At Toitū, we hold the standard and are dedicated to science-backed approach as best practice in our commitment to the environment and our people. Join our collective movement and mark progress with us.

Resources

ISO 14064-3: Greenhouse gases — Part 3: Specification with guidance for the verification and validation of greenhouse gas statements

Measuring emissions: A guide for organisations: 2023 detailed guide | Ministry for the Environment

GHG Protocol: GHG Protocol guidance on uncertainty assessment in GHG inventories and calculating statistical parameter uncertainty

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