REPORT, June 2022

2019 Community-wide Greenhouse Gas Emissions Inventory

City of Cambridge

PREPARED FOR

City of Cambridge
795 Massachusetts Avenue
Cambridge, MA, 02139
617.349.4000

PREPARED BY

vhb

101 Walnut Street
PO Box 9151
Watertown, MA 02471
617.924.1770

IN ASSOCIATION WITH

DNV

ARUP

Table of Contents

1

Introduction

It is scientific consensus that the Earth's climate is warming due to human activity, and that the warming will lead to significant and long-term negative impacts on our communities and ecosystems. As an important step towards protecting residents and local businesses from the potential impacts of climate change, the City of Cambridge has committed to achieving carbon neutrality by 2050.[1] In this commitment, the City has joined other local governments across the United States and world, which are also dedicated to reducing GHG emissions at the community-scale.

The 2019 Community-wide Greenhouse Gas Emissions Inventory helps the City of Cambridge benchmark community-wide emissions and provides a necessary foundation that enables the City to track its progress towards emission reduction goals. It also helps the City to engage specific market sectors in actions to reduce emissions. This 2019 inventory serves as an update to the City's baseline community-wide GHG emissions inventory from 2017, which was based on 2012 data. It provides background on the 2019 update and details its methodology, noting any changes made to the methodology since the baseline inventory was conducted. This report also presents the results of the 2019 update, both independently and compared to the results of the baseline inventory.

Note that this inventory was prepared for the City of Cambridge by VHB (report compilation and Waste sector estimates), DNV GL (Buildings and Energy Production sector estimates), and ARUP (Transportation sector estimates).

Purpose

Primarily through policy enactment and enforcement, local governments yield a significant amount of control and influence over GHG emissions from community activities, such as those associated with buildings, energy production, transportation, and waste. Conducting and regularly updating GHG emissions inventories can be useful in understanding how to best design policies and programs that reduce GHG emissions, as well as for tracking their effectiveness. This iterative process of data

1 City of Cambridge. (2022). *Greenhouse Gas Emissions*. Retrieved 15 June 2022, from https://sustainabilitydashboard.cambridgema.gov/category/greenhouse-gas-emissions#community-ghg-emissions

collection, analysis, targeted policy making, and program implementation is a strong tool in the fight against climate change.

The purpose of the City of Cambridge's 2019 Community-wide GHG Emissions Inventory is to quantify GHG emissions from community-wide activities and determine whether the City is on track to meet its GHG emissions reduction targets. Further, it will inform whether policy changes or new policies or implementation strategies are required, and if so, to which community activities should they be directed.

Understanding a Greenhouse Gas Emissions Inventory

GHG emissions inventories are developed to help organizational leaders and members understand how and in what quantities their activities generate GHG emissions. For cities, GHG emissions are generally compiled at both the government operations scale and community-wide scale.

Emissions associated with government operations, such as fuel use from fleet vehicles and energy use in city government buildings, are included as part of the community-wide inventory. These emissions are a subset of the community inventory. For example, the data in the community inventory on commercial energy use includes energy consumed by municipal buildings, and vehicle-miles-traveled estimates include miles driven by municipal fleet vehicles. Details on the emissions from municipal operations are often presented in a separate inventory report. The latest City of Cambridge Municipal GHG Emissions Inventory can be found here.

Global Protocol for Community-Scale Greenhouse Gas Inventories

This report presents the methodology used to estimate the GHG emissions from the Cambridge community as a whole. It follows the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC), which was developed by the World Resources Institute, C40 Cities, and ICLEI Local Governments for Sustainability. The GPC is a requirement to remain compliant with the Global Covenant of Mayors for Climate and Energy (GCoM), a global network of thousands of cities that are also committed to reducing GHG emissions from city-level activities, of which Cambridge is a member.

The GPC was designed to provide guidance to local governments across the globe on developing community GHG emissions inventories. It establishes the reporting requirements for all community GHG emissions inventories and provides detailed accounting guidance for quantifying GHG emissions associated with a range of emission sources and activities. The GPC also provides several optional reporting frameworks to help local governments customize their community GHG emissions inventory reports based on the data available, local goals, and capacity.

