Greenhouse Gas Report 2025

LOTT Energy Usage and Emissions Inventory, 2019 – 2025

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1. Summary

The LOTT Clean Water Alliance (LOTT) has undertaken a greenhouse gas emissions inventory, using industry standard methods, to assess emissions from its operations. The purpose of this report is technical and aims to give LOTT and decision-makers an accounting of greenhouse gases and carbon emissions. The report can also be used in making decisions about equipment and processes insofar as they affect LOTT's carbon footprint. To remain consistent with regional goals, inventories, and planning by the Thurston Regional Planning Council (TRPC) and Thurston Climate Mitigation Collaborative (TCMC), the baseline year for emissions was 2015 (Thurston Climate Action Team, 2018). LOTT accounted for various sources, including fuel use and emissions that occur during wastewater processing. Data from 2015 and 2019 through 2025 are presented. There are many similarities in emissions data over these eight years, both in total emissions and in the relative contributions from each emission source. Most greenhouse gas emissions in each year come from purchased electricity, which is used to power pumps and aerators – essential equipment for wastewater treatment.

In 2025, an overall decrease in greenhouse gas emissions of 28% was noted in comparison to the 2015 baseline, from 8622 Metric Tons (MT) in 2015 to 6216 MT in 2025. On a per capita basis, the decrease was even greater at 42%. Despite an increasing population, LOTT has worked to make its processes and equipment more efficient both operationally and through capital improvements.

The decrease primarily stemmed from two changes: the sources of energy used to supply the Puget Sound Energy (PSE) electricity have been transitioning to more renewable sources and the emission factor for PSE was updated to reflect that change in 2021, and then again in 2023. Additionally, in March 2023, the Biological Process Improvements (BPI) project was fully commissioned and has been in operation ever since. The BPI project drastically cut down on the need for aeration and pumping through a reconfiguration of flow through the treatment plant and replacement of more efficient equipment. Other recent changes such as replacing some gas-powered vehicles with electric vehicles, removing methanol as a supplement to the biological process and prioritizing biogas utilization over natural gas usage have also reduced the amount of greenhouse gases emitted overtime.

LOTT has reduced its energy consumption and greenhouse gas emissions since 2009 through various efforts, described in more detail in the Background section below. Despite the increasing population in our region resulting in increased flow to the plant, LOTT has been able to drive down its greenhouse gas emissions over time.

2. Background: Regional Climate Adaptation Planning

TRPC has been instrumental in starting the conversation about greenhouse gas emissions in Thurston County and attempting to track them. In 2018, TRPC published a Greenhouse Gas Inventory Report for calendar years 2010 – 2016 (Thurston Climate Action Team. 2018). This inventory took a broad approach, categorizing emissions into built environment emissions for both residential and commercial buildings and into transportation for passenger vehicles and light- and heavy-duty trucks. Given TRPC's broad approach, some of the sources of greenhouse gas emissions generated by LOTT were captured in two broad categories: "Commercial – built environment" includes the electricity and natural gas used at LOTT, and "Transportation – passenger and light-duty trucks" includes the fuel used in LOTT vehicles. In subsequent reports from TRPC and TCMC, LOTT's emissions were characterized by a few wastewater-specific parameters: digester gas, methanol, nitrogen discharges and nitrification/denitrification. These parameters represent only a small portion of the total emissions at LOTT. Because of the way LOTT's emissions are divided between general categories in the TRPC/TCMC reports, wastewater sector progress in reducing emissions is not fully reflected.

This LOTT Energy Usage and Emissions inventory provides a more comprehensive evaluation of progress in emissions reduction specific to LOTT. TRPC led a regional planning effort to develop the Thurston Climate Adaptation Plan, published in 2018 (Thurston Regional Planning Commission, 2018), and the Thurston Climate Mitigation Plan in 2020 (Thurston Regional Planning Commission, 2020). The planning effort also established goals for Thurston County to reduce greenhouse gas emissions to 45% below 2015 levels by 2030 and 85% below 2015 levels by 2050.

The 2018 Climate Adaptation Plan contained 90 possible actions to help adapt to climate change. LOTT was mentioned as a potential lead entity in two energy-related actions: increasing energy efficiency of the water infrastructure and capturing energy from waste products. LOTT is active in both of those areas.

The 2020 Mitigation Plan also included a community-wide actions list. Additional action ideas listed and associated with LOTT were capturing nitrous oxide, using hydrogen power, using heat energy transfer from wastewater, and using fats, oils and grease as energy sources. These ideas have been reviewed by LOTT staff, and some are being considered further.

3. Background: LOTT's Energy Conservation Efforts

LOTT has been a leader in energy conservation for many years. Energy conservation fits with LOTT's commitment to environmental stewardship, which is integral to LOTT's mission to preserve and protect public health and the environment by cleaning water and recovering resources for our community. LOTT contracted with Oregon State University in 2013 and with Cascade Energy in 2015 and 2017 to conduct energy audits. LOTT used information from these audits to incorporate energy-saving practices and to purchase energy-saving equipment. Saving energy also helps lower wastewater treatment costs and keep rates low.

Early energy-saving projects started in 2009 and 2010 with the implementation of a biogas cogeneration system (2009) and upgrades to indoor lights, outdoor lights and a blower in the first aeration stage of the wastewater treatment process (2010). These upgrades alone were estimated to save approximately 3 million kWh/year, 20% of LOTT's energy use at the time.

In LOTT's 2013 – 2018 Performance Plan, LOTT put forth the goal of reducing electricity consumption by an additional 5%, approximately 680,000 kWh/year. This goal was met through activities in 2015 and 2016.

LOTT control systems and operations teams saved 869,083 kWh in 2016 compared to 2015 levels. Most of these savings were achieved through an effort aimed at maximizing plant performance by reducing aeration, a highly energy consumptive process. The amount of aeration needed in the biological nutrient removal phase of wastewater treatment was reduced by switching the control of the blowers from dissolved oxygen concentration to ammonia. Ammonia is a more sensitive control that still ensures a high level of biological nutrient removal. LOTT also reduced energy use by making operational changes to some wastewater treatment processes, such as shutting off equipment not in use, and altering the run-time for some pumps and blowers while still ensuring wastewater treatment efficiency. Most of the lighting in the plant (2015 and 2016) and administration building (2016) was replaced with motion sensor-equipped, energy-reducing LED lights. Nest Learning thermostats were installed to ensure that office temperature settings were appropriate for their use.

From 2017 through 2021, LOTT continued to invest in energy-saving measures, mainly through lighting and thermostat changes. In 2020, a contract was awarded for the BPI project. The BPI project optimized the biological treatment process at LOTT by reconfiguring the existing first aeration and first anoxic basins and improving control of the nutrient removal process. Construction began in 2021 and was completed in March 2023. The project reduced power consumption by approximately 12% by increasing the efficiency of mixing and blower technologies and reducing recycle pumping.

In 2024, a rooftop solar array was added to the top of the centrate handling facility encompassing approximately 11,000 square feet. It was commissioned on February 26, 2025, and is estimated to provide 179,412 to 195,335 kWh/year in electricity depending on solar intensity. In its first year of operations, the solar panels have met expectations, providing 1.3% of LOTT's electricity usage.

In March 2025, LOTT was awarded a grant from the Department of Commerce to proactively come into compliance with Washington State's Clean Buildings Performance Standards (CBPS). The CBPS created energy performance standards for Tier 1 (larger than 50,000 square feet) and Tier 2 occupied buildings (larger than 20,000 square feet), with compliance deadlines of June 1, 2026, and July 1, 2027, respectively. While most of LOTT's facilities are industrial in nature, LOTT's administration building, the Regional Services Center (RSC) is over 20,000 square feet and subject to the law. To comply with the law, LOTT must benchmark its electricity usage for one year and then prepare and utilize an Operation and Maintenance program and an Energy Management Program. In 2025, LOTT installed separate metering equipment for the RSC and has been tracking electricity usage for the year.

LOTT also shows commitment to energy efficiency through an in-house energy conservation committee and its WET Science Center public education program. In 2015, LOTT staff formed an energy conservation committee, which encourages and evaluates energy-saving ideas from staff. This committee, now meeting as the Green Team, meets quarterly and has hosted internal competitions to reduce energy usage and to brainstorm energy-savings ideas.

The WET Science Center's offerings in the schools highlight energy use and conservation in two ways. The wastewater program includes sharing how LOTT generates energy through resource recovery and the cogeneration system. The drops and watts program further focuses on the connection between water and energy usage. In the 2024 – 2025 school year, 1,018 students attended the wastewater program, and 1,201 students attended the drops and watts program. The WET Science Center will continue to offer this and similar programs in the future.

4. Background: LOTT's Greenhouse Gas Emissions Inventory

In support of LOTT's own energy and emissions reduction objectives and to contribute towards regional goals, LOTT initiated an annual comprehensive greenhouse gas emissions inventory in 2019. Cascade Energy was hired to assist with this effort. LOTT adopted the regional baseline year of 2015 to be consistent with past TRPC efforts. LOTT used its historical data to assess emissions from 2015 and will use that information to compare all future years. To ensure that LOTT's greenhouse gas emissions can seamlessly be incorporated into the overall Thurston County total, LOTT chose to build from the same wastewater protocol that TRPC used in its 2018 report.

5. Methodology

Standard methods are used to calculate greenhouse gas emissions. For common energy sources such as electricity, natural gas, propane and diesel fuel, the amount of energy used is tracked, and a calculation is applied to convert the energy source to carbon dioxide (CO_2) equivalents (CO_2e).

The amount of CO_2 or CO_2e emitted is calculated by multiplying the amount of the energy source by specific emission factors for each type of greenhouse gas (CO_2, CH_4, N_2O) that it emits. Emission factors are specific to the material being combusted (Climate Registry, 2025). For example, when one gallon of unleaded fuel is combusted, it emits 8.78 kg of CO_2, 0.014 g of CH_4 and 0.022 g N_2O. The values of 8.78, 0.014 and 0.022 are emission factors and are specific to the combustion of unleaded fuel.

The resulting emissions of CO_2, CH_4 and N_2O are then multiplied by their respective global warming potential (how powerful they are as greenhouse gases compared to CO_2) and summed to result in a CO_2e figure for that energy source.

To calculate wastewater-specific emissions, the International Council for Local Environmental Initiatives (ICLEI), now Local Governments for Sustainability, protocol is used with some modifications particular to LOTT. Modifications include items such as the amount of nitrous oxide estimated to off-gas during the nitrification/denitrification process and the amount of nitrogen discharged in the effluent (see Appendix A for ICLEI protocol modifications).

Over time, some changes to formulas have occurred to correct assumptions or incorrect data. For this reason, the totals noted in each of the annual reports do not always agree. The most accurate data will always be found in LOTT's most recent report. Changes and discrepancies are noted in Appendix B.

6. Uncertainty in Estimates

There are several uncertainties in estimating overall greenhouse gas emissions from wastewater treatment plants. New inquiries and methods continue to be developed. Important questions include whether the reduction in carbon from the treatment of waste should be considered, how to account for possible fugitive or unintentional emissions of methane from the plant, and how to calculate and how variable are nitrous oxide from the nitrification/denitrification process. Questions also arise regarding emerging science and data considerations that could affect the calculation of greenhouse gases from past reports, such as refined electricity emission factors and carbon sequestration rates for biosolids.

Historically, the reduction of waste carbon in the system was not accounted for because it was considered biogenic in origin and a short-term product. Recent inquiries suggest that up to 25% of the influent carbon could be of fossil fuel origin (Law et al, 2013, Tseng et al, 2016, and He et al, 2025). Some researchers have taken these estimates into account. The ICLEI protocol, however, has not changed. There is also not an easily prescribed method to determine what percentage of the carbon load is biogenic and what percentage is not. For those reasons, LOTT is keeping the current approach. In the future, LOTT may choose to account for waste carbon depending on the state of the science and associated changes in standard protocols.

Another recent finding has shown that fugitive methane emissions can occur at treatment plants and even in sewage collection pipes (Song et al, 2023). Where methane emissions have been measured, data suggests that plants with anaerobic digestors emit higher amounts of methane than those without. It is very difficult to measure fugitive methane emissions, and there is no accepted value used in standard protocols at this point.

Industry professionals believe that anaerobic digestors with fixed covers emit less methane than those with floating covers. As part of LOTT's effort to maintain and upgrade its four digesters, LOTT is currently replacing the floating covers with fixed covers. The first cover was replaced in 2025, and work is underway on the second cover. The project is expected to finish in 2028, with an estimated cost of $44.5 million. This will likely reduce fugitive methane emissions at LOTT. In the absence of definitive measures or an industry standard protocol, fugitive methane is not quantified as part of the inventory.

The amount of nitrous oxide from the nitrification/denitrification process is calculated using a very basic relationship between the size of the population served and the number of days in a year, per the ICLEI protocol. Measurement of nitrous oxide from wastewater treatment plants is notoriously difficult because these gases are hard to capture in an open system and rate likely vary depending on nitrogen removal process stressors. Where nitrous oxide has been measured, it has been found that there is a relationship between the amount of nitrogen discharged and the amount of nitrous oxide emitted. The lower the amount of nitrogen discharged, the lower the amount of nitrous oxide emitted (Valkova et al, 2021). Using this relationship, the amount of nitrous oxide emitted at LOTT would be far less than estimated by the ICLEI protocol. Again, because of the lack of a standard protocol to account for this, LOTT is relying upon the calculated value, which may be higher than the actual value.

The Water Research Foundation (WRF) initiated a research opportunity for consultants, academics and governments in 2023, called "Advancing the Understanding of Nitrous Oxide Emissions through Enhanced Whole-Plant Monitoring and Quantification," WRF #5251. The grant was awarded in 2024 to the consultant group Jacobs, which is working with a number of academics and utilities. The overall project is working with different types of treatment plants with the aim of understanding the factors that contribute to nitrous oxide emissions and formulating a more realistic emission factor for this gas at wastewater treatment plants.

LOTT is one of the partner utilities for this work. LOTT has purchased, calibrated and installed nitrous oxide probes and is working with Jacobs to download and interpret the data. Initial results indicate that the amount of nitrous oxide emitted in the aeration basins is much less than the calculated number. Data for the denitrification process will be updated when LOTT has more certainty around the results.

7. Changes in Calculations

In several instances, LOTT has had to determine how to manage new information that could affect calculations used in past years. One example is the emission factor from PSE used to calculate greenhouse gases from electricity use. The emission factor represents the mix of energy sources used to obtain electricity. The more fossil fuel-intensive those sources are, the higher the emission factor. PSE occasionally updates emission factors for past years, and those updates can be issued a year or more after they are in effect. LOTT is choosing to use the emission factor available at the time the report is written, usually April – June of the following year. Recalculations using the updated emission factor may be made on a case-by-case basis if more precise data is needed for any given year. For the most part, however, LOTT will not recalculate past years' emissions based on delayed updates to the emission factors.

A second example is the carbon sequestration factor used to calculate the offset provided by land application of biosolids. This was changed in the 2022 Biosolids Assessment Emission Model (BEAM) protocol because newer data became available showing that not as much carbon is taken up as previously thought. LOTT recalculated biosolids data from previous years in the 2022 report to reflect this new understanding and ensure that readers could look at the data from year to year and see an accurate comparison.