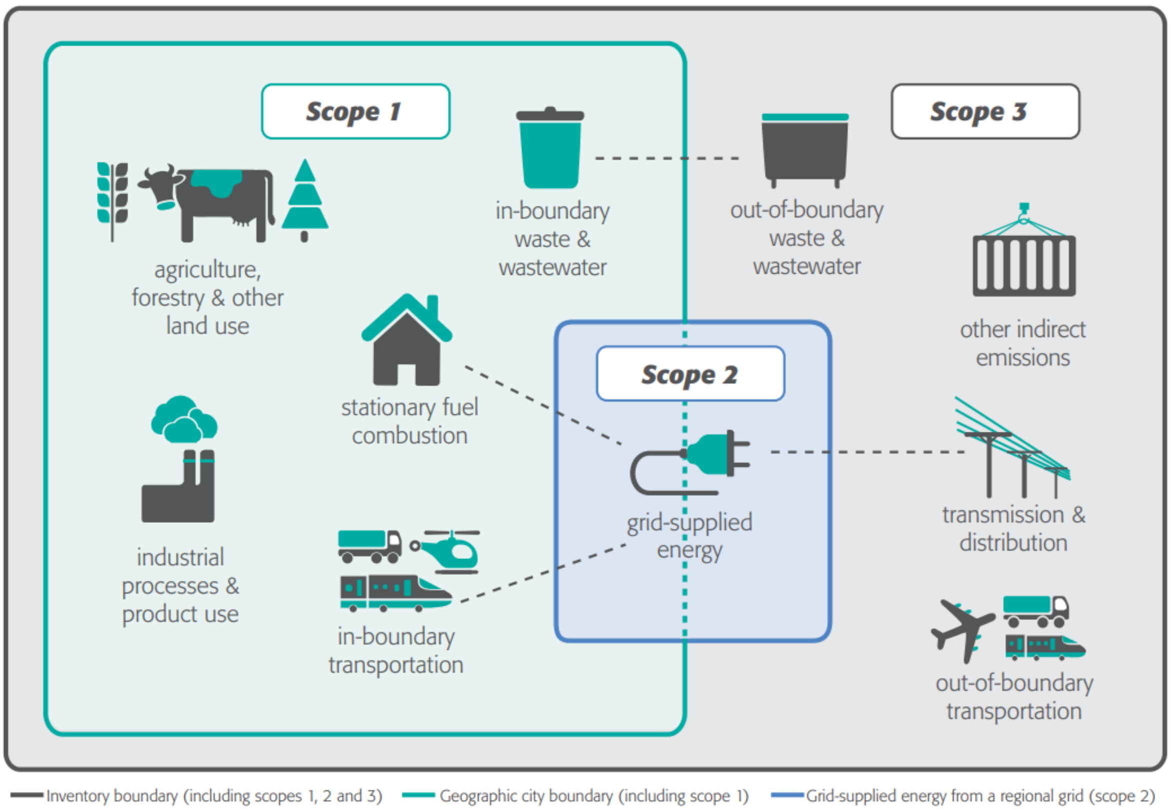
GHG Emissions Sectors and Sources

GHG emissions associated with city activities can result from sources within the city boundaries as well as outside the city boundaries. To distinguish these emissions, the GPC categorizes them as either Scope 1, Scope 2, or Scope 3.

- Scope 1: GHG emissions from sources located within the geographical limits of the city.
- Scope 2: GHG emissions associated with the use of grid-supplied electricity, heat, steam, and/or cooling within the geographical limits of the city.
- Scope 3: GHG emissions occurring outside of the geographical limits of the city as a result of activities taking place within the city (e.g., on-road personal vehicle transportation with an origin outside of the city boundary to a place of employment within the city boundary).

Figure 1-1 shows which sources are associated with each of the scopes.

Figure 1-1: Sources and Boundaries of City GHG Emissions



Source: Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC)

The GPC requires that cities report their emissions using two distinct but complementary approaches – according to the Scopes framework and the City-induced framework. The Scopes framework totals emissions by scope, as described above, while the City-induced framework covers select Scope emissions sources using two reporting levels: BASIC and BASIC+. The BASIC level includes Scopes 1 and 2 emissions from stationary energy and transportation, as well as Scopes 1 and 3 emissions associated with the generation of waste and wastewater within the city boundaries. The BASIC+ level has a more comprehensive coverage of emissions sources, including transboundary transportation, energy transmission and distribution losses, industrial processes and product use, and agriculture. According to the GPC, where these sources are significant and relevant for a city, the city should aim to report according to BASIC+. However, BASIC+ involves more challenging methods and calculations, and should only be used when adequate data is available. As data and data collection processes evolve, the City of Cambridge will continue to evaluate the feasibility of reporting GHG emissions using the BASIC+ level. Measuring additional Scope 3 emissions, although not directly attributable to the City from a reporting standpoint, would allow the City to take a more holistic approach to tackling climate change by assessing the GHG impact of supply chains, and identifying areas of shared responsibility for upstream and downstream GHG emissions.

Similar to the 2012 Community-wide GHG Emissions Inventory, the 2019 update accounts for Scopes 1 and 2, as well as select Scope 3 emissions from the following sectors and sub-sectors, as required by the GPC BASIC framework.

› Buildings and Energy Production[2] (Scopes 1, 2, and 3)
  - Residential buildings
  - Commercial and institutional buildings and facilities
  - Manufacturing industries and construction
  - Energy production facilities[3]
  - Fugitive emissions from oil and natural gas systems
› Transportation (Scopes 1, 2, and 3)
  - On-road vehicles
  - Railways
  - Off-road vehicles/equipment
› Waste (Scope 3)
  - Disposal of solid waste generated in the city
  - Biological treatment of waste generated in the city
  - Incineration and open burning of waste generated in the city
  - Wastewater generated in the city

Also similar to the 2012 community-wide inventory, the 2019 inventory does not include GHG emissions from the following sub-sectors that are required by the GPC BASIC framework due to limited data or limited activity data occurring within the City's boundaries.

› Other Stationary Energy
  - Agriculture, forestry, and fishing activities
  - Non-specified sources
  - Fugitive emissions from mining, processing, storage, and transportation of coal
› Transportation

[2] The term "Buildings and Energy Production" is used interchangeably with "Stationary Energy" throughout this report and in associated 2019 Community-wide Greenhouse Gas Inventory materials. Stationary Energy was used in the 2012 inventory and is the terminology used by the GPC.

[3] The term "Energy Production Facilities" is used interchangeably with "Energy Industries" throughout this report and in associated 2019 Community-wide Greenhouse Gas Inventory materials.

- Waterborne navigation
- Aviation
- Off-road vehicles

Further, this 2019 inventory does not report on sectors required by the GPC BASIC+ framework, such as Industrial Processes and Product Use and Agriculture, Forestry, and Land Use, due to difficulty in collecting the required data.

Table 1-1 summarizes the sectors, emissions sources, and energy types included in Cambridge's 2019 Community-wide GHG Emissions Inventory, while **Table 1-2** provides a summary of the sectors and fuel types by reporting framework.

Table 1-1: Sectors and Sources in the 2019 Community-wide GHG Emissions Inventory

Sector	Sub-Sector	Emissions Sources	Energy Types
Buildings and Energy Production (i.e., Stationary Energy)	Residential	Energy use in residential buildings as well as losses from electricity distribution systems	Electricity Natural gas Petroleum products
	Commercial, government, and institutional buildings and facilities	Energy use in commercial, government, and institutional buildings as well as losses from electricity distribution systems	
	Manufacturing Industries and Construction	Energy use in industrial facilities and processes, as well as losses from electricity distribution systems	
	Energy Production Facilities (i.e., Energy Industries)	Stationary combustion of fuel in various equipment, such as boilers and generators.	Various – may include natural gas, propane, and diesel
	Fugitive emissions from oil and natural gas systems	GHG emissions associated with the delivery of natural gas, such as equipment leaks, evaporation and flashing losses, venting, flaring, incineration, and accidental releases.	Natural gas
Transportation	On-road	Mobile combustion of fuels in on-road vehicles, such as passenger cars and light trucks	Gasoline Diesel Electricity
	Railways	Mobile combustion of fuels in commuter and light rail	
Waste	Solid Waste	Disposal of solid waste at landfills Biological treatment of waste Incineration and open burning of waste	Landfill gas (methane) Biogas (methane)
	Wastewater	Process and fugitive emissions from treating wastewater	Not applicable

Table 1-2: Sectors and Sub-sectors included in the Community-wide GHG Emissions Inventory by City-Induced Framework Reporting Requirements