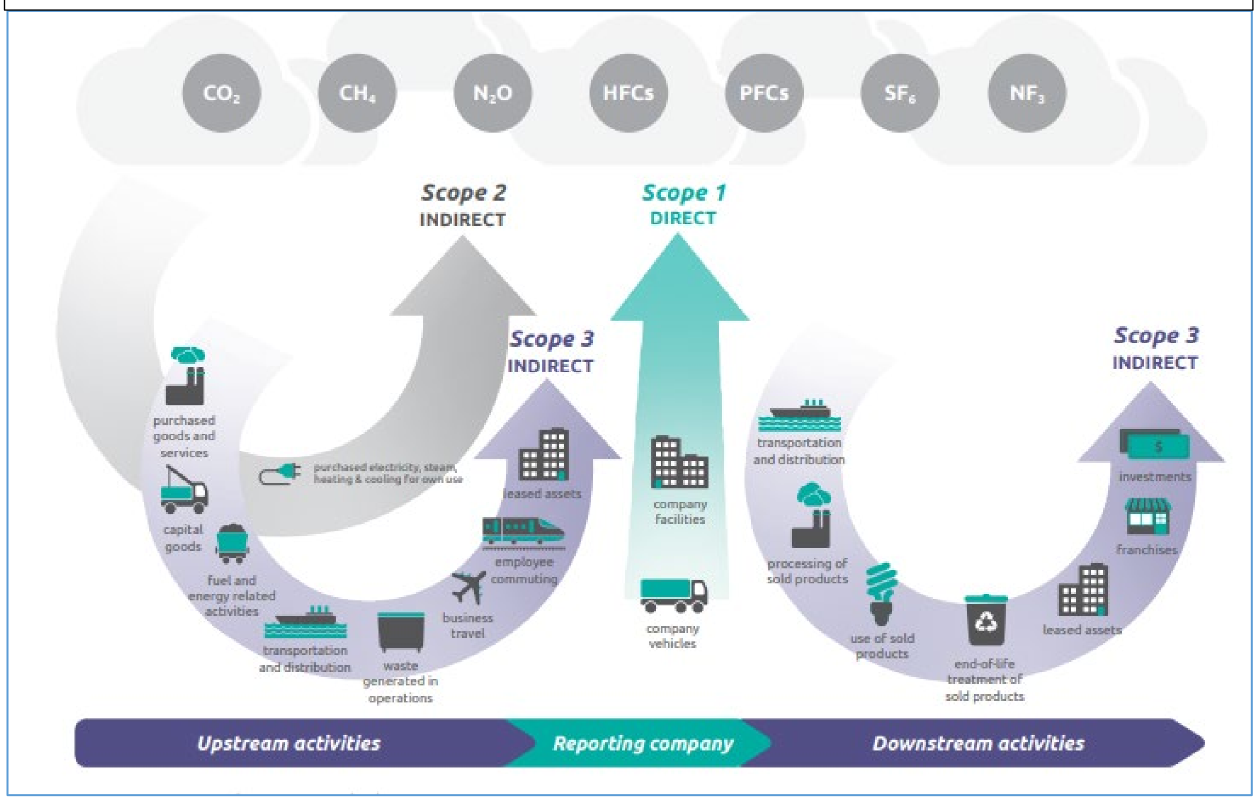
8. Findings

The total amount of annual greenhouse gas emissions at LOTT for the eight years assessed, 2015 and 2019 – 2025, ranged from 6,049 to 8,622 metric tons of CO_2 equivalents (MT CO_2e).

The emissions can be displayed by source type and location to understand the processes that contribute to emissions. Sources are often grouped by scope. Scope 1 emissions are all direct emissions that occur at the facility. Scope 2 and 3 are indirect sources. Scope 2 emissions come from electricity purchased by the organization for business purposes. Scope 3 emissions are all other indirect sources, including the carbon footprint associated with all the materials used at the business and employee travel.

At LOTT, Scope 1 includes sources used to provide energy or fuel, those that are produced during the wastewater treatment process, and other products used in the running of the facility. Scope 2, the largest source of emissions, consists of purchased electricity. Scope 3 is a very difficult scope of emissions to track. It can include the emissions produced to make the steel structures in the buildings and office equipment, transportation to move the equipment from the producer to LOTT and even employee travel to and from work. Most companies do not account for Scope 3 emissions. LOTT decided to account for two Scope 3 sources due to their relevance to LOTT: biosolids application and conference travel.

Sources of Scope 1,2, and 3 Emissions

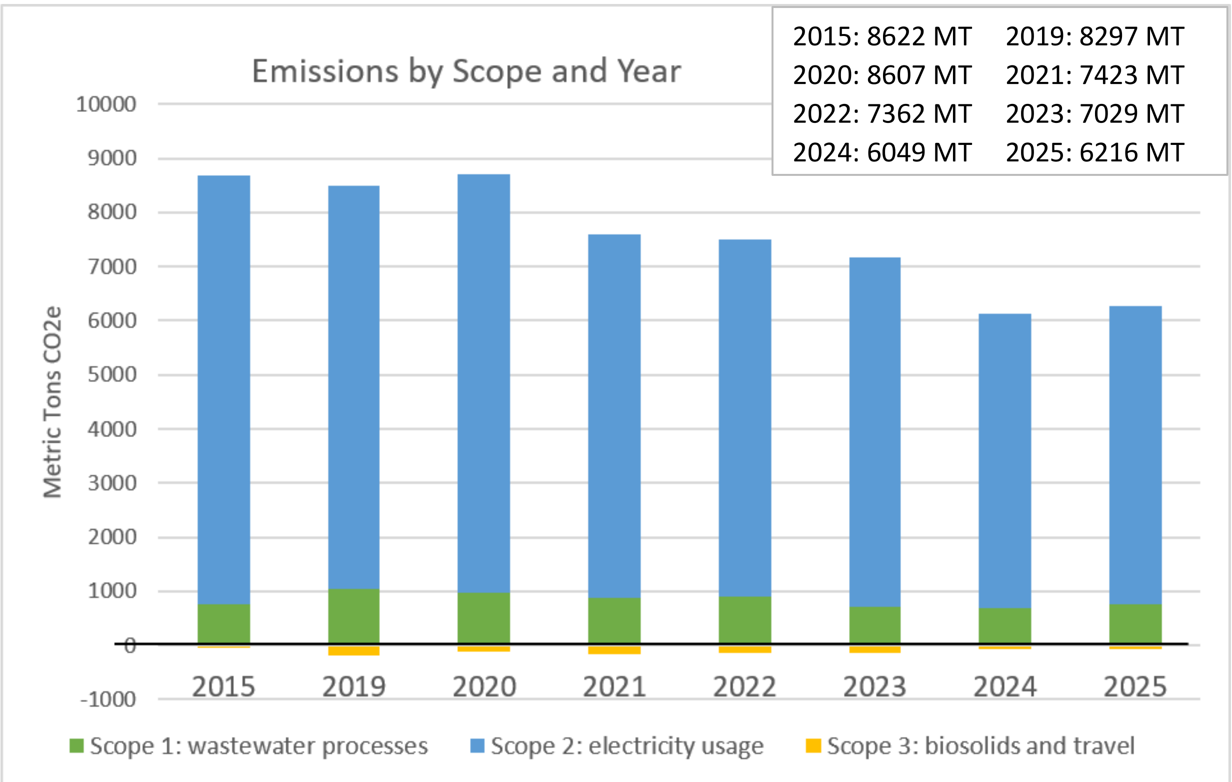


[1]

[1] CO_2 – Carbon dioxide, CH_4 – Methane, N_2O – Nitrous oxide, HFCs – Hydrofluorocarbons, PFCs – Perfluorinated chemicals, SF_6 – Sulfur hexafluoride, NF_3 – Nitrogen trifluoride

The amounts of emissions for each of the scopes in each year are shown in the following graphic. The footprint is similar from year to year, with electricity being the biggest source of emissions. Scope 3 results in a net negative emission, which yields a carbon offset.

The notable decrease seen in 2021 is mostly a reflection of a change in the emission factor for electricity, which is described in more detail in the Electricity section. The decrease in 2024 results from another change to the emission factor as well as the commissioning of the BPI project. Emissions were slightly higher in 2025 than in 2024 due to higher electricity and natural gas usage during times when the cogeneration system was offline.



Scope 1

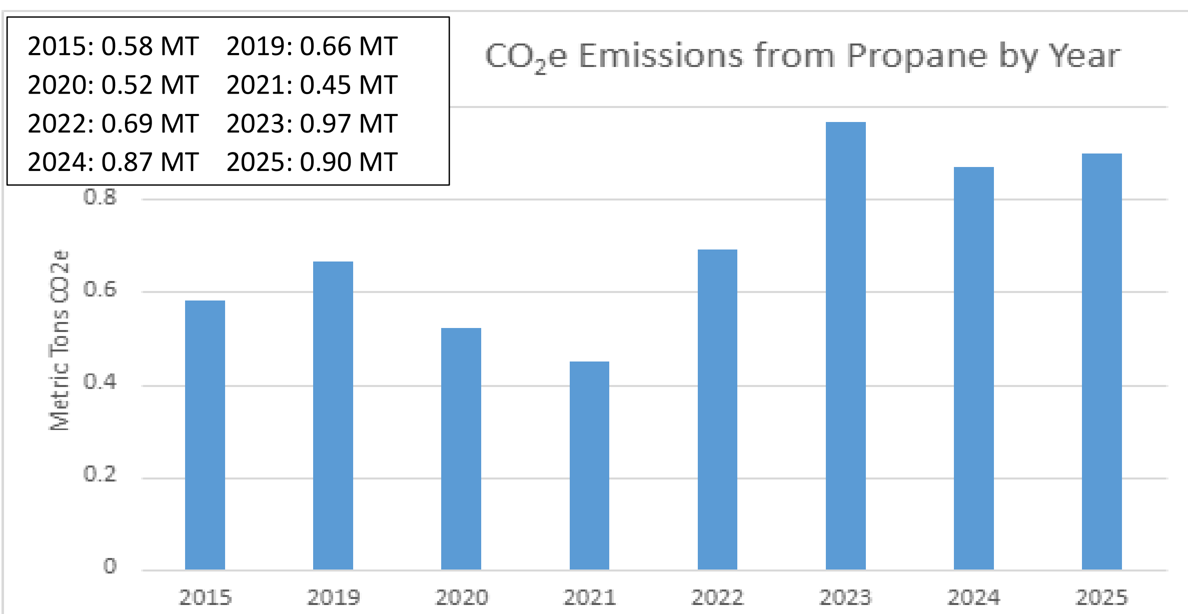
Scope 1 is limited to the processes that produce greenhouse gas emissions at the facility itself. It includes sources used to provide energy (propane, unleaded fuel, diesel, natural gas), sources that are produced during the wastewater treatment process (digester gas, nitrogen discharge, denitrification), and other products used in the running of the facility (refrigerants).

Propane

Propane is used to power forklifts used at the plant. The burning of propane results in the emission of carbon dioxide, nitrous oxide and methane. Note that the scale of emissions associated with propane use is less than 1.0 MT CO_2e, which is very small in relation to LOTT's overall emissions. An increase in propane use was seen in 2023; this is likely related to the purchase of a second forklift for use at a different location. The amount of propane used is estimated by tracking how much is purchased.

Formula to Calculate Greenhouse Gas Emissions from the Amount of Propane Used

	X		X		X		X	
Propane	Conversion Factor	Result	Emission Factor	Result	Global Warming Potential	Result	Conversion Factor	Result
gal	1	gal	5.72 kg CO_2/gal	kg CO_2	1	kg CO_2	0.001	MT CO_2e
	3.785	L	0.024 g CH_4/L	g CH_4	28	g CO_2e	0.000001	MT CO_2e
	3.785	L	0.108 g N_2O/L	g N_2O	265	g CO_2e	0.000001	MT CO_2e
								Sum for Total MT CO_2e



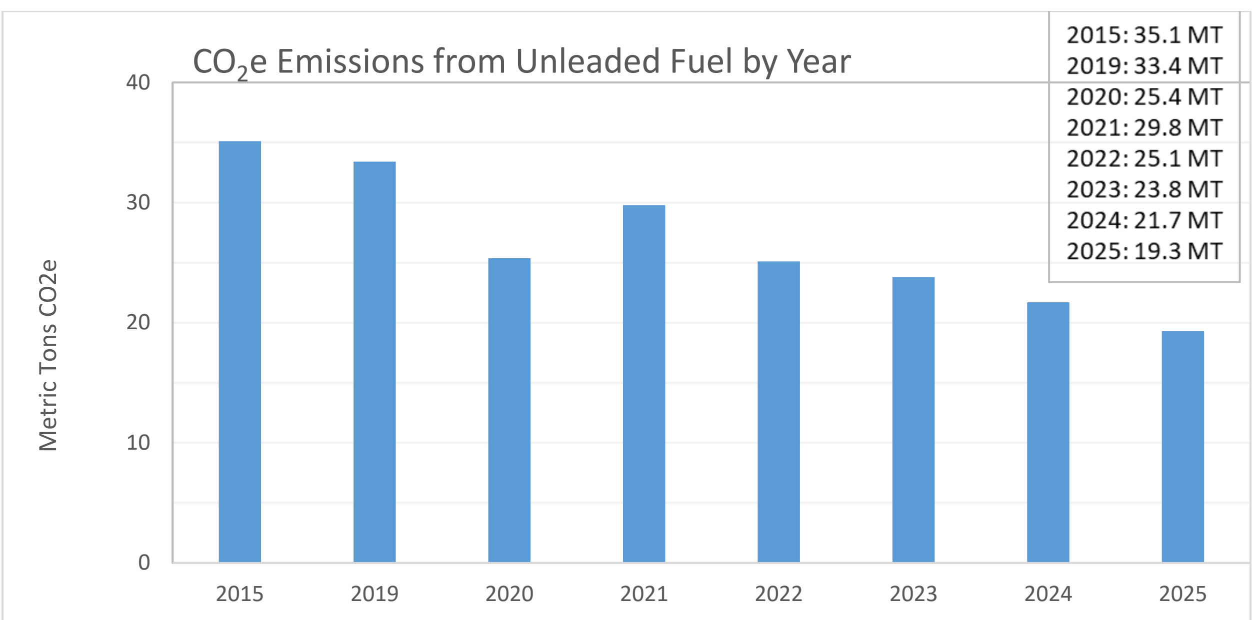
Unleaded Fuel

Unleaded fuel is used in LOTT fleet vehicles. Trips mainly occur between LOTT-owned facilities and for conducting local business, such as attending meetings offsite or picking up supplies. Occasionally, a LOTT-owned vehicle is used to travel to a nearby conference in cities such as Spokane or Portland. The burning of unleaded fuel results in the emission of carbon dioxide, nitrous oxide and methane.

LOTT tracks the amount of gasoline used for fleet vehicles at the time of fuel purchase. Reasons for the decline in unleaded fuel are likely related to pandemic restrictions in 2020 and the increased purchase and use of hybrid, hybrid plug-in and electric vehicles, comprising 7 of 14 fleet vehicles in 2025.

Formula to Calculate Greenhouse Gas Emissions from the Amount of Unleaded Fuel Used

	X		X		X		X	
Unleaded	Conversion Factor	Result	Emission Factor	Result	Global Warming Potential	Result	Conversion Factor	Result
gal	1	gal	8.78 kg CO_2/gal	kg CO_2	1	kg CO_2	0.001	MT CO_2e
	1	gal	0.14 g CH_4/gal	g CH_4	28	g CO_2e	0.000001	MT CO_2e
	1	gal	0.022 g N_2O/gal	g N_2O	265	g CO_2e	0.000001	MT CO_2e
								Sum for Total MT CO_2e

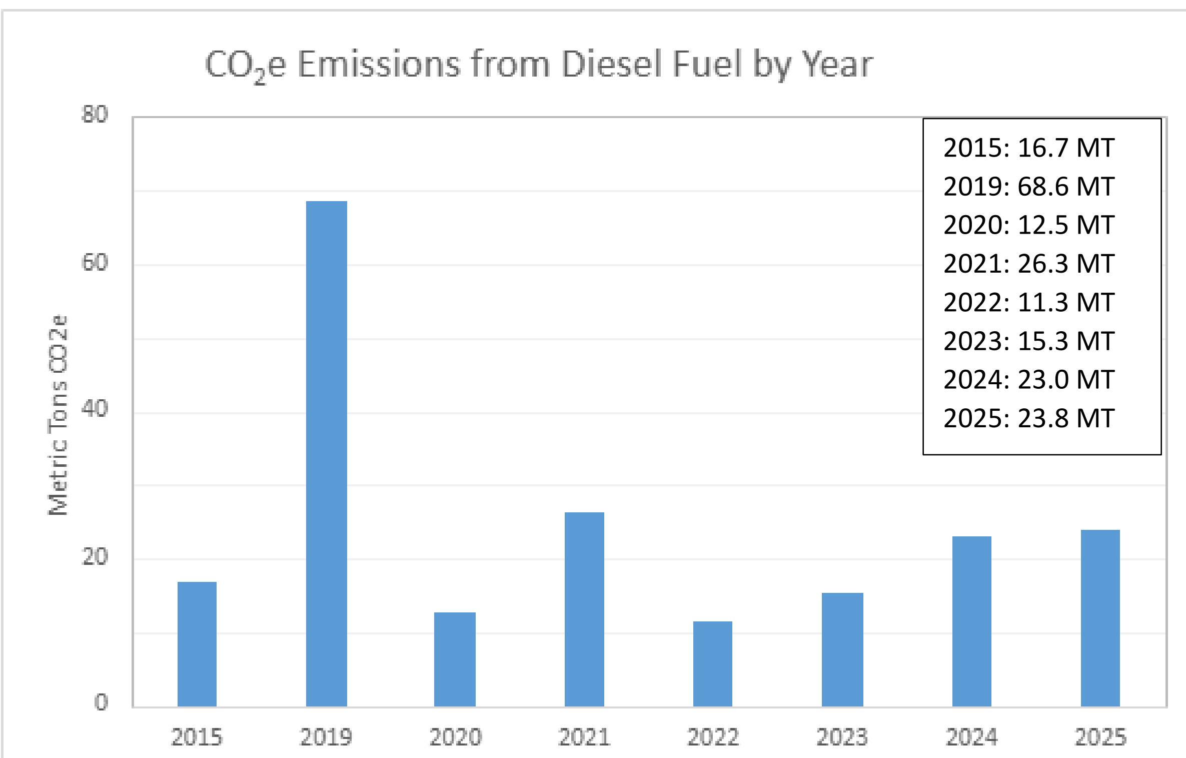


Diesel Fuel

Diesel fuel is used in LOTT's air compressors and generators and to fuel some light-duty trucks. The burning of diesel fuel results in the emission of carbon dioxide, nitrous oxide, and methane. In 2019, the use of diesel was much higher than usual due to a foaming problem at one of the digesters, which necessitated the use of diesel-fueled air compressors to knock down the foam. In 2024, LOTT made the decision to exercise the generators monthly for preventive maintenance; this does result in somewhat higher diesel fuel usage and emissions.

Formula to Calculate Greenhouse Gas Emissions from the Amount of Diesel Fuel Used

	X		X		X		X	
Diesel	Conversion Factor	Result	Emission Factor	Result	Global Warming Potential	Result	Conversion Factor	Result
gal	3.78541	L	2681 g CO_2/L	g CO_2	1	g CO_2	0.000001	MT CO_2e
	3.78541	L	0.14 g CH_4/L	g CH_4	28	g CO_2e	0.000001	MT CO_2e
	3.78541	L	0.082 g N_2O/L	g N_2O	265	g CO_2e	0.000001	MT CO_2e
								Sum for Total MT CO_2e



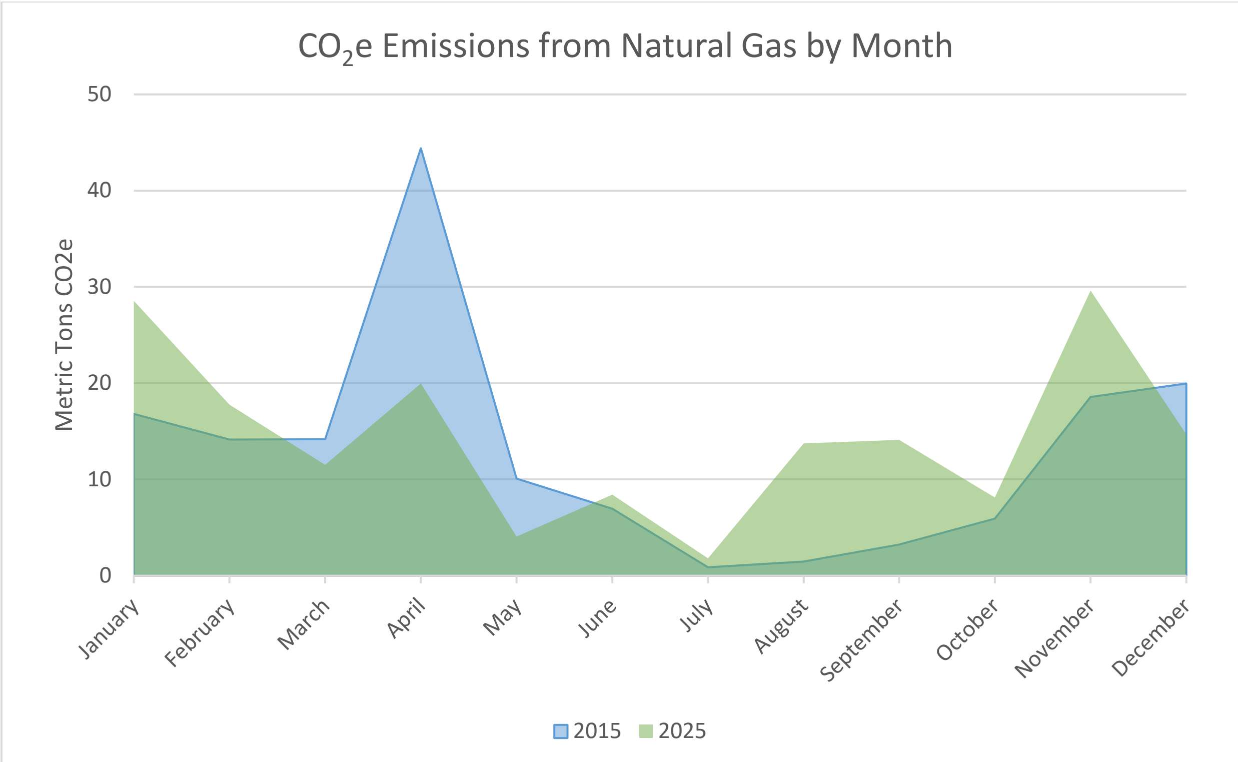
Natural Gas

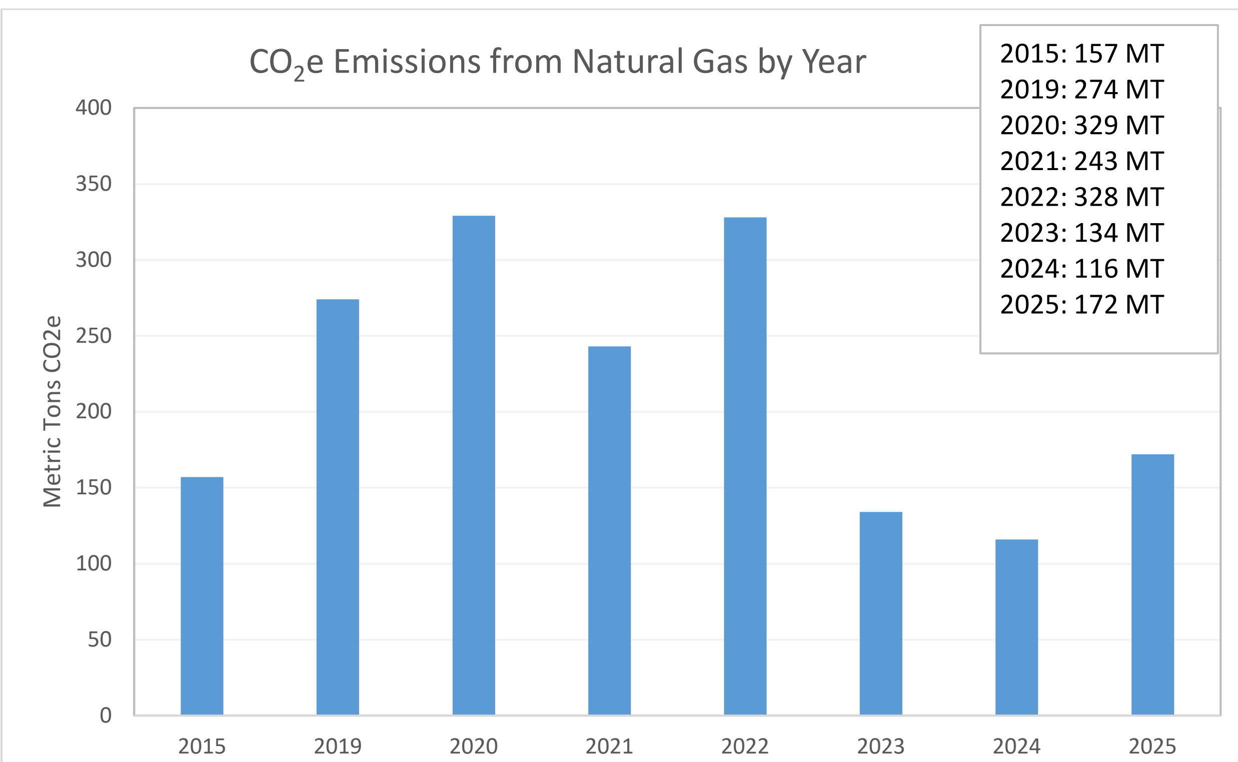
Natural gas, also known as methane, is supplied to the boilers and is used for heating at LOTT. The burning of natural gas results in the emission of nitrous oxide, carbon dioxide, and some uncombusted methane. There are two sources of natural gas at LOTT: it is either purchased, or it is a byproduct of the digester process. LOTT tracks the amount of natural gas when it is purchased. These graphics show the purchased natural gas amounts.

The amount of purchased natural gas used in 2015 and 2023 - 2025 was relatively low. This reflects that most of the gas used for heating for those years was digester gas. In fact, starting in 2023, LOTT decided to prioritize the use of digester gas in the boilers for heating, instead of using it in the cogeneration unit for electricity generation. This was done to reduce natural gas use and its associated greenhouse gases.

Formula to Calculate Greenhouse Gas Emissions from the Amount of Natural Gas Used

	X		X		X		X	
Natural Gas	Conversion Factor	Result	Emission Factor	Result	Global Warming Potential	Result	Conversion Factor	Result
therms	0.1	MMBtu	53.06 kg CO_2/MMBtu	kg CO_2	1	kg CO_2	0.001	MT CO_2e
	0.1	MMBtu	4.7 g CH_4/MMBtu	g CH_4	28	g CO_2e	0.000001	MT CO_2e
	0.1	MMBtu	0.1 g N_2O/MMBtu	g N_2O	265	g CO_2e	0.000001	MT CO_2e
								Sum for Total MT CO_2e


CO_2e Emissions from Natural Gas by Month
50
40
30
20
10
0
Metric Tons CO2e
January
February
March
April
May
June
July
August
September
October
November
December
2015
2025


CO_2e Emissions from Natural Gas by Year
2015: 157 MT
2019: 274 MT
2020: 329 MT
2021: 243 MT
2022: 328 MT
2023: 134 MT
2024: 116 MT
2025: 172 MT
400
350
300
250
200
150
100
50
0
Metric Tons CO2e
2015
2019
2020
2021
2022
2023
2024
2025

Digester Gas

Digester gas is natural gas or methane that is produced in the digesters. It is part of the methane supplied to the boilers and is used for heating at LOTT. The burning of digester gas results in the emission of carbon dioxide, nitrous oxide and methane. Only nitrous oxide and uncombusted methane are used to calculate CO_2 equivalents when calculating the emissions for digester gas because the source of the carbon dioxide that is produced is plant-based and thus considered carbon neutral.

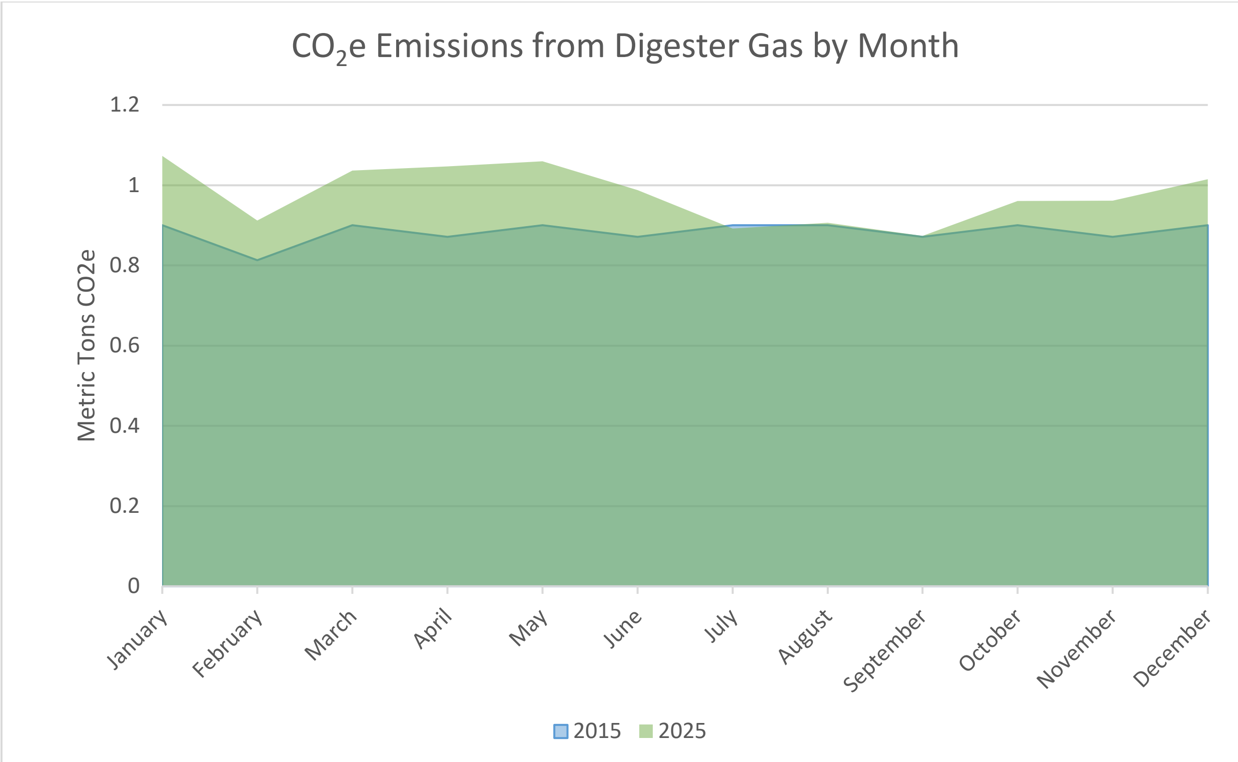
Digester gas was one of the initial parameters analyzed by the Thurston Climate Action Team (TCAT) in their 2018 report on emissions from 2010 to 2016. The range from 2010 to 2018 in the TCAT report was 9 – 12 metric tons of CO_2e, with the same value of 11 MT CO_2e for 2015 as calculated in this exercise.