Sector	Sub-Sector	Scope 1	Scope 2	Scope 3
Buildings and Energy Production (i.e., Stationary Energy)	Residential – Natural Gas / Fuel Oil Use	X		
	Residential – Electricity Use		X	
	Commercial – Natural Gas / Fuel Oil Use	X		
	Commercial – Electricity Use		X	
	Manufacturing and Construction – Fuel Use (including vehicles)	X		
	Manufacturing and Construction – Electricity Use		X	
	Energy Production Facilities (i.e., Energy Industries)	X		
	Electricity Distribution System Losses			X
	Fugitive emissions from oil and natural gas systems	X		
Transportation	Vehicle Travel On-road (Fuel Use)	X		
	Vehicle Travel On-road (Electricity Use)		X	
	Public Transit (Fuel Use)	X		
	Public Transit (Electricity Use)		X	
	Electricity Distribution System Losses			X
Waste	Solid Waste – Landfill Disposal			X
	Solid Waste – Biological Treatment			X
	Solid Waste – Incineration			X
	Wastewater Treatment			X

X = included in inventory

= Sources required for BASIC reporting alone

= Sources required for BASIC+ reporting alone*

= Sources included in Other Scope 3

* BASIC+ reporting also includes sources required for BASIC reporting

Inventory Boundary

The GPC requires that cities identify a geographic area for the inventory that most appropriately serves the purpose of the inventory. Consistent with the 2012 GHG emissions inventory, the 2019 inventory utilizes the administrative boundary of the City of Cambridge as the boundary for the community-wide inventory. As outlined in the GPC, establishing this geographic boundary does not exclude emissions related to city activities that occur outside the city limits (e.g., electricity generation or landfilled waste emissions).

Inventory Year

Limited community-wide inventories were completed in 1990, 1998, and 2010. In 2017, the calendar year 2012 was chosen as the baseline year for the community-wide inventory, using improved data sources and methodology.

Calendar year 2019 was chosen as the reporting year for this community-wide inventory update. The selection of this year was based on the availability of data, determined through discussions with organizations that manage much of the data needed for the analysis. CY2020 was considered, though it was determined to not be a viable option as the COVID-19 pandemic disrupted normal activities within the City and would not provide an accurate estimate of the City's progress in reducing community-based emissions.

Inventories for the Buildings and Energy Production and Transportation sectors were completed in 2021, while the Waste sector inventory was completed in 2022. Since all three inventories account for 2019 emissions, this report combines the methodologies and results of each sector into one document to provide a comprehensive analysis of 2019 GHG emissions.

Quantifying Greenhouse Gas Emissions

All GHG emissions sources in the 2019 GHG emissions inventory are quantified using formula-based methodologies, which calculate emissions using activity data from each reporting sector identified in the GPC and emission factors. The basic equation is:

Activity Data (unit) x Emission Factor ($MTCO_2e$ / unit) = Emissions ($MTCO_2e$).

The exact equation may vary due to the activity data and emissions factors available for the activity. Activity data refer to the relevant measurement of energy use or other GHG emissions-generating processes, such as fuel consumption by fuel type, metered annual electricity consumption, annual vehicle miles traveled (VMT), and tons of waste generated.

Known emission factors are used to convert energy usage or other activity data into quantities of emissions generated by the activity. Emissions factors are usually expressed in terms of emissions per unit of activity data (e.g., metric tons of CO_2 per kWh of electricity). There are seven GHGs of concern according to the GPC – carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF6), and nitrogen trifluoride (NF3); however, the 2019 inventory only reports on CO_2, CH_4, and N_2O.

Due to their scale, emissions are reported using the unit of metric tons of carbon dioxide equivalent (MT CO_2e). The base unit CO_2e is used to compare the atmospheric impact of different GHGs. Global warming potential (GWP) values are used to convert GHGs – CH_4 and N_2O in the case of the 2019 inventory – to amounts of CO_2 that have a comparable impact. This is because CH_4 and N_2O are emitted in smaller amounts than CO_2, but have a much larger greenhouse effect on the atmosphere per unit emitted. To achieve the equivalency, the calculated emission of each gas is multiplied by the GWP values for each gas. The GWP values applied in the 2019 inventory were sourced from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, 2014 (AR5): 1 (CO_2), 28 (CH_4), and 265 (N_2O).

2

Buildings and Energy Production

Emissions associated with the Buildings and Energy Production sector result from the use of electricity, natural gas, fuel oil, and other energy sources within the City's boundaries. Most of this energy use occurs in residential buildings, commercial and institutional buildings, manufacturing industries, and construction. In the City of Cambridge, the energy production facilities, specifically three privately owned cogeneration plants, account for about 15 percent of stationary emissions.

Data Sources

Electricity and natural gas consumption were provided by Eversource, the municipal supplier for the City of Cambridge, while fuel oil consumption is estimated based on a proportional abstraction of regional data to reflect the inventory boundary. Residential fuel oil usage data was based on the number of housing units in Cambridge by type, and a percentage of units determined to be heated with fuel oil from the *2015-2019 American Community Survey 5-Year Estimates*. For the commercial buildings sector, fuel oil use estimates were based on the total number of employees, establishments by Primary Building Activity (PBA), and the average expected energy use per employee for each PBA.

Electricity

Grid-supplied electricity is provided throughout the City and powers the residential, commercial, and industrial building sectors, in addition to City infrastructure and transport systems. The City of Cambridge has a single electricity provider, Eversource, to transmit and distribute electricity. As such, Eversource was the primary source for gathering electricity consumption data in the City. Real consumption data was used to determine the electricity consumption (kWh/year) from each building sector.

When coordinating with Eversource to acquire the sector level consumption data for future inventories, Special Ledger Accounts are also reviewed. These Special Ledge Accounts are maintained separately from the general population account data and are associated with customers who require that their account information be kept private. These types of accounts exist for both electricity and natural gas customers.

Natural Gas

As previously noted, Eversource maintains a list of Special Ledger Accounts for both electricity and natural gas customers. Special Ledger Accounts were included. In addition, data was used from the U.S. Environmental Protection Agency's (U.S. EPA) Large Facilities Database to determine emissions associated with co-generation facilities within the City of Cambridge.

Building Sector

Grid-supplied natural gas is provided throughout Cambridge and is primarily used by the residential, commercial, and industrial sectors for heat and hot water production. As previously noted, Eversource was the primary source of data for natural gas consumption in the City. Metered data was used as the source of the annual consumption for each building sector.

In addition to the building sector natural gas usage, the GPC also requires the losses from distribution systems be accounted for. This ensures that the methane leaked into the atmosphere during natural gas transport is considered as a contribution to overall natural gas emissions (note: methane has a global warming potential that is approximately 28x higher than carbon dioxide). Based on an assessment of several studies that have been done on the subject of gas leakage from the distribution system network in and around the Boston area, it was determined that an average leakage rate of 0.6 percent[4] was appropriate for the inventory.

Co-Generation Systems

There are four large electricity and steam generation facilities located in the City of Cambridge that were assessed as part of this inventory: The Kendall Co-Generation Station, the Massachusetts Institute of Technology (MIT) Central Utilities Plant, the Harvard University Blackstone Plant, and the Biogen IDEC plant.

Consumption and emissions data for these facilities were gathered from publicly available reports provided on the U.S. EPA's Greenhouse Gas Reporting Program tool, FLIGHT.[5] These facilities are required to report biogenic CO_2 emissions and CO_2 emissions excluding biogenic CO_2 separately.

The Kendall Co-Generation Station is a 256 MW steam and electricity energy plant. The primary gas turbine produces electricity and high-pressure steam. This steam is recycled to power secondary steam turbines to generate additional power. For this emissions inventory, emissions from the Kendall Co-Generation Station are excluded because the emissions from energy generators greater than 25 MW in capacity are included in the ISO New England emissions factors for electricity. Energy generation supplied to the grid is not included in BASIC or BASIC+ reporting.

4 McKain, K., Down, A., Raciti, S.M., Budney, J., Hutyra, L.R., Floerchinger, C., Herndon, S.C., Nehrkorn, T., Zahniser, M.S., Jackson, R.B., Phillips, N., Wofsy, S.C. (January 23, 2015). Methane emissions from natural gas infrastructure and use in the urban region of Boston, Massachusetts. *Proceedings of the National Academy of Sciences (PNAS)*. https://doi.org/10.1073/pnas.1416261112

5 U.S. EPA. FLIGHT Tool: 2020 Greenhouse Gas Emissions from Large Facilities. Available at https://ghgdata.epa.gov/ghgp/main.do#

Harvard University manages the Blackstone Steam Plant. This plant uses four dual-fuel boilers operating primarily on natural gas. They have a service area covering a substantial portion of Harvard's campuses extending from Harvard Yard, the Law School and Divinity School in the North campus, along the River Houses, across the river to the Harvard Kennedy School, and Athletics and One Western Avenue in Allston. The boilers generate up to 5.7 MW of electricity through the back-pressure turbine system. While steam is used on properties in Boston, the CHP plant is located within Cambridge's boundaries, and therefore has been wholly included in this inventory. A CHP unit was added to the Blackstone plant in 2013 with an 8 MW turbine generator; the CHP unit is included in the inventory data for years 2015-2019.

MIT's Central Utilities Plant is a 21 MW natural gas turbine used to produce both electric and thermal energy for the campus. The heat recovery steam generator captures waste heat from turbine exhaust, and the captured steam is used for heating and cooling (via chillers driven by steam turbines). Emissions from this plant that were reported to the U.S. EPA were included for the years 2012-2019.

The BioGen IDEC facility is a 5.3 MW natural gas turbine with a heat recovery steam generator (HRSG). This system operates in parallel with the electric utility. Emissions from this plant that were reported to the U.S. EPA were also included for the years 2012-2019.

Fuel Oil

While electricity and natural gas heating are limited to specific municipal suppliers, fuel oil is supplied by many different private companies. Because customer data cannot be collected from each supplier, consumption must be estimated using community-specific assumptions. Any limited fuel oil usage by the Kendall Co-Generation Station, Blackstone Steam Plant, and MIT CUP is accounted for in the U.S. EPA Greenhouse Gas Reporting Systems reports.

For the 2019 Community-wide GHG Emission Inventory, residential oil usage data was based on the number of housing units in Cambridge by type, and a percentage of units determined to be heated with fuel oil from the *2015-2019 American Community Survey 5-Year Estimates*. The property types identified were:

- Single-Family, Detached
- Single-Family, Attached
- Multi-Family, 2-4 Units (Sum of 2-Family and 3-4 Units categories)
- Multi-Family, 5+ Units (Sum of 5-19 Units, 20-49 Units, and 50+ Units categories)
- Other

Residential fuel oil combustion emissions were totaled using state average use and expenditure by fuel type and applied to Cambridge housing data. Massachusetts has a lower concentration of single-family homes and a higher concentration of two- to four-unit apartments. To account for this when comparing an average Massachusetts home with an average New England home (averaged across all housing units), a weighted New England Average Consumption based on the percentage breakdown of housing unit types in Massachusetts was used.

For the commercial buildings sector, fuel oil use estimates were based on the total number of employees, establishments by Primary Building Activity (PBA), and the average expected energy use per employee for each PBA. The Executive Office of Labor and Workforce Development (EOWLD) ES-292 Employment and Wages Survey lists the number of employees and establishments by industry, sorted by North American Industry Classification System (NAICS) codes.[6] The U.S. Energy Information Administration (EIA) 2012 Commercial building Energy Survey (CBECS) analyzes energy use and consumption data based on PBA.

Table 2-1 roughly correlates the PBA codes used in CBECS with standard three-digit NAICS codes between 400 and 1000.

Table 2-1: NAICS Code Crosswalk Table for Identifying Primary Building Activity

PBA	NAICS Code (3-digit)
Education	611
Food Sales	445
Food Service	722
Inpatient Health Care	622
Outpatient Health Care	621
Lodging	623, 721
Retail (non-mall)	441, 442, 443, 444, 451, 452, 453, 532
Retail (mall)	446, 448
Office	454, 486, 511, 516, 517, 518, 519, 521, 522, 523, 524, 525, 561, 624, 921, 923, 924, 925, 926, 928
Public Assembly	481, 482, 485, 487, 512, 515, 711, 712, 713
Public Order/Safety	922
Religious Worship	813
Service	447, 483, 484, 488, 491, 492, 811, 812
Warehouse/Service	423, 424, 493
Other	562, 927

Certain data required alternate collection methods due to a lack of direct employee data. PBA's with incomplete data used one of two options for estimating the missing data for the purposes of this baseline:

- Option 1: Compare average fuel oil use to average natural gas use in the same building types, using Office buildings as a baseline. For example, if a PBA that uses natural gas uses 50 percent more natural gas than an Office building, assume that if the same PBA used fuel oil, it would use 50 percent more fuel oil than an Office building. This is the preferred method, as it yields a more conservative estimate.
- Option 2: Find average fuel oil consumption for an average New England building (across all PBAs) and divide.