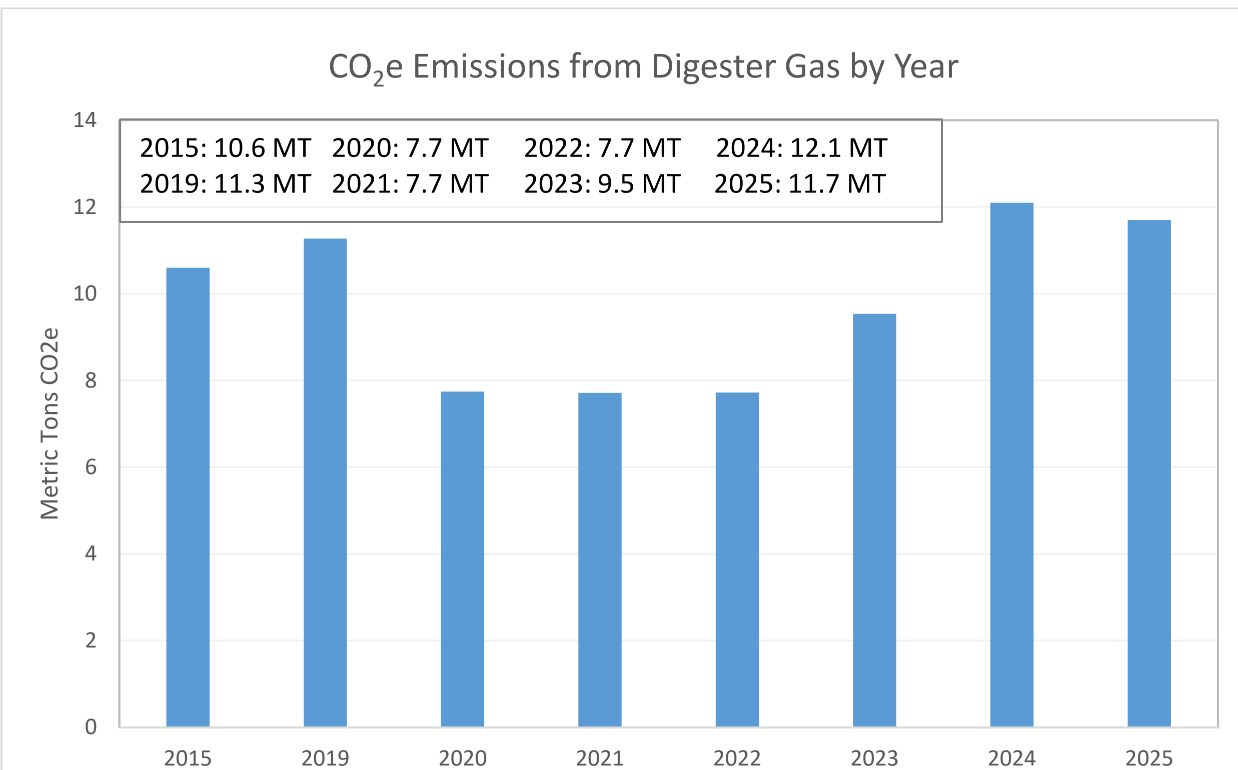
These graphics show the methane produced from the digesters. The amount of digester gas decreased by approximately one-third in 2020 and stayed relatively constant through 2022. Starting in 2023, the amount of digester gas and associated emissions increased because more sludge from the primary clarifiers was fed into the digesters. The use of digester gas instead of natural gas for heating emits less greenhouse gases because the source of CO2 emissions are not counted, as explained above.

LOTT tracks the amount of digester gas in a wastewater-specific database and management software system (Hach WIMS), which tracks digester gas by volume in cubic feet. The ICLEI protocol formula converts these gases into CO_2e and takes into account the fraction of methane in the natural gas and the volume of natural gas.

Formula to Calculate Greenhouse Gas Emissions from the Amount of Digester Gas Used

	X	X		X		X		X		X	
Digester Gas	Fraction of CH_4 in Gas	Heat Content of CH_4	Result	Conv. Factor	Result	Emission Factor	Result	Global Warm. Pot.	Result	Conv. Factor	Result
ft^3	varies (0.57 to 0.70)	1028 Btu/ft^3	Btu	1E-06	MMBtu	3.2 g CH_4 (biogas) /MMBtu	g CH_4	28	g CO_2e	1E-06	MT CO_2e


CO2e Emissions from Digester Gas by Month
1.2
1
0.8
0.6
0.4
0.2
0
Metric Tons CO2e
January
February
March
April
May
June
July
August
September
October
November
December
2015
2025


CO2e Emissions from Digester Gas by Year
2015: 10.6 MT 2020: 7.7 MT 2022: 7.7 MT 2024: 12.1 MT
2019: 11.3 MT 2021: 7.7 MT 2023: 9.5 MT 2025: 11.7 MT
14
12
10
8
6
4
2
0
Metric Tons CO2e
2015
2019
2020
2021
2022
2023
2024
2025

Nitrogen Discharge

Nitrogen discharge refers to the amount of nitrogen that gets discharged in the wastewater effluent and subsequently gets converted to nitrous oxide. This value is calculated using the ICLEI protocol and is based on the total amount of nitrogen discharged.

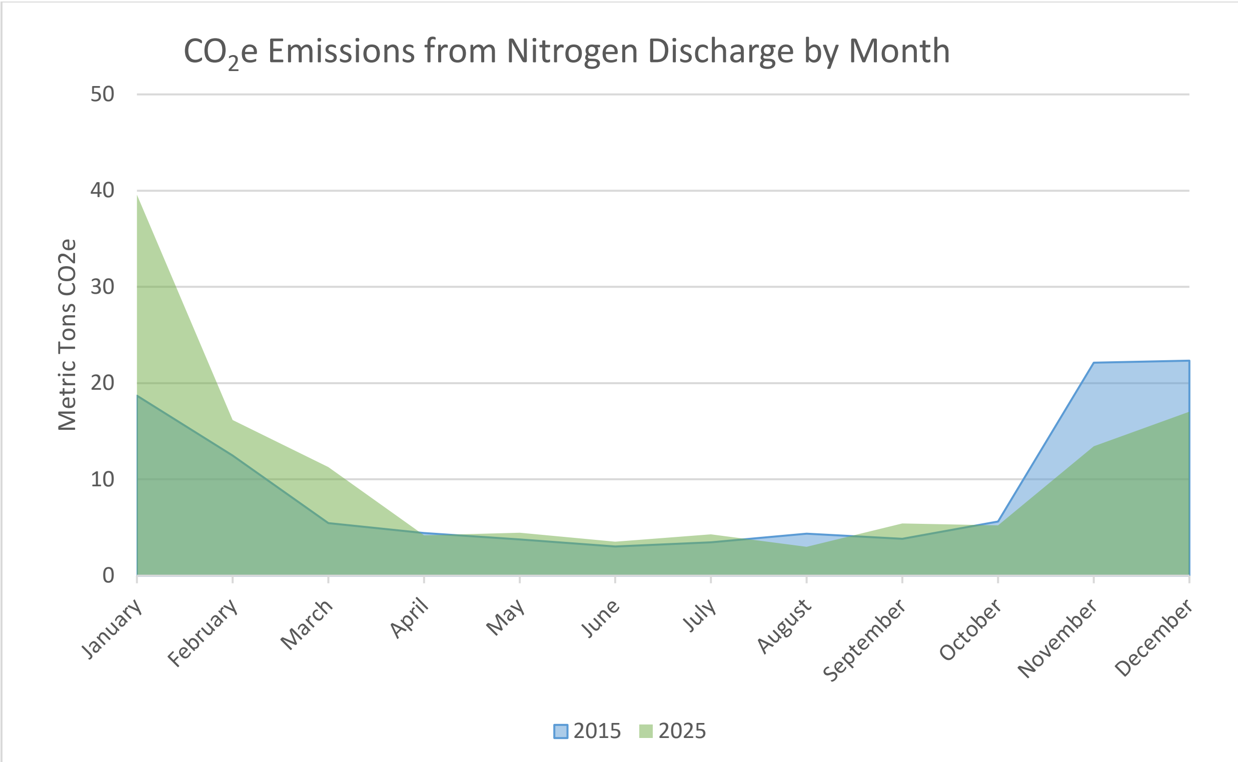
Nitrogen values discharged to Budd Inlet are higher in the winter because the biological nutrient removal (nitrification/denitrification) process is not as efficient in cooler water. Because of this inefficiency, LOTT previously did not run the biological nutrient process in the winter, and the data in 2019 and 2020 reflect this.

From 2021 through 2023, a number of changes occurred to the biological process to improve efficiency, decrease emissions and reduce nitrogen in the effluent. Starting in 2021, LOTT began to employ nearly year-round biological nutrient reduction, depending on conditions at the plant. This strategy helps decrease the amount of nitrogen entering the water. In mid-2022, the BPI project began to be put into operation and was completed in March 2023. This project was aimed at increasing the efficiency and control of the biological process.

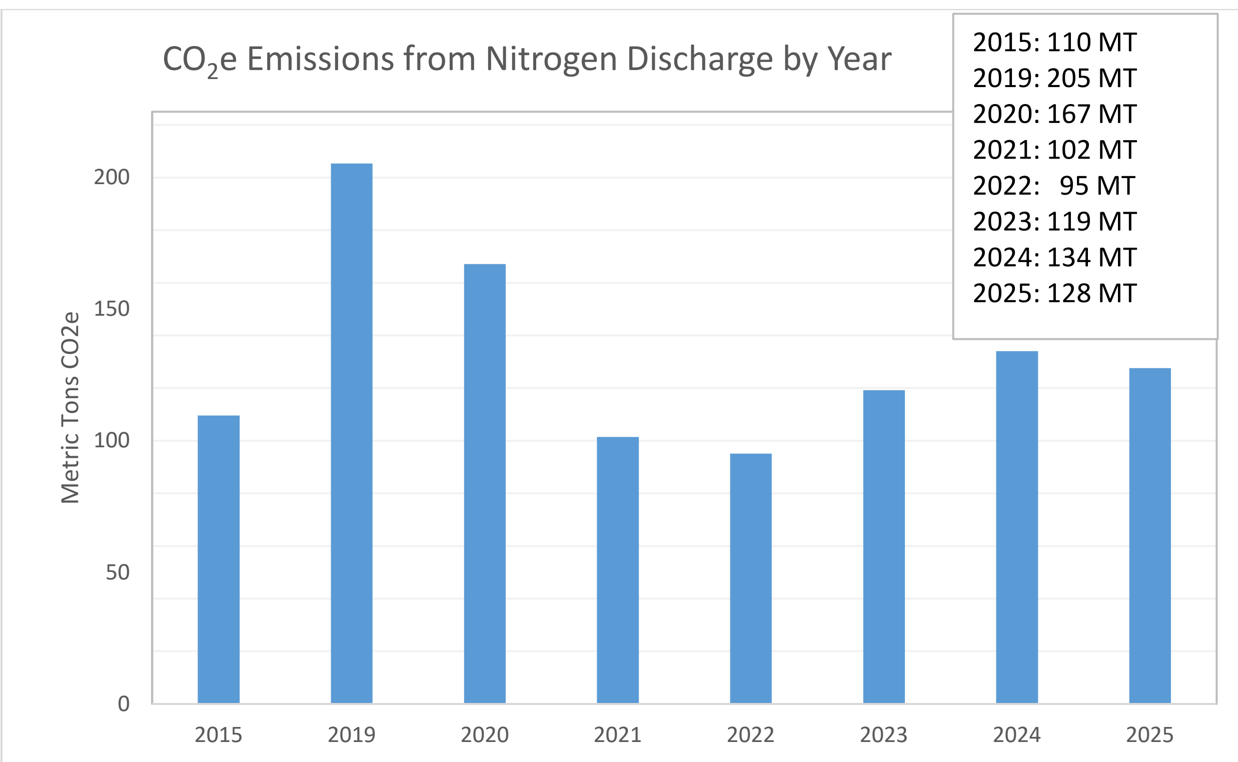
In addition to the systemic changes at the plant to increase efficiency, there are day-to-day operational conditions that also affect discharges. Slightly higher nitrogen discharges occurred in 2023 than in 2022 because the plant conditions (microbiology, temperature, pH, retention time, etc.) in 2022 were conducive to achieving the microbiological process called nitrite shunt, which can reduce more nitrogen than the usual nitrification/denitrification process. Nitrite shunt could not be achieved in later years, however.

Formula to Calculate Greenhouse Gas Emissions from the Amount of Nitrogen Discharge

	X		X		X	X		X	
Nitrogen Discharge	Conversion Factor	Result	Emission Factor	Result	Molecular Weight Ratio N_2O/N_2 (Nitrite/ Nitrogen)	Global Warming Potential	Result	Conversion Factor	Result
lb	0.453592	kg	0.005 kg N_2O/kg N discharge	kg N_2O	1.57	265	kg CO_2	0.001	MT CO_2e



CO2e Emissions from Nitrogen Discharge by Month
Metric Tons CO2e
50
40
30
20
10
0
January
February
March
April
May
June
July
August
September
October
November
December
2015
2025



CO2e Emissions from Nitrogen Discharge by Year
2015: 110 MT
2019: 205 MT
2020: 167 MT
2021: 102 MT
2022: 95 MT
2023: 119 MT
2024: 134 MT
2025: 128 MT
Metric Tons CO2e
200
150
100
50
0
2015
2019
2020
2021
2022
2023
2024
2025

Nitrification/Denitrification

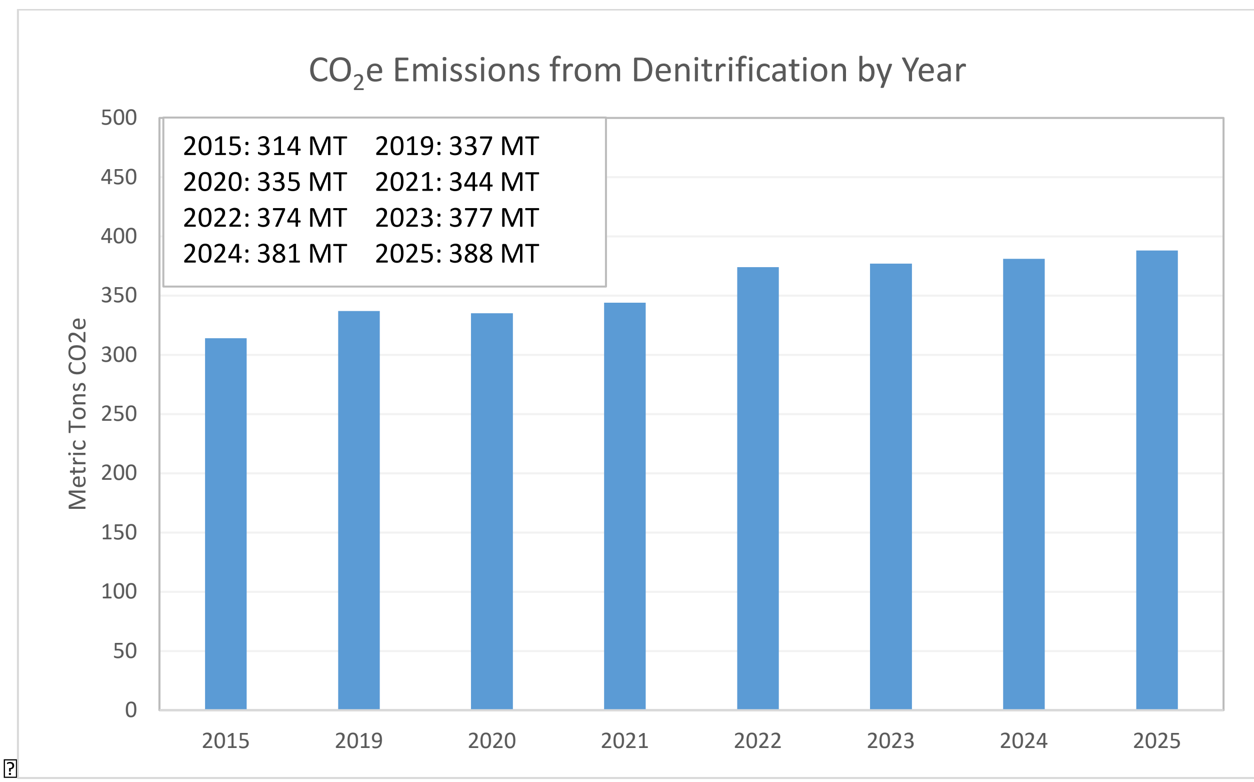
Nitrification/denitrification refers to the amount of nitrous oxide produced during the biological nutrient removal (nitrification/denitrification) process that LOTT uses to reduce the amount of nitrate in the final effluent. The amount of nitrous oxide emitted is difficult to measure, especially in an open system. Thus, it is estimated via calculation.

The calculation used to estimate nitrification/denitrification is from the ICLEI protocol and relies on the number of days in the year and population. The increase in 2025 is due to a higher population.

As discussed in the Uncertainty section, efforts are being made to more accurately assess the quantity of nitrous oxide through a research project.