For the industrial buildings sector, data was collected similarly to commercial data, using the total number of employees and establishments by PBA, and the average expected energy use per employee for each PBA. Executive Office of Labor and Workforce Development (EOWLD) ES-202 Survey lists the number of employees and establishments by industry, sorted by NAICS codes.[3] This

6 Executive Office of Labor and Workforce Development. EOWLD ES-292 Employment and Wages Survey. Retrieved from http://lmi2.detma.org/lmi/lmi_es_a.asp

sector encompasses NAICS codes between 311 and 339 as shown in **Table 2-2**. Industrial energy uses between 100 and 200 (such as power generation and utility operations) were not incorporated in this methodology. The EIA 2012 Manufacturing Energy Consumption Survey (MECS) analyzes energy use and consumption data based on PBA.

Table 2-2: Industrial NAICS Codes

NAICS_3	Industry	NAICS_3	Industry
311	Food	326	Plastics and Rubber Products
312	Beverage and Tobacco Products	327	Nonmetallic Mineral Products
313	Textile Mills	331	Primary Metals
314	Textile Product Mills	332	Fabricated Metal Products
315	Apparel	333	Machinery
316	Leather and Allied Products	334	Computer and Electronic Products
321	Wood Products	335	Electrical Equipment, Appliances, and Components
322	Paper	336	Transportation Equipment
323	Printing and Related Support	337	Furniture and Related Products
324	Petroleum and Coal Products	339	Miscellaneous
325	Chemicals		

As previously mentioned, fuel oil consumption from the Kendall Co-Generation Station, Blackstone Steam Plant, and MIT CUP are reported directly from the EPA Greenhouse Gas Reporting Program submittals and therefore were not estimated here.

Estimating Greenhouse Gas Emissions

The methodology specified by the GPC is what was used for the Building Stock Inventory completed as part of the 2021 City of Cambridge Net Zero Action Plan (NZAP) and is further described below.

Electricity

Electricity generation in Massachusetts is made up of a mix of natural gas, nuclear, coal, hydroelectric, and other renewable generators, and accounts for over 20 percent of Massachusetts's total GHG emissions. Much of the electricity used in the Commonwealth is imported from power plants located in other states and in Canada. At the city level, electricity consumption is primarily considered a Scope 2 emissions source.

In accordance with Section 6.5 of the GPC, the location-based method was used to estimate electricity emissions for this inventory. Reported emissions from all grid-supplied electricity consumed within the City's boundaries were reported as Scope 2 emissions. BASIC/BASIC+ reporting avoids double counting by excluding Scope 1 emissions from electricity generation supplied to the grid.

The grid-based average emission factor is necessary due to the imprecise available supply balance of electricity generated and consumed within the City boundaries. The emissions factor used for grid supplied electricity is provided in **Table 2-3** and is based on data from ISO New England.[7] In addition, CH_4 emissions as well as N_2O emissions from grid supplied energy also need to be considered to determine the total CO_2e emissions factor. The CH_4 and N_2O emissions rates were gathered from the U.S. Environmental Protection Agency's eGRID data.

Table 2-3: ISO New England Electricity System Emissions Rates Used for Inventory

Year	CO_2 Emission Factor (lbs. CO_2 / MWh)	CO_2 Emission Factor (MT CO_2 / kWh)
2012	719	0.000326
2013	730	0.000331
2014	726	0.000329
2015	747	0.000339
2016	710	0.000322
2017	682	0.000309
2018	658	0.000298
2019	658	0.000298

Natural Gas

The primary uses for natural gas in the City of Cambridge are for space heating, water heating equipment, and co-generation stations. The emissions from the co-generation units are attributed to fuel burned for heat, steam and electricity generation. The emissions from these sources are defined as Scope 1 emissions. The approaches to estimating the emissions from natural gas consumption in the buildings sectors and by the co-generation plants are summarized separately below because of the different approaches used for each.

Buildings Sector

In accordance with Section 6.3 of the GPC, real consumption data for each fuel type, disaggregated by sector, was used for the inventory. Reported emissions from the usage of natural gas within the City's boundaries were reported as Scope 1 emissions. Because Eversource-specific emission factors for natural gas emissions were not available, a universal emission factor provided by the Climate Registry[8] was used to calculate natural gas emissions. The emissions factor used for natural gas consumption is provided in **Table 2-4**.

Table 2-4: Natural Gas Consumption Emission Rates

Type of Emission	CO_2 Emission Factor (kg CO_2 / MMBtu)	CO_2 Emission Factor (MT CO_2 / Therm)
Natural Gas Consumption	53.06	0.0053

Note: CH_4 and N_2O are not included because these emissions are considered to be de minimis.

7 ISO New England. 2012 ISO New England Electric Generator Air Emissions Report. Retrieved from www.iso-ne.com/static-assets/documents/genrtion_resrcs/reports/emission/2012_emissions_report_final_v2.pdf

8 The Climate Registry (April 2015). 2015 Climate Registry Default Emissions Factors.

In addition, CH_4 emissions associated with distribution systems leakage also need to be considered in the inventory. The total CO_2e emissions factor for fugitive emissions from natural gas leakage was determined based on:

- Volume of natural gas per heat energy (m^3 gas / therm gas)
- A density value of natural gas of 0.7 kg/m^3 based on values provided in the GHG Protocol stationary combustion tool.
- The IPCC Tier 1 default for the mass fraction of methane in delivered natural gas (93.4 percent).
- A carbon dioxide content of 1.0 percent in the delivered natural gas.

The overall emissions factor was then calculated to be 0.04628 MT CO_2e/leaked therm.

Co-Generation Systems

In accordance with Section 6.3 of the GPC, the community-wide inventory for the City of Cambridge used the real consumption data, disaggregated by sub-sector approach. The emissions associated with these facilities are taken directly from U.S. EPA reports that are submitted by large facilities and use standard emissions calculation methodologies. Facilities generally have some flexibility in choosing which calculation method to use and their methods may change from year to year as long as they still meet the requirements of the U.S. EPA's Greenhouse Gas Reporting Program.