Formula to Calculate Greenhouse Gas Emissions from the Amount of Denitrification

	X	X		/			X	
Population Served/ Day	Factor for High N_2 (Nitrogen) Loading	Emission Factor	Result	Days/ Year	Result	Global Warming Potential	Conversion Factor	Result
persons	1.25	7 g N_2O/ person/day	g N_2O * day	365.25 days	g N_2O	265	0.000001	MT CO_2e



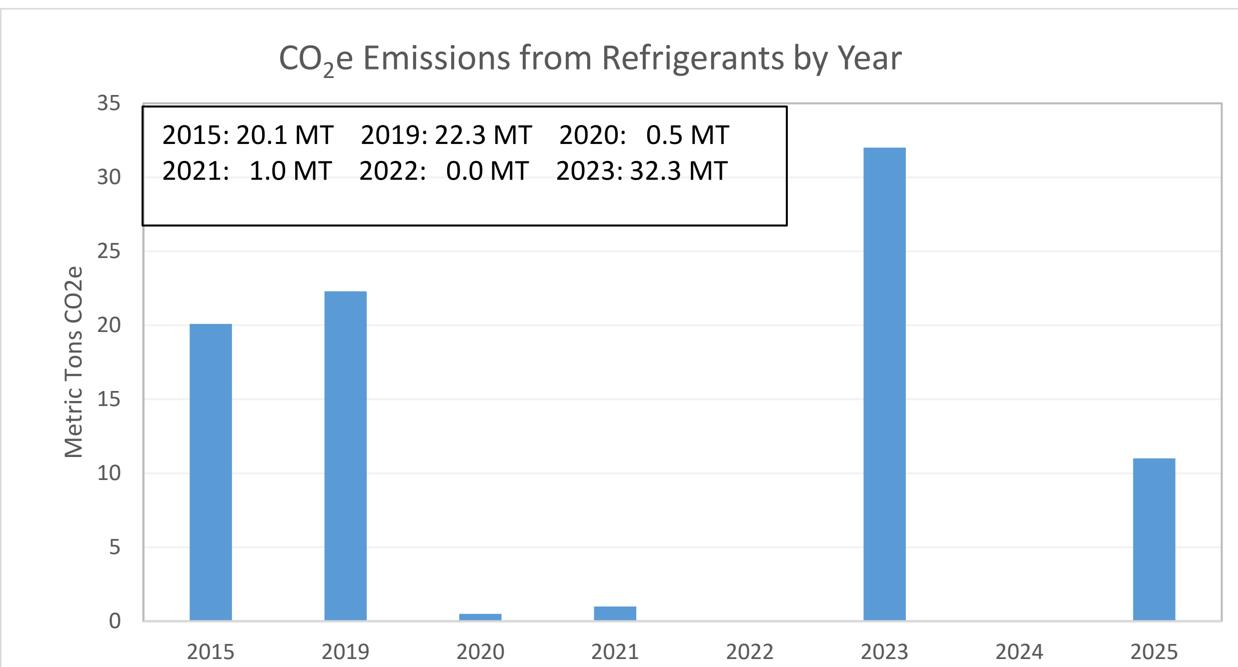
Refrigerants

Many refrigerants are potent greenhouse gases, and over time they can leak or evaporate from their heat exchanger units and need to be replaced. LOTT tracks the greenhouse gas emissions from refrigerants at the time they are needed for recharge or repair. In 2015 and 2019, maintenance work was conducted on the cooling and refrigeration systems; thus the amount of refrigerants used was greater than usual. In 2020 and 2021, refrigerants were only added to these systems to replace the amount of refrigerant that was lost to leakage or evaporation. In 2022 and 2024, no refrigerants needed to be replaced. In 2023 and 2025, repairs of refrigerated equipment necessitated the use of more refrigerants than usual.

Each type of refrigerant has a different global warming potential. The amount of refrigerants purchased is multiplied by its global warming potential to get its CO_2e.

Formula to Calculate Greenhouse Gas Emissions from the Amount of Refrigerants Used

	X		X	
Refrigerants	Conversion Factor	Result	Global Warming Potential	Result
R-22 in lb	0.000453592	MT	1760	MT CO_2e
R-410A in lb	0.000453592	MT	1924	MT CO_2e
R-421A in lb	0.000453592	MT	2385	MT CO_2e
				Sum for Total MT CO_2e



Scope 2

Electricity

Electricity usage accounts for approximately 90% of the greenhouse gas emissions at LOTT. For the years measured, electricity usage at LOTT was estimated between 5,438 and 7,899 metric tons of CO_2e per year.

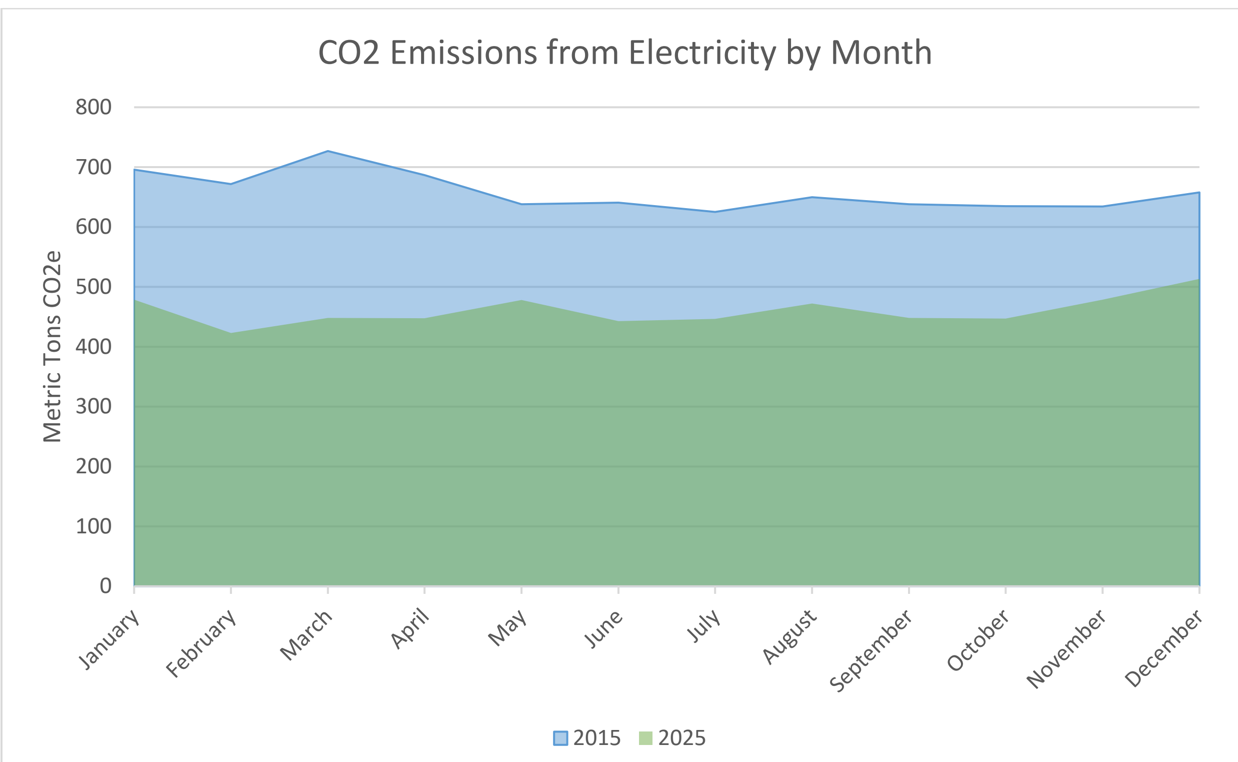
Electricity use is quantified from the electricity bills supplied by Puget Sound Energy (PSE). These bills list kWh for each of the meters. These meters are then bundled together according to the query of interest (location, scope, etc.). The kWh are converted to CO2e using emission factors that consider the mix of energy sources (coal, hydro, nuclear, natural gas, wind, solar) that PSE is using (Puget Sound Energy, 2023). This mix of energy is relatively static, so the conversion formula usually does not change from year to year. However, the mix of PSE's energy sources did change enough that they issued a new, lower emission factor in 2021 and in 2023. The new emission factor reflected the use of sources that were more renewable and emitted fewer greenhouse gases. The decrease in 2021 electricity emissions is related to the change in PSE's emission factor. The decrease in 2024 emissions is related to the additional change in emission factor and the BPI project.

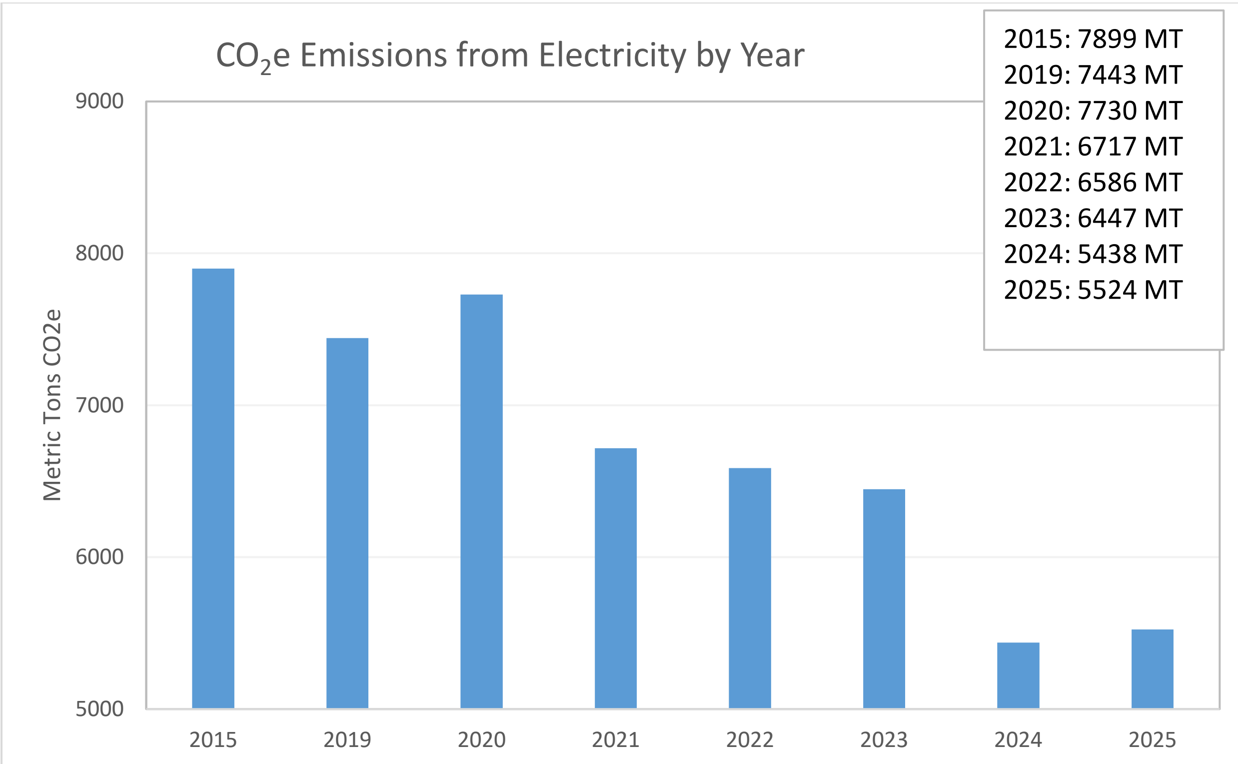
In 2022, commissioning of the BPI project was underway. This project involved rerouting the wastewater around the plant so that fewer pumps were needed and installing more efficient pumps and aerators. The project was completed in March 2023. In 2024, the first full year of BPI operation decreased electricity use and concomitant CO_2e by 12% from 2021 levels, the year before the project was started.

Using the PSE emission factor and calculation for greenhouse gases shows the amount of greenhouse gases emitted based on the mix of energy and PSE's calculated emission factor at the time. The emission factor sometimes gets changed based on new information. Because of this, the amount of greenhouse gases emitted does not always directly correlate with the amount of electricity used at the plant. For example, the amount of electricity used increased in the years of 2021 and 2022 compared to the baseline of 2015, whereas the calculated amount of greenhouse gases decreased for those same years. For this reason, electricity usage is also shown as total kWh as a basis for comparison.

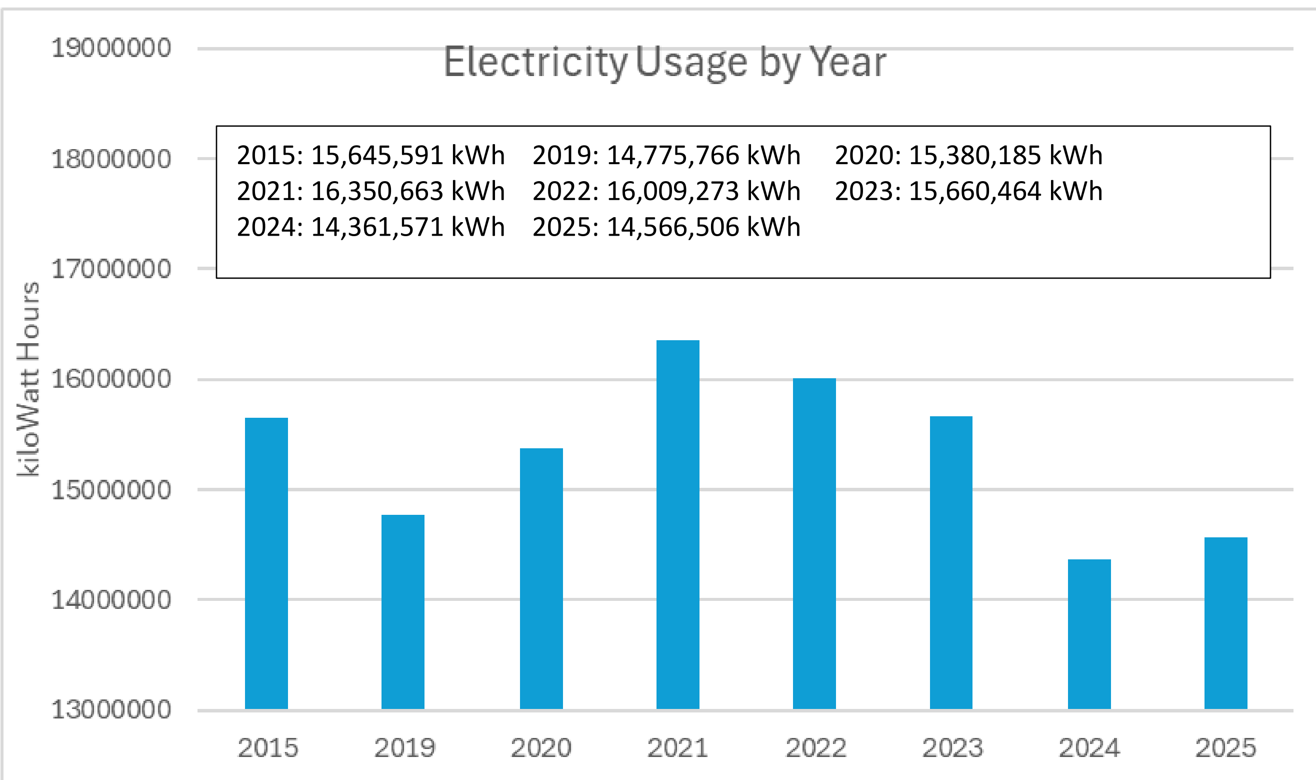
Formula to Calculate Greenhouse Gas Emissions from the Amount of Electricity Used

	X		X		X	
Electricity	Emission Factor	Result	Conversion Factor	Result	Global Warming Potential	Result
kWh	2015 – 2020: 1.1 2021 – 2022: 0.9 2024: 0.83	lb CO_2	0.000453592	MT CO_2	1	MT CO_2e
	2015 – 2020: 0.000060 2021 – 2022: 0.000063 2024: 0.000063	lb CH_4	0.000453592	MT CH_4	28	MT CO_2e
	2015 – 2020: 0.000015 2021 – 2022: 0.0000089 2024: 0.0000090	lb N_2O	0.000453592	MT N_2O	265	MT CO_2e
						Sum MT CO_2e





CO_2e Emissions from Electricity by Year
2015: 7899 MT
2019: 7443 MT
2020: 7730 MT
2021: 6717 MT
2022: 6586 MT
2023: 6447 MT
2024: 5438 MT
2025: 5524 MT
Metric Tons CO2e
9000
8000
7000
6000
5000
2015
2019
2020
2021
2022
2023
2024
2025



Electricity Usage by Year
2015: 15,645,591 kWh
2019: 14,775,766 kWh
2020: 15,380,185 kWh
2021: 16,350,663 kWh
2022: 16,009,273 kWh
2023: 15,660,464 kWh
2024: 14,361,571 kWh
2025: 14,566,506 kWh
kiloWatt Hours
19000000
18000000
17000000
16000000
15000000
14000000
13000000
2015
2019
2020
2021
2022
2023
2024
2025

Scope 3

Travel

Travel data includes conference travel emissions associated with airplane flights, taxis, shuttle services and hotel stays, as shown in the calculations below. A curtailment of conference attendance occurred in 2020 and 2021 due to the COVID-19 pandemic, and the emissions data reflect that. Starting in 2022, LOTT staff again started more widely participating in relevant industry conferences. An increase in travel-associated emissions reflects LOTT's expanded interest in learning about and implementing cutting-edge technologies and networking with colleagues. Many of these technologies offer energy efficiency potential and help LOTT meet our strict discharge limits.