Fuel Oil

In accordance with Section 6.3 of the GPC, the emissions from stationary energy sources are calculated by multiplying activity data by the corresponding emission factors for each fuel. Estimated energy consumption by fuel type, applicable consumption rates, and the total quantity of energy consumption overall are used to obtain a percentage that can be used to approximate how much of each fuel type is used by each sector in the community.

As detailed above, a collection of representative consumption surveys, modeled energy consumption, and regional fuel consumption data was used to properly characterize the City of Cambridge emissions. Being that there is likely a higher number of employees per square foot in Cambridge than industry averages, oil consumption emissions are likely overestimated in this inventory.

Buildings and Energy Production Emissions

It is estimated that the City of Cambridge emitted 1,167,913 MT CO_2e of buildings and energy production emissions in 2019. Buildings and energy production emissions are generated through the consumption of fuel and electricity in residential and commercial buildings, manufacturing industries, and the energy industry within the City's boundaries. At 45 percent, commercial and institutional buildings generated the greatest share of GHG emissions within the Buildings and Energy Production sector, followed by residential buildings at 25 percent. Together, these buildings comprise 70 percent of buildings and energy production emissions. This is primarily due to Cambridge's high density of education, research, and commercial activity. Energy production facilities, which account for 15 percent of emissions in the Buildings and Energy Production sector, include power plants that provide energy to commercial and institutional buildings in Cambridge. Manufacturing industries and construction, which include industrial and energy services, are responsible for the remaining 15 percent of buildings and energy production emissions. **Table 2-5** provides a breakdown of the City's 2019 buildings and energy production emissions by sub-sector.

Table 2-5: Cambridge 2019 Buildings and Energy Production Emissions, by Subsector

Sub-sector	2019 Emissions (MT CO_2e)	Percent of Total
Residential Buildings	288,407	24.7%
Commercial & Institutional Buildings and Facilities	528,953	45.3%
Manufacturing Industries & Construction	170,870	14.6%
Energy Industry	179,682	15.4%
Total Buildings and Energy Production Emissions	**1,167,913**	**100%**

As mentioned above, there are four large electricity and steam generation facilities located in the City of Cambridge that were assessed as part of this inventory: The Kendall Co-Generation Station, the Massachusetts Institute of Technology (MIT) Central Utilities Plant, the Harvard University Blackstone Plant, and the Biogen IDEC plant. Consumption and emissions data for these facilities were gathered from publicly available reports provided on the U.S. EPA's Greenhouse Gas Reporting Program tool, FLIGHT. These facilities are required to report biogenic CO_2 emissions and CO_2 emissions excluding biogenic CO_2 separately. The emissions emitted by each of these facilities is presented in **Table 2-6.** The MIT Central Utility Plant represents the largest share of emissions from the energy industry that are attributed to Cambridge, followed closely by the Harvard University Blackstone Plant. Although located in Cambridge, the Kendall Co-Generation Station was ultimately excluded from this inventory, as well as prior inventories, because it is included as part of ISO New England's emission factors for electricity due to its size.

Table 2-6: Emissions from Energy Generation Supplied to Grid Included in Inventory

Plant Name	Plant Address	Non-Biogenic Emissions (MT CO2e)
Biogen IDEC Plant	225 Binney St	288,407
Cambridge Allston Blackstone (Harvard)	46 Blackstone St	528,953
MIT Central Utility Plant	59 Vassar St	170,870
2019 Energy Industry Emissions		**179,682**

The sub-sectors listed in **Table 2-5** generate emissions through the consumption of fuel and electricity, as well as transmission and distribution losses associated with the transport of electricity and natural gas through power lines and pipes. Stationary emissions by source (i.e., fuel type) are presented in **Table 2-7.**

Table 2-7: Cambridge 2019 Buildings and Energy Production Emissions, by Source

Scope	Source	2019 Emissions (MT CO_2e)	Percent of Total
1	Natural Gas	387,596	33.2%
	Natural Gas Distribution Losses	22,858	2.0%
	Fuel Oil	31,886	2.7%
	Energy Industries (Multiple Fuels)	179,682	15.4%
2	Electricity	496,436	42.5%
3	Electricity T&D Losses	49,454	4.2%
Total Buildings and Energy Production Emissions		**1,167,913**	**100%**

Scope 1 sources, including natural gas, natural gas distribution losses, fuel oil, and energy industries (multiple fuels) accounted for 53 percent of emissions in the Buildings and Energy Production sector in 2019. Scope 2 emissions from purchased electricity accounted for 43 percent of buildings and energy production emissions. Scope 3 emissions, which for the purposes of this inventory are only comprised of electricity transmission and distribution losses, accounted for 4 percent of buildings and energy production emissions. Focusing on specific fuel types, natural gas and electricity are responsible for the greatest share of buildings and energy production emissions, at 33.2 percent and 42.5 percent, respectively.

2012 Emissions Inventory Comparison

It is estimated that Buildings and Energy Production sector emissions increased 11 percent between 2012 to 2019, from 1,048,969 MT CO_2e to 1,167,913 MT CO_2e. This is likely due to increased growth in the City of Cambridge, including the construction of commercial, institutional, and residential buildings, especially energy-intensive research facilities. Detailed comparisons can be found in **Table 2-8**.

Table 2-8: Comparison of Cambridge Buildings and Energy Production Emissions 2012-2019

Subsector	2012 Emissions (MT CO_2e)	2019 Emissions (MT CO_2e)	Percent Change
Residential Buildings	264,858	288,407	8.9%
Commercial & Institutional Buildings and Facilities	410,178	528,953	29.0%
Manufacturing Industries & Construction	179,026	170,870	-4.6%
Energy Industry	194,907	179,682	-7.8%
Total Buildings and Energy Production Emissions	**1,048,969**	**1,167,913**	**11.3%**

Cambridge's manufacturing industries and energy generation plants both saw a decrease in emissions from 2012 to 2019, while residential, and commercial and institutional buildings saw an increase in emissions. The largest change occurred in the Commercial and Institutional Buildings and Facilities subsector, where GHG emissions grew 29 percent, from 410,178 MT CO_2e to 528,953 MT CO_2e. One factor influencing this increase is the robust growth the City has experienced in the life sciences and technology industries since the previous inventory.

3

Transportation

Transportation emissions are a combination of on-road vehicle activity and rail travel. On-road vehicle activity includes both personal and commercial vehicles registered to the City of Cambridge, as well as public transportation service that occurs on roadways within the geographic boundary previously described, such as buses. Rail travel incorporates the portion of public transportation that occurs within the city boundary but off roadways, which in the case of Cambridge is the Fitchburg Line (commuter heavy rail), Red Line (subway heavy rail), and Green Line E Branch (light rail).

Data Sources

Emissions from on-road personal and commercial vehicles are estimated using both fuel sales data from the Commonwealth of Massachusetts, as well as information from the Massachusetts Registry of Motor Vehicles (RMV). These data sources were combined with fuel efficiencies projected from the National Highway Transportation Safety Administration's (NHTSA) Corporate Average Fuel Economy (CAFE) standards to determine the emissions from on-road personal and commercial vehicles.

Emissions from public transportation, both on-road and rail, were estimated using service information available through Massachusetts Bay Transportation Authority (MBTA) online archives. A variety of modes make up the public transportation operating within the City of Cambridge, including buses, trackless trolleys, subway heavy rail, light rail, and commuter heavy rail. The buses use a mix of bio-diesel and compressed natural gas (CNG). It is important to note that in 2012, buses also used diesel as a source of fuel, which has since been phased out and replaced with bio-diesel which is generally considered to have zero emissions depending on the production method; it is considered to be carbon neutral for the purposes of this inventory.[9] The trackless trolleys, subway heavy rail, and light rail use electricity. The commuter heavy rail uses diesel as its sole fuel source.

Table 3-1 provides these data sources along with their associated uses in the hopes of expediting future inventories. Data sources are also stated in the accompanying Emissions Inventory Tool (provided as an Excel workbook).

Table 3-1: 2019 Community-wide GHG Emissions Inventory Data Sources

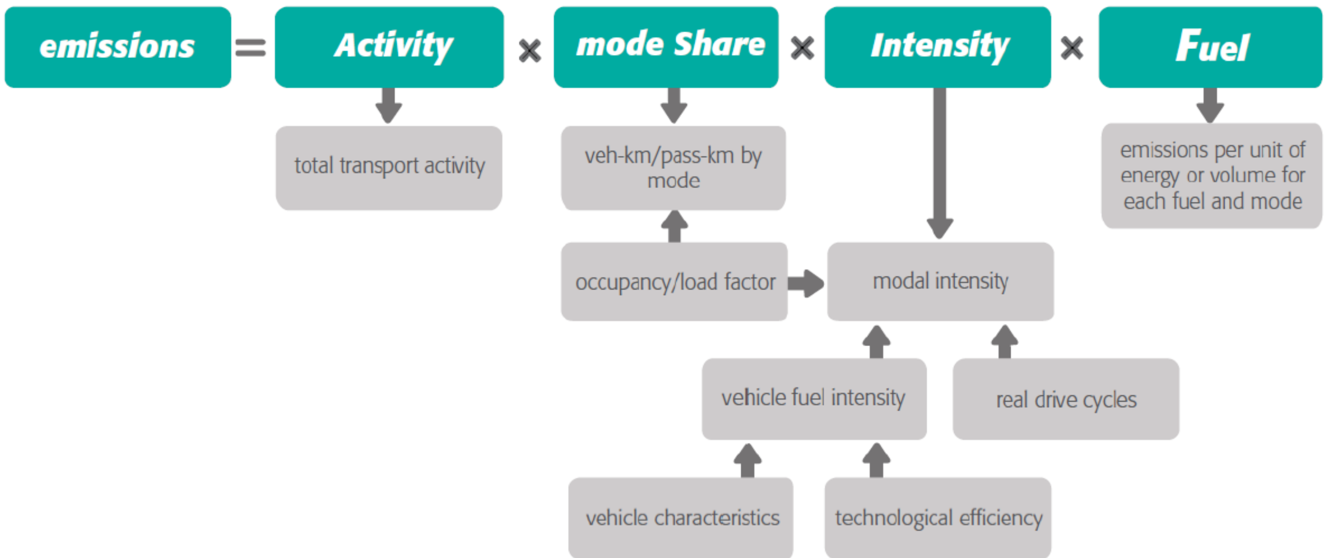
Data Source	Data Type	Provided By	Data Use
2018 raw EVSE Use Data.xlsx	Spreadsheet	City of Cambridge	EV Charging Analysis
Cambridge Emissions Inventory Tool 2017 (2012 Inventory)	Spreadsheet	City of Cambridge	VMT by fuel type Fuel Efficiencies Rail System Track Length
MBTA Routes	Shapefile	Available Online	GIS Analysis of Bus Routes
Cambridge City Boundary	Shapefile	Available Online	GIS Analysis of Bus Routes
2019 MBTA GTFS Data	GTFS Zip File	MBTA GTFS Archives	GIS Analysis of Bus Routes
2019 Fuel and Energy	Spreadsheet	National Transit Database (NTD)	Fuel Consumption Rail System and Bus Route Lengths
Cambridge RMV Registrations 1996-2020	Spreadsheet	City of Cambridge	Resident Activity
FHWA 2019 Fuel Taxed	Spreadsheet	FHWA	Fuel Sales
Alternative Fuel Stations	Spreadsheet	US DOE	EV Charging Analysis
CAFE Targets	Equation	Code of Federal Regulations	Fuel Efficiency Improvements
Monthly Transportation Statistics	Spreadsheet	US DOT	EV Analysis
Land Area	Spreadsheet	US Census	Scaling Factors
Population	Spreadsheet	US Census	Scaling Factors
2019 Air Emissions	Spreadsheet	ISO NE	GHG Emissions from Electricity Generation

Estimating Greenhouse Gas Emissions

The process for estimating GHG emissions is laid out in the GPC and follows the ASIF framework. ASIF is a four-part calculation, with each letter representing one input to the calculation: **A**ctivity, mode **S**hare, **I**ntensity, and **F**uel. Data on transportation activity, VMT, fuel efficiency, and emission actors are all variables of the inputs. **Figure 3-1** shows the ASIF framework in detail.