The emission factors for automobile travel and medium-range air travel changed between 2021 and 2022 (EPA, 2022). These decreased slightly due to updated regulations, a slightly different makeup of the fuel source and newer engine designs coming on the market.

Formula to Calculate Greenhouse Gas Emissions from the Amount of Fuel Used During Vehicle Travel

	X		X		X	
Auto	Emission Factor	Result	Global Warming Potential	Result	Conversion Factor	Result
mi	0.332 (2022) or 0.335 (2015 – 2021) CO_2 kg/mi	kg CO_2	1	kg CO_2	0.001	MT CO_2e
	0.007 (2022) or 0.009 (2015 – 2021) CH_4 g/mi	g CH_4	28	g CO_2e	0.000001	MT CO_2e
	0.007 (2022) or 0.008 (2015 – 2021) N_2O g/mi	g N_2O	265	g CO_2e	0.000001	MT CO_2e
						Sum for Total MT CO_2e

Formula to Calculate Greenhouse Gas Emissions from the Amount of Fuel Used During Air Travel

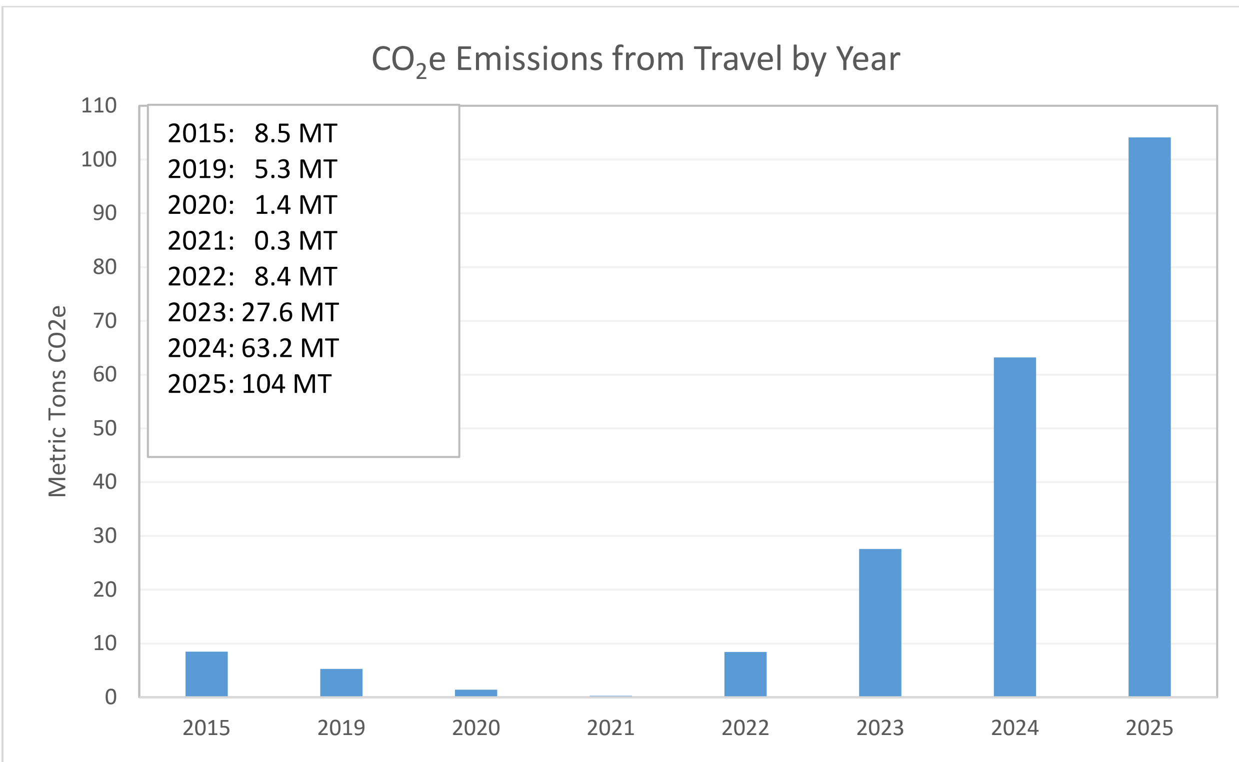
	X		X		X	
Air	Emission Factor	Result	Global Warming Potential	Result	Conversion Factor	Result
mi	0.129 (2022) or 0.133 (2015 – 2021) CO_2 kg/mi	kg CO_2	1	kg CO_2	0.001	MT CO_2e
	0.0006 CH_4 g/mi	g CH_4	28	g CO_2e	0.000001	MT CO_2e
	0.0041 (2022) or 0.0042 (2015 – 2021) N_2O g/mi	g N_2O	265	g CO_2e	0.000001	MT CO_2e
						Sum for Total MT CO_2e

Formula to Calculate Greenhouse Gas Emissions from the Amount of Natural Gas Used in Hotel Stays

	X		X		X		X	
Hotel-Natural Gas	Average Use	Result	Emission Factor	Result	Global Warming Potential	Result	Conversion Factor	Result
nights	0.059 MMBtu/night	MMBtu	53.06 kg CO_2/MMBtu	kg CO_2	1	kg CO_2	0.001	MT CO_2e
	0.059 MMBtu/night	MMBtu	1 g CH_4/MMBtu	g CH_4	28	g CO_2e	0.000001	MT CO_2e
	0.059 MMBtu/ night	MMBtu	0.1 g N_2O/MMBtu	g N_2O	265	g CO_2e	0.000001	MT CO_2e
								Sum for Total MT CO_2e

Formula to Calculate Greenhouse Gas Emissions from the Amount of Electricity Used in Hotel Stays

	X		X		X	
Hotel-Electric	Average Use	Result	Emission Factor	Result	Conversion Factor	Result
nights	19 kWh/night	kWh	dependent on region – g CO_2e/kWh (from EPA eGRID)	g CO_2	0.000001	MT CO_2e



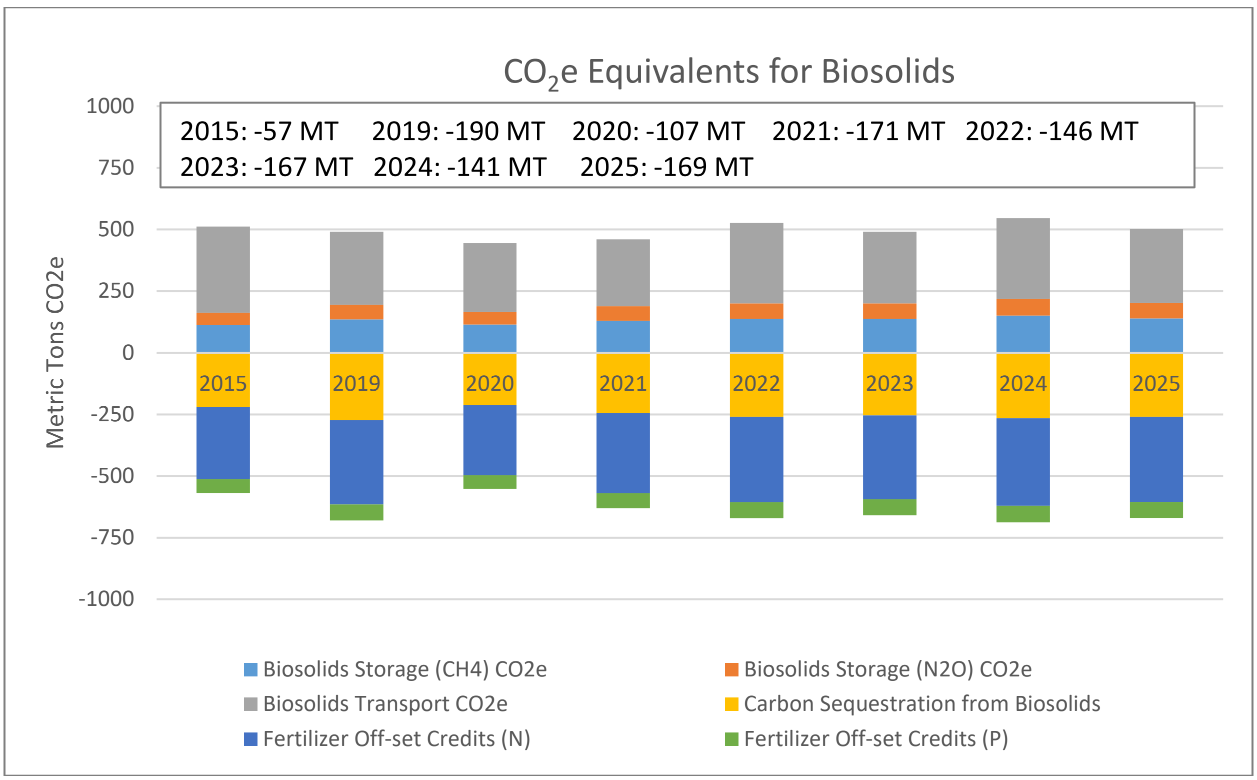
Biosolids

Biosolids data is comprised of six different parameters – three that result in greenhouse gas emissions and three that result in a net uptake of greenhouse gases, or a carbon offset. The Biosolids Assessment Emission Model (BEAM) was used to assess the emissions (North East Biosolids and Residuals Association, 2022). The 2022 version of BEAM was updated from a 2009 version. Notably, the calculations used to estimate the amount of carbon uptake were changed because newer data became available showing that not as much carbon is taken up as previously thought. Biosolids data from previous years were recalculated to reflect this new understanding. Calculations are referenced in Appendix A.

Processes that result in emissions of greenhouses gases are transportation and storage of biosolids. Diesel fuel is burned to transport the biosolids to Eastern Washington, which results in the emission of CO_2, methane, and nitrous oxide. Methane and nitrous oxide are also emitted from the biosolids due to off-gassing and biological activity. This mostly happens during storage.

The processes that result in an offset of greenhouse gases are the sequestration of carbon and the use of biosolids as nitrogen (N) and phosphorus (P) fertilizer. When biosolids are applied, they become incorporated into the soil. The carbon can become part of the organic carbon of the soil and can be incorporated into humic and fulvic acids and microbial biomass. The nitrogen and phosphorus in the biosolids offset the need to use inorganic fertilizers and offset the carbon footprint associated with their production.

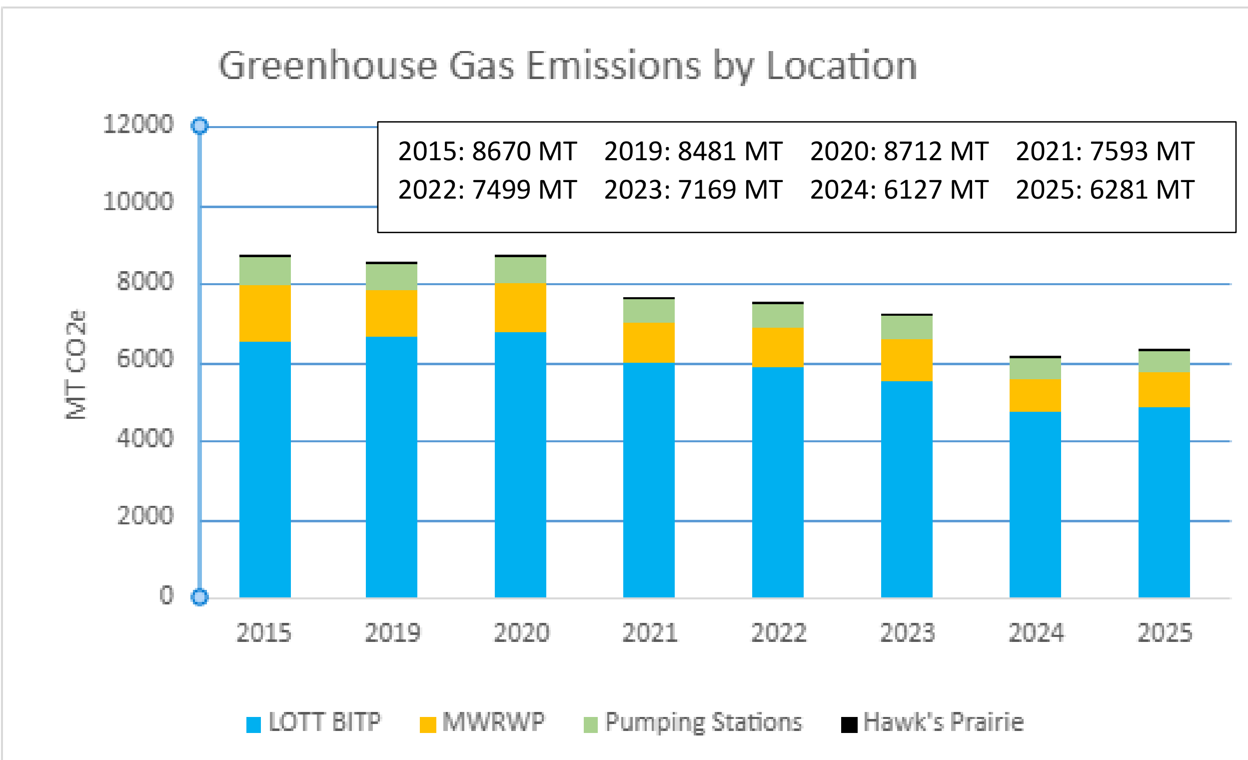
The amount of greenhouse gas emissions from biosolids has been fairly steady since 2021. The amount largely varies depending on conditions at the plant.



Total Usage by Location

The Budd Inlet Treatment Plant (BITP) is the center of operations for the LOTT Clean Water Alliance. It treats an average of 13 million gallons of wastewater per day (mgd), including all solids from the wastewater service area, and produces approximately 1 mgd of Class A reclaimed water. It also houses staff and the WET Science Center. The Martin Way Reclaimed Water Plant (MWRWP) is a smaller satellite plant, producing only reclaimed water and treating an average of about 1 mgd. There are three LOTT-owned pump stations in the service area, which use electricity as they lift wastewater from lower to higher ground as part of LOTT's conveyance system. The Hawks Prairie Ponds and Recharge Basins is a site where Class A reclaimed water flows through constructed wetlands and is infiltrated into recharge basins. Its operation emits minimal greenhouse gases, the energy use there being limited to electricity for lighting and control systems.

The graph below shows the total of all emissions for eight years in each location, without the addition of biosolids and travel, as these Scope 3 activities are not directly attributable to any specific location.



Avoided Emissions

Some LOTT practices result in avoided emissions. When methane is produced in the digesters, it goes to one of three places: to the cogeneration system where it is used to produce electricity and heat, to the boilers where it is used to provide heat, or to the flare where it is flared or burned off. Methane from the digesters is preferentially used in the cogeneration system, followed by the boilers. When additional heat is needed, however, output at the cogeneration system is turned down to send more digester gas to the boilers, thereby reducing LOTT's natural gas consumption. The use of methane in these systems helps offset the use of natural gas and electricity. Notably, the amount of avoided emissions ranges from 15%-18% of the total energy used at LOTT in the years 2015 – 2022. In 2023, this number increased to 21% and in 2025 to 26%. Avoided emissions likely increased due to the increased production of methane from the digesters and the increased efficiency of operations from the BPI project.

Cogeneration Conversion

The cogeneration system or combined heat and power system (CHP) produces electricity. This electricity can be used for heating or for other electrical applications. To account for the offset when using the cogeneration system for electric heating, multiple conversion factors are applied to estimate the equivalent amount of natural gas that would be used for heating.

To account for the offset when using the cogeneration system for electricity and to obtain greenhouse gas emission values, the kWh generated by the cogeneration system is multiplied by the generation intensity in metric tons (MT) of CO_2e from the PSE generation portfolio. These values are found in Puget Sound Energy's Annual Report.

Formula to Calculate Avoided Greenhouse Gas Emissions from the Use of Electricity Provided by CHP Instead of Natural Gas

Start	X		X		X		/	
CHP Generator Gas Flow	Conversion Factor	Result	CHP Thermal Efficiency	Result (Heat Output)	Heat Exchange Effect	Result (Heat Output to High Heat Loop)	Boiler 2&3 (Natural Gas) Efficiency	Result (Heat Input to Boiler)
ft_3	0.00069	MMBtu	0.21	MMBtu	0.90	MMBtu	0.84	MMBtu

(from above)	X		X		X	
Result (Heat Input to Boiler)	Emission Factor	Result	Global Warming Potential	Result	Conversion Factor	Result
MMBtu	53.06 kg CO_2/MMBtu	kg CO_2	1	kg CO_2	0.001	MT CO_2e
	4.7 g CH_4/MMBtu	g CH_4	28	g CO_2e	0.000001	MT CO_2e
	0.1g N_2O/MMBtu	g N_2O	265	g CO_2e	0.000001	MT CO_2e
						Sum for Total MT CO_2e

Formula to Calculate Avoided Greenhouse Gas Emissions from the Use of Electricity Provided by CHP Instead of Purchased Electricity

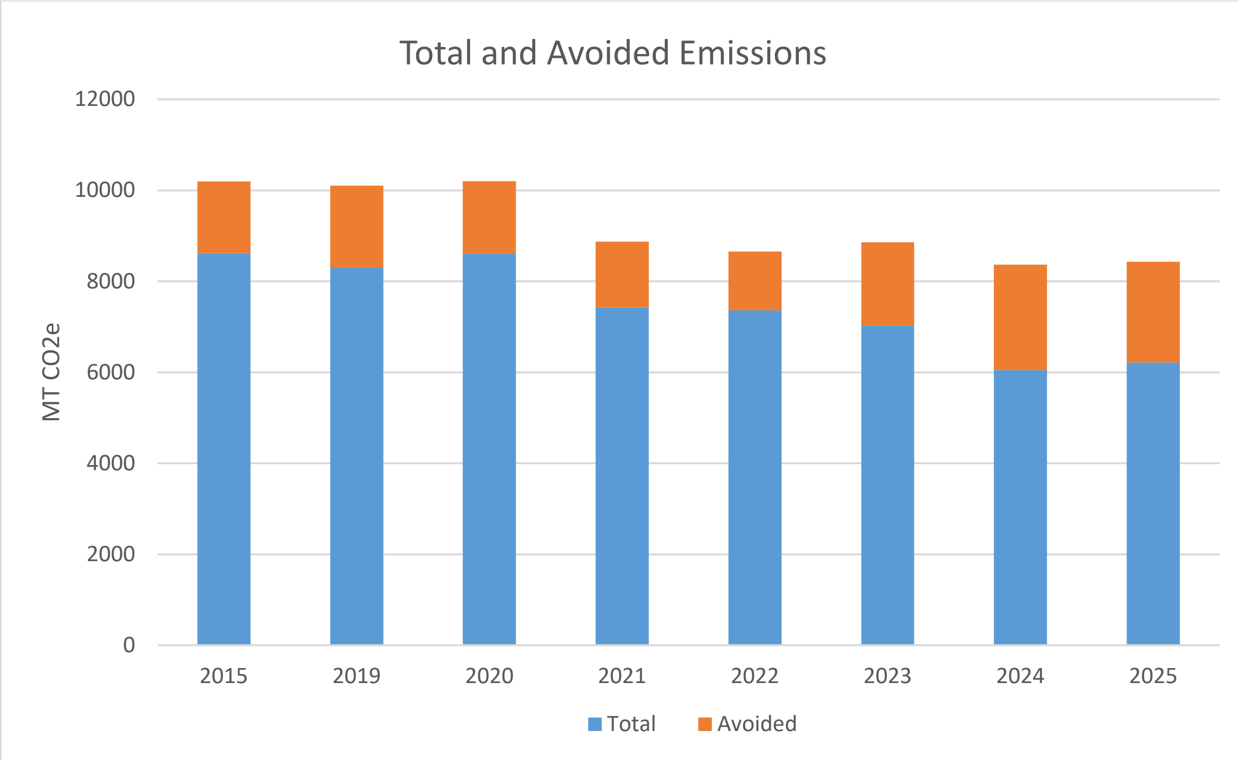
	X	
Average CHP Generator Power Output	PSE Emission Factor (MT CO_2e/kWh)	Result
kWh	varies	MT CO_2e

Boiler Conversion

Methane sent to the boilers is burned to heat water. The greenhouse gas emissions produced from this are CO_2, CH_4 and N_2O. The offset for heat obtained through using digester gas in the boilers is calculated by determining the amount of greenhouse gases that would be produced from an equivalent amount of natural gas to produce the same amount of heat.

Formula to Calculate Avoided Greenhouse Gas Emissions from the Use of Digester Gas Instead of Natural Gas

Start	X		X		/	
Boiler Biogas Consumption	Conversion Factor	Result	Boilers 1&4 (Dig. Gas) Efficiency	Result (Heat Output)	Boilers 2&3 (Natural Gas) Efficiency	Result (Heat Input to Boiler)
ft_3	0.00069	MMBtu	0.8279	MMBtu	0.84	MMBtu
(from above)	X		X		X	
Result (Heat Input to Boiler)	Emission Factor	Result	Global Warming Potential	Result	Conversion Factor	Result
MMBtu	53.06 kg CO_2/MMBtu	kg CO_2	1	kg CO_2	0.001	MT CO_2e
	4.7 g CH_4/MMBtu	g CH_4	28	g CO_2e	0.000001	MT CO_2e
	0.1g N_2O/MMBtu	g N_2O	265	g CO_2e	0.000001	MT CO_2e
						Sum for Total MT CO_2e



9. Conclusion

LOTT's greenhouse gas emissions are considerable, with most emissions attributed to electricity used for pumps and aeration. Given the nature of the wastewater treatment plant processes, options for reducing electrical use and related emissions are limited. LOTT has endeavored to reduce its carbon footprint when feasible and will continue to evaluate opportunities for reduction.

Reductions have been achieved through several measures, such as recovering and using methane from the digestion process, changing out lighting systems and altering the run-times of equipment. The use of methane from the digesters has resulted in measurable energy savings that can be tracked. The BPI project, completed in March 2023, reduced overall electricity use by 12%.

Since 2015, CO_2 emissions at LOTT have decreased by 28% overall and by 42% per capita, from 8622 MT to 6216 MT, through changes to process, operations and equipment at LOTT and to the electrical grid by PSE. Additional operational changes helped LOTT avoid emissions, with avoided emissions increasing from 15% to 26% from 2015 to 2025.

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11. Appendix A

Calculations used in LOTT Greenhouse Gas (GHG) Emissions Inventory, adapted from ICLEI protocol.

Summary of GHG Emissions Calculations from the Treatment of Wastewater for LOTT Clean Water Alliance.

<u>General Methodology and Calculation Selection</u>

Figure 1:

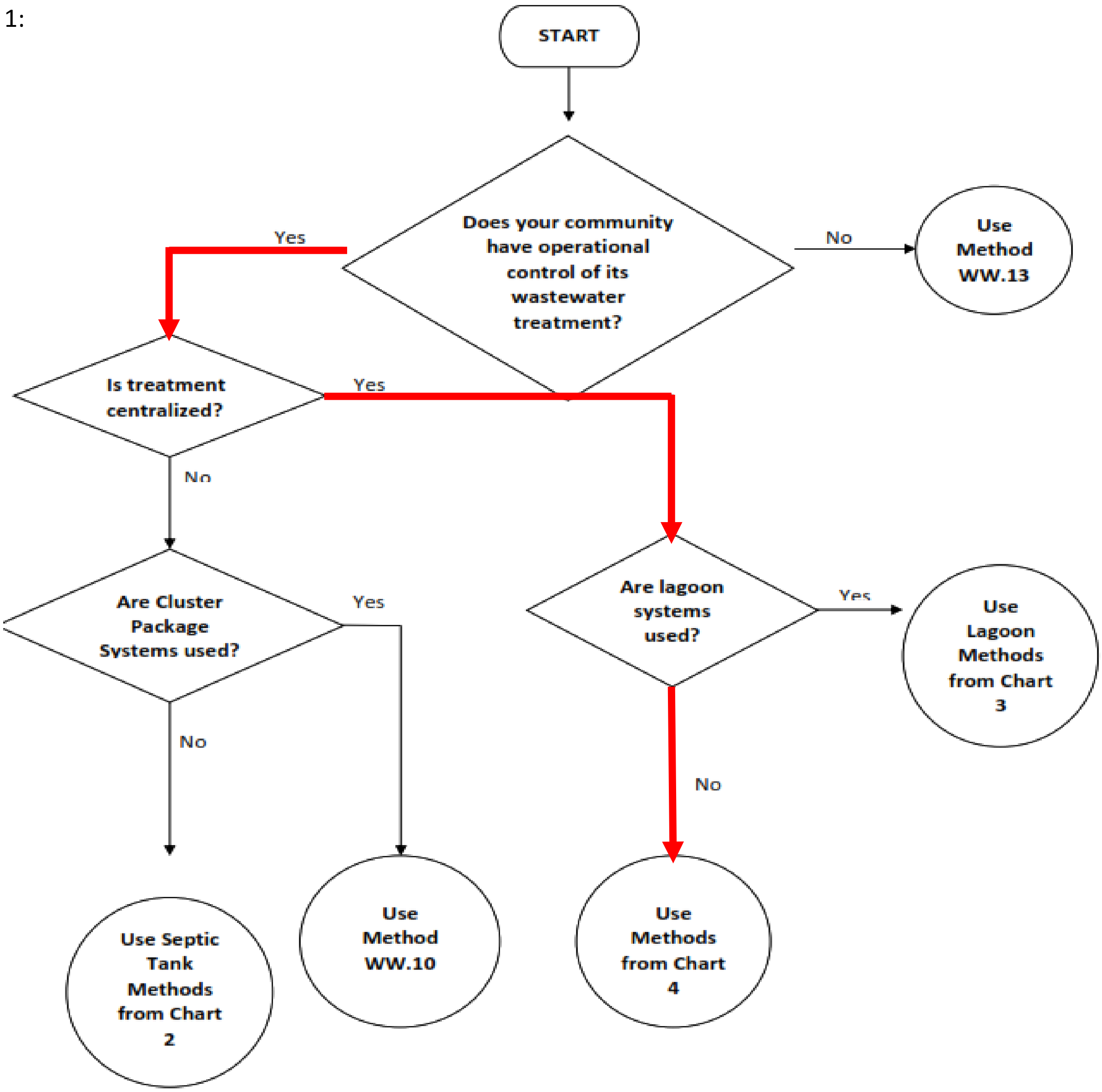
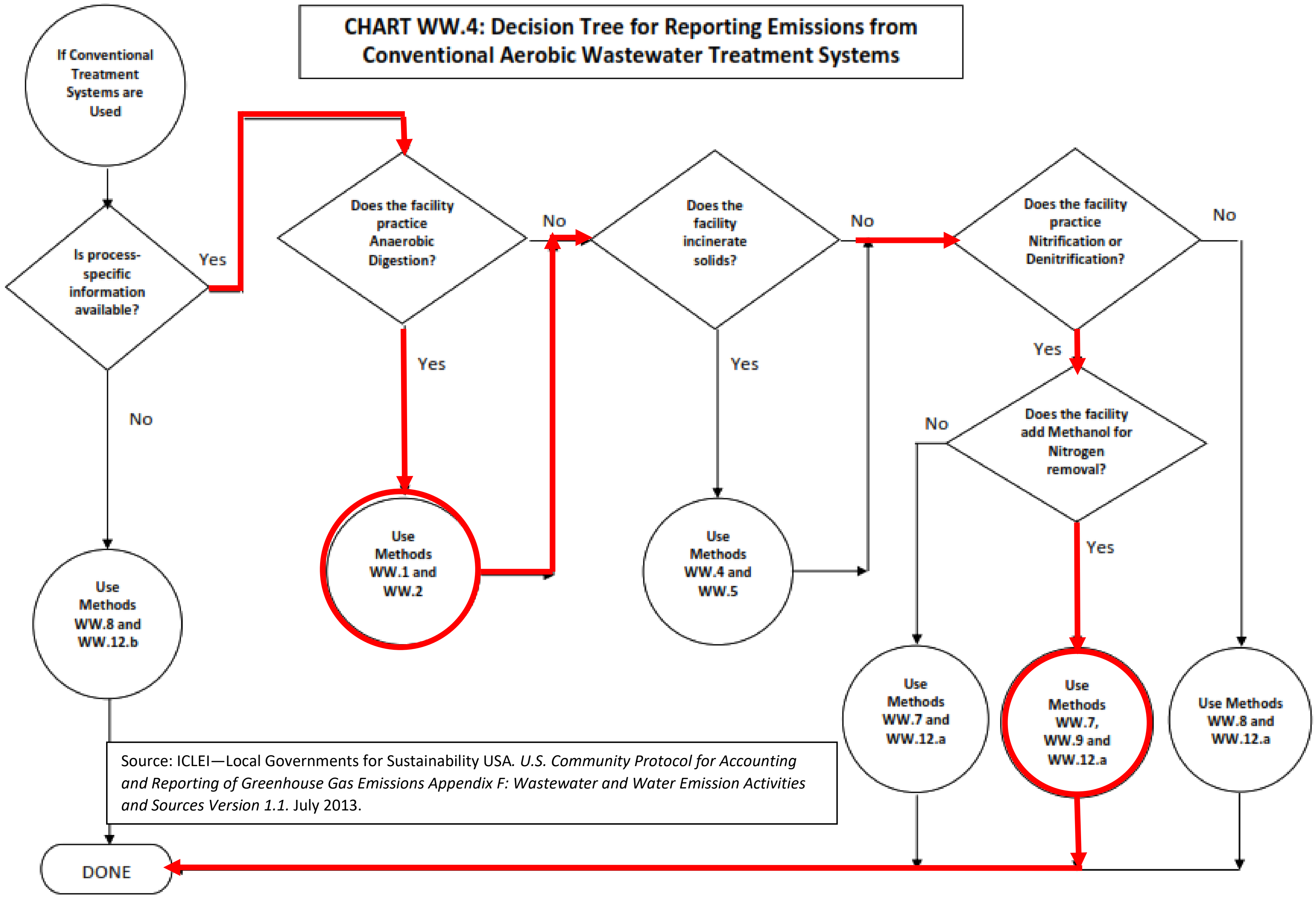


CHART WW.4: Decision Tree for Reporting Emissions from Conventional Aerobic Wastewater Treatment Systems



Source: ICLEI—Local Governments for Sustainability USA. *U.S. Community Protocol for Accounting and Reporting of Greenhouse Gas Emissions Appendix F: Wastewater and Water Emission Activities and Sources Version 1.1.* July 2013.

Detailed Calculations

Scope 1

Equation WW.1.a: Emissions from Devices Designed to Combust Digester Gas, with CH_4 Content Known

***Equation WW.1.a* Emissions from Devices Designed to Combust Digester Gas, with CH_4 Content Known**

Annual CH_4 emissions =

$(\text{Digester Gas} \times fCH_4 \times BTU_{CH4} \times 10^{-6} \times EF_{CH4} \times 365.25 \times 10^{-3}) \times GWP$

Where:

Description		Value
Annual CH_4 emissions	= Total annual CH_4 emitted by incomplete combustion ($mtCO_2e$)	Result
Digester gas	= Standard cubic feet of digester gas produced per day (std ft^3/day)	User Input
fCH_4	= Fraction of CH_4 in gas	User Input
BTU_{CH4}	= Default BTU content of CH_4, higher heating value (BTU/ft^3)	1028 (nation-wide average)
10^{-6}	= Conversion from BTU to 1 MMBTU	10^{-6}
EF_{CH4}	= CH_4 emission factor (kg CH_4/MMBTU)	3.2 X 10^{-3} kg CH_4 per MMBTU
365.25	= Conversion factor (day/year)	365.25
10^{-3}	= Conversion from kg to mt (mt/kg)	10^{-3}
GWP_{CH_4}	= Global Warming Potential; conversion from mt of CH_4 into mt of CO_2 equivalents	GWP[5]

***Equation WW.1.a* Emissions from Devices Designed to Combust Digester Gas, with CH_4 Content Known**

Source: In 40 CFR Part 98, Mandatory Reporting of Greenhouse Gases; Final Rule, Table C-2, page 79154 of the Federal Register / Vol. 75, No. 242 / Friday, December 17, 2010 / Rules and Regulations, is referenced an emission factor for digester gas combustion: 3.2 X 10^{-3} kg CH_4 per million BTU. See: http://edocket.access.gpo.gov/2010/pdf/2010-30286.pdf

Variable	Data source	Frequency	Notes
Digester Gas	Hach WIMS	Daily	This project uses actual daily data rather than a daily average calculated at the end of the year
fCH_4	LOTT	Annually	
$BTUCH_4$	National Average	n/a	
$EFCH_4$	ICLEI U.S. Comm. Protocol	n/a	
365.25	n/a	n/a	See ** below
10^{-3}	Unit Conversion	n/a	
$GWPCH_4$	IPCC (Intergovernmental Panel on Climate Change) AR5	n/a	

** Rather than applying an average daily production number for the cubic feet of digester gas produced, this project receives actual daily production values in the Energy Sensei® platform. This allows for daily emissions calculations that can then be summed for an annual emissions total. Therefore, our calculations omit the 365.25 factor.

Equation WW.2: Stationary Nitrous Oxide Emissions from Combustion of Digester Gas

For N_2O emissions from the combustion of digester gas, use the same formula as for CH_4, except:

- Replace the CH_4 emission factor with the N_2O emission factor per MMBtu.
- Replace the CH_4 global warming potential (GWP) with the N_2O GWP.

Box WW.2.a	**Example Calculation of N_2O Emissions from the Combustion of Anaerobic Digester Gas when fraction of CH_4 is known**	
A wastewater facility generates 1,000,000 ft^3 per day of digester gas containing 65% CH_4. The BTU content of the digester gas is not available. Based on this scenario the N_2O emissions from the combustion of digester biogas can be calculated as follows		
Description		Value
N_2O emissions	= Total N_2O emitted by combustion ($mtCO_2e$)	Result
Digester gas	= Measured standard cubic feet of digester gas produced per day (std ft^3/ day)	1,000,000
fCH_4	= Fraction of CH_4 in biogas	0.65
BTU_{CH4}	= Default BTU content of CH_4, higher heating value (BTU/ft^3)	1028
10^{-6}	= Conversion from BTU to 1 MMBTU	10^{-6}
EF_{N2O}	= N_2O emission factor (kg N_2O/MMBTU)	6.3×10^{-4} kg N_2O per MMBTU
365.25	= Conversion factor (day/year)	365.25
10^{-3}	= Conversion from kg to mt (mt/kg)	10^{-3}
GWP_{N_2O}	= Global Warming Potential; conversion from mt of N_2O into mt of CO_2 equivalents	GWP[9]
Sample Calculation:		
Annual N_2O emissions $= (1{,}000{,}000 \times 0.65 \times 1028 \times 10^{-6} \times (6.3 \times 10^{-4}) \times 365.25 \times 10^{-3}) \times 310 = 47.7\ mtCO_2e$		

Variable	Data Source	Frequency	Notes
Digester Gas	Hach WIMS	Daily	This project uses actual daily data rather than a daily average calculated at the end of the year
fCH_4	LOTT	Annually	
$BTUCH_4$	National Average	n/a	
EFN_2O	ICLEI U.S. Comm. Protocol	n/a	
365.25	n/a	n/a	See ** below
10^{-3}	Unit Conversion	n/a	
$GWPN_2O$	IPCC AR5	n/a	

** Rather than applying an average daily production number for the cubic feet of digester gas produced, this project receives actual daily production values in the Energy Sensei® platform. This allows for daily emissions calculations that can then be summed for an annual emissions total. Therefore, our calculations omit the 365.25 factor.

Equation WW.7: Process Nitrous Oxide Emissions from Wastewater Treatment Plants with Nitrification or Denitrification

Equation WW.7 **N_2O Process Emission from Wastewater Treatment Plants (or aeration basin) that Uses Nitrification or Denitrification**

Annual N_2O emissions = $((P \times F_{ind\text{-}com}) \times EF \times 10^{-6}) \times GWP$

Where:

Description			Value
Annual N_2O emissions	=	Total annual N_2O emitted by WWTP processes ($mtCO_2e$)	Result
P	=	Population served by the WWTP	User input
$F_{ind\text{-}com}$	=	Factor for high nitrogen loading of industrial or commercial discharge	1.25
$F_{ind\text{-}com}$	=	Factor for insignificant industrial or commercial discharge	1
EFnit/denit	=	Emission factor for a WWTP with nitrification or denitrification (g N_2O/ person / year)	7
10^{-6}	=	Conversion from g to mt (mt/g)	10^{-6}
GWP_{N_2O}	=	Global Warming Potential; conversion from mt of N_2O into mt of CO_2 equivalents	GWP[21]

Source: *As listed in LGO protocol Equation 10.7 from EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1890-2007, Chapter 8, 8-13 (2009)*

Variable	Data Source	Frequency	Notes
Population Served	LOTT	Annual	Due to timing, this will most likely need to reference the prior year's population served
$F_{ind\text{-}com}$	ICLEI	n/a	LOTT serves several Significant Industrial Users (SIUs) and therefore should use the higher factor of 1.25
EFnit/denit	ICLEI	n/a	
10^{-6}	ICLEI U.S. Comm. Protocol	n/a	
$GWPN_2O$	IPCC AR5	n/a	

Equation WW.9: Process Carbon Dioxide Emissions from the Use of Fossil Fuel-Derived Methanol for Biological Nitrogen Removal

***Equation WW.9* CO2 Emission from Methanol Use**

*Annual CO_2 emissions = Methanol Load *F *(44.01/32.04) *GWP *365.25*

Where:

Description		Value
Annual CO_2 emissions	= Total annual CO_2 emitted ($mtCO_2e$)	Result
Methanol load	= Amount of neat chemical used per day (mt CH_3OH/day)	User Input
F	= Factor to be applied based on WWTP's sludge treatment type: • Raw Solids Disposal 80% • Anaerobic Digestion 90% • Solids Combustion 100%	0.80, 0.90, 1.0
44.01/32.04	= Molecular weight ratio of 44.01 (for CO_2) to 32.04 (for CH_3OH)	1.37
GWP	= Global Warming Potential for CO_2	1
365.25	= Conversion factor from days to year	365.25

Variable	Data Source	Frequency	Notes
Methanol Load	LOTT	Daily	LOTT supplies daily data versus applying an average CH_3OH/day for the year
F	ICLEI	n/a	Use Anaerobic Digestion factor of 0.90
44.01/32.04	ICLEI	n/a	
365.25	n/a	n/a	See ** below
$GWPCO_2$	IPCC AR5	n/a	Equal to 1

** Rather than applying an average daily amount of methanol used, this project receives actual daily production values in the Energy Sensei® platform. This allows for daily emissions calculations that can then be summed for an annual emissions total. Therefore, our calculations omit the 365.25 factor.

Equation WW.12: Fugitive Nitrous Oxide Emissions from Effluent Discharge

***Equation WW.12* N_2O Emission from Effluent Conversion**

Annual N_2O emissions = (N-Load $\times EF_{effluent} \times 365.25 \times 10^{-3} \times 44/28) \times GWP$

Where:

Description		Value
N_2O emissions	= Total annual N_2O emitted by effluent conversion ($mtCO_2e$)	Result
N-Load	= Average total nitrogen per day (kg N/day)	User input
$EF_{effluent}$	= Emission factor (kg N_2O-N/kg sewage-N discharged)	0.005 for river or stream discharge, 0.0025 for direct ocean discharge[31]
365.25	= Conversion factor (day/year)	365.25
10^{-3}	= Conversion from kg to mt (mt/kg)	10^{-3}
44/28	= Molecular weight ratio of N_2O to N_2	1.57
GWP_{N_2O}	= Global Warming Potential; conversion from mt of N_2O into mt of CO_2 equivalents	GWP[32]

Source: As listed in LGO protocol Equation 10.9 from EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007, Chapter 8, 8-13 (2009)

Variable	Data Source	Frequency	Notes
N-Load	LOTT	Daily	LOTT supplies daily data versus applying an average kg N/day for the year
$EF_{effluent}$	ICLEI	n/a	This project uses the effluent factor of 0.005 for direct ocean discharge*
365.25	n/a	n/a	See ** below
10^{-3}	Unit conversion	n/a	
44/28	ICLEI	n/a	
$GWPCO_2$	IPCC AR5	n/a	Equal to 1

* The value of 0.005 was used instead of 0.0025 because “neither the IPCC nor the EPA have yet to distinguish between effluent conversion that occurs in rivers (and then subsequent conversion in estuaries), as opposed to conversion that only occurs in estuaries” (ICLEI).

** Rather than applying an average kg N/day, this project receives actual daily production values in the Energy Sensei® platform. This allows for daily emissions calculations that can then be summed for an annual emissions total. Therefore, our calculations omit the 365.25 factor.

Scope 3

Biosolids Land Application

The calculation of GHG emissions, credits, and offsets from the land application of biosolids is still very much in its infancy. Few publicly available tools exist to facilitate this calculation. However, the Biosolids Emissions Assessment tool (BEAM) was developed through substantial research and testing for the purpose of calculating GHG emissions for biosolids processing and end use. Therefore, we have decided to rely on this calculator for estimated GHG emissions associated with the transport, storage and disposal of biosolids generated at the BITP and applied to agricultural land in King County. A summary of the inputs and calculation methodologies and outputs are listed below.

Table 1: Inputs

Variable	Data Source	Frequency	Notes
Mg/day – Wet	LOTT/King County	Daily	Megagrams applied to land. Daily values input in Energy Sensei®, average Mg/day used in GHG calculations
Mg/day – Dry	LOTT/King County	Daily	Megagrams applied to land. Daily values input in Energy Sensei®, average Mg/day used in GHG calculations
Solids Content (%)	LOTT/King County	Daily	Average of daily applications solids content
Density (kg/m^3)	BEAM Default	Daily	Default value provided by BEAM calculator
Type of Biosolids	LOTT	n/a	Limed vs Digested – LOTT uses Digested
Total N (%-dry weight)	BEAM Default	n/a	Default value provided by BEAM calculator
Total P (%-dry weight)	BEAM Default	n/a	Default value provided by BEAM calculator
TVS (Total Volatile Solids) (%-dry weight)	BEAM Default	n/a	Default value provided by BEAM calculator
Organic Carbon (%-dry weight)	BEAM Default	n/a	Default value provided by BEAM calculator
$CACO_3$ (Calcium carbonate) equivalence (%-dry weight)	BEAM Default	n/a	Default value provided by BEAM calculator
Avg # of Days Stored	LOTT	n/a	Estimate of 60 days based on communications with LOTT
Soil Texture (% Fine-textured)	BEAM Default	n/a	Default value provided by BEAM calculator
Soil Texture (% Coarse-textured)	BEAM Default	n/a	Default value provided by BEAM calculator
Fuel Use (L/day)	LOTT	Daily	Fuel used in the transportation of biosolids to application site

Table 2: Outputs

Output	Calculation Summary	Governing Protocol
Fuel Use CO_{2e} (MT/day)	Fuel consumed multiplied by emission factors for CO_2, CH_4, N_2O, and converted to MT CO_{2e}	GHG Protocol
Methane Emissions from Storage of Biosolids	Product of amount applied, density, number of days stored, and CH_4 emission factor for stored biosolids, converted to MT CO_{2e}	BEAM
Nitrous Oxide Emissions – Land Application (fine-textured soils)	Product of quantity applied to land, nitrogen content %, organic carbon %, fine textured %, converted to MT N_2O	BEAM
Nitrous Oxide Emissions – Land Application (coarse-textured soils)	Product of quantity applied to land, nitrogen content %, organic carbon %, coarse textured %, converted to MT N_2O	BEAM
Nitrous Oxide Emissions from Storage of Biosolids	Product of amount applied, density, number of days stored and N_2O emission factor for stored biosolids	BEAM
Total N_2O Emissions	Sum of three N_2O calculations above, converted to MT CO_{2e}	BEAM
Carbon Sequestration	Product of amount applied to land and carbon sequestration factor developed by authors of BEAM tool	BEAM
Fertilizer Offset Credits (from N applied to soil)	Product of amount applied, nitrogen content and nitrogen credit factor, converted to MT CO_{2e}	BEAM
Fertilizer Offset Credits (from P applied to soil)	Product of amount applied, phosphorus content and phosphorus credit factor, converted to MT CO_{2e}	BEAM

Formula to Calculate Emissions from Storage of Biosolids Prior to Land Application

Start	X		X		/	
Wet Biosolid	Conversion Factor	Result	# of Days Stored	Result	Density of Biosolid	Result
Tons/day	907.185	kg/day	60	kg	950 kg/m^3	m^3

	X		X		X	
Result (from above)	Emission Factor during Storage	Result	Global Warming Potential	Result	Conversion Factor	Result
m^3	0.0091 kg CH_4/m^3	kg CH_4	28	kg CO_2e	1000	MT CO_2e
	0.00043 kg N_2O/m^3	kg N_2O	265	kg CO_2e	1000	MT CO_2e
						Sum for Total MT CO_2e

Formula to Calculate Fertilizer Offset Credits from Land Application

Start	X		X	X		X	
Dry Biosolid	Conversion from Tons to Mg (MT)	Result	Total Nitrogen/ Phosphorus % of Dry Weight	Credit (Nitrogen & Phosphorus)	Result	Global Warming Potential	Result
Tons/day	0.907185	MT	5% N	4 kg CO_2/kg N	MT CO_2	1	MT CO_2e
			1.9% P	2 kg CO_2/kg P	MT CO_2	1	MT CO_2e
							Sum for Total CO_2e

Formula to Calculate Carbon Sequestration from Land Application

Start	X	X		X		X	
Dry Biosolid	Conversion from Tons to Mg	Sequestration Factor	Result	Conversion from Mg to MT	Result	Global Warming Potential	Result
Tons/day	0.907185	0.15	Mg CO_2/dry Mg biosolids	1	MT CO_2	1	MT CO_2e

Formula to Calculate Emissions from Biosolids Transport Diesel

	X	X		X		X	
Starting Units	Conversion to Liters	Emission Factor (TCR Default Emission Factors in g/L)	Result	Unit Conversion from g to MT	Result	Global Warming Potential	Result
gal	3.78541	2681	g CO_2	0.000001	MT CO_2	1	MT CO_2e
		0.14	g CH_4	0.000001	MT CH_4	28	MT CO_2e
		0.082	g N_2O	0.000001	MT N_2O	265	MT CO_2e
							Sum for Total CO_2e

12. Appendix B: Modifications to Formulas Over Time

Over time, some changes to formulas have occurred to correct assumptions or incorrect data. For this reason, the totals noted in each of the annual reports do not always agree. The most accurate data will always be found in the most recent report.

Changes in 2021:

- New emission factors were incorporated for electricity based on a change in electricity generation sources. These new emission factors are incorporated for 2021 data onward.

Changes in 2022:

- An error was corrected in the 2020 population number, slightly affecting the denitrification and totals for that year.
- New, more accurate data for carbon sequestration was obtained by researchers; thus NEBRA/BEAM changed their assumption about the amount of carbon sequestered. This change was made retroactively to all years, which decreased the carbon offset for all years.
- The emission factors for automobile travel and medium-range air travel changed between 2021 and 2022. These decreased slightly due to updated regulations, a slightly different makeup of fuel source and newer engine designs coming on the market. These new emission factors are incorporated for 2022 data onward.

13. Appendix C: Unit Abbreviations

UNIT	ABBREVIATION
British thermal unit	Btu
CO_2 equivalent/emitted	CO_2e
cubic feet	Ft^3
feet	ft
gallons	gal
gram	g
kilogram	kg
kilowatt-hour	kWh
liters	L
megagrams	Mg
meters	m
metric tons	MT
mile	mi
million British thermal units	MMBtu
million gallons/day	mgd
pounds	lb