9 U.S. EIA (April 2022). Biofuels and the environment. Retrieved from https://www.eia.gov/energyexplained/biofuels/biofuels-and-the-environment.php

Figure 3-1: ASIF Framework



Source: GPC

To further demonstrate the ASIF framework, emissions from private gasoline powered transportation will be used as an example. The activity would include all private vehicle transportation, in this case VMT for all fuel types.

$$Activity = Total\ VMT\ for\ all\ private\ vehicle\ fuel\ types$$

The mode share is the percentage of total VMT represented by private gasoline powered vehicles, which when multiplied by the activity leaves just the VMT traveled by private gasoline powered vehicles.

$$Mode\ Share = \%\ of\ all\ private\ vehicle\ fuel\ types\ that\ are\ gasoline\ powered$$

$$Activity \times Mode\ share = Mode\ specific\ VMT$$

The intensity input is fuel efficiency, or miles per gallon. And the fuel input uses emission factors, provided by various independent sources, to calculate MT CO_2e per gallon.

$$Intensity = Fuel\ efficiency\ (gallons/mile)$$

$$Fuel = Emissions\ factors\ (MT\ CO_2e/gal)$$

When multiplied together, the output is total MT CO_2e emitted from private gasoline powered vehicles.

$$Mode\ specific\ VMT \times Intensity \times Fuel = miles \times (gallons\ /\ mile) \times (MTCO_2e\ /\ gallon) = MT\ CO_2e$$

$$Emissions = MT\ CO2e$$

The same approach is followed for all modes of transportation, using their specific vehicle miles, route miles, and fuel efficiencies to determine their emissions. While each mode has unique values for activity, mode share, and intensity, the emission factors used for the fuel input of ASIF are consistent and are provided by independent research or government entities. **Table 3-2** shows the amount of CH_4, CO_2, and N_2O produced for various fuel types as well as the sources for the emissions factors.

Table 3-2: Transportation Fuel Emission Factors

Fuel Type	Unit	MT CH_4/Unit	MT CO_2/Unit	MT N_2O/Unit	Source
Diesel	Gallon	0.0000005	0.010206	0.0000004	The Climate Registry[10]
Bio-Diesel	Gallon	0.0000000	0.000000	0.0000000	US EIA[11]
Gasoline	Gallon	0.0000004	0.008775	0.0000006	The Climate Registry
CNG	MMBTU	-	0.052941	-	The Climate Registry

To report emissions in terms of MT CO_2e, conversion factors were used to determine the amount of CO_2 that would have an equivalent atmospheric effect to one unit of CH_4 and N_2O. **Table 3-3** shows the IPCC conversion factors used in this inventory.

Table 3-3: IPCC AR5 100-Year Global Warming Potentials

GHG Type	Unit	MT CO_2/MT GHG Type	Source
Methane (CH_4)	MT CH_4	28	IPCC AR5
Nitrous Oxide (N_2O)	MT N_2O	265	IPCC AR5

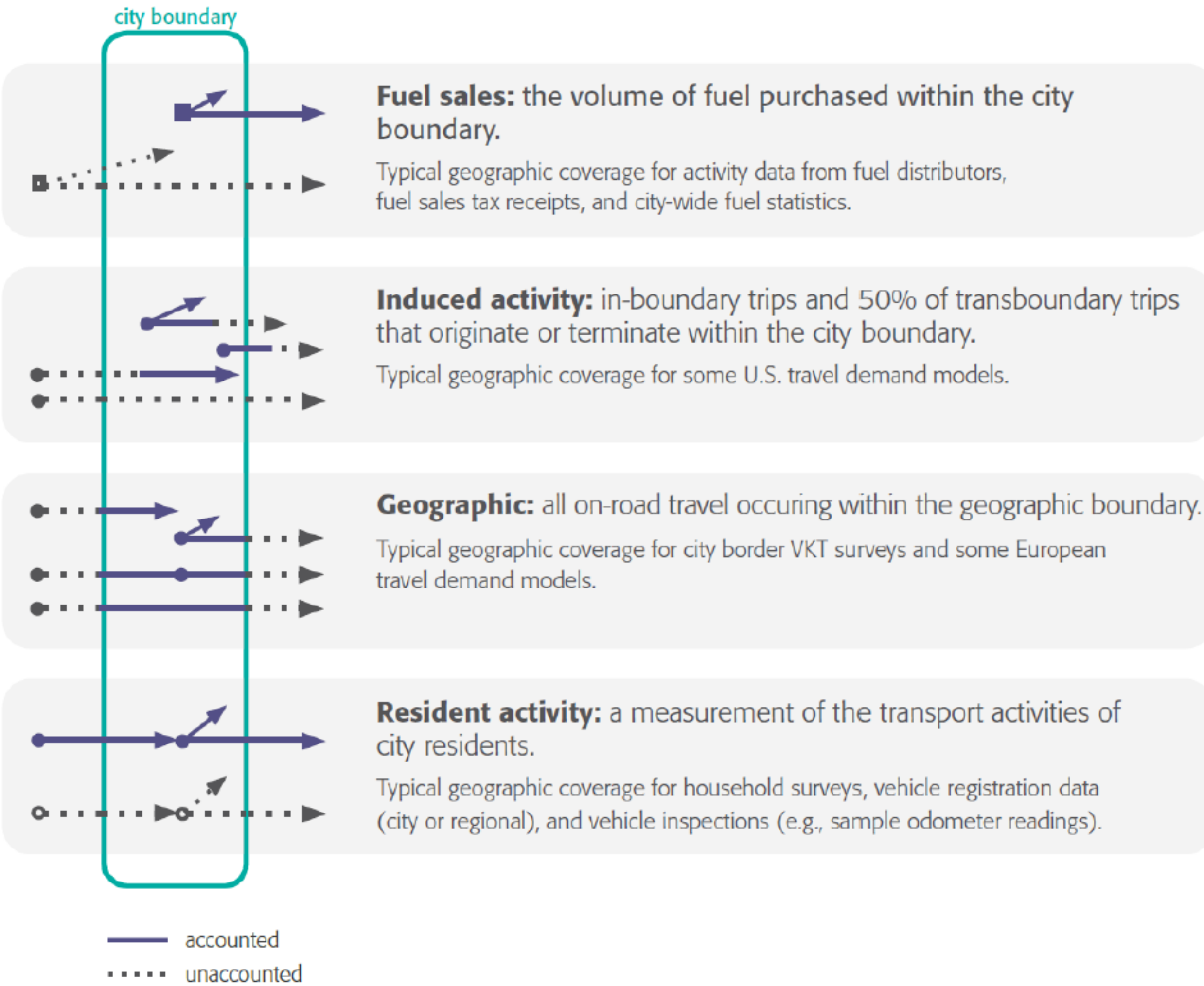
Approach

There are four different methodologies for calculating on-road emissions, as defined by the GPC. The GPC recommends the induced activity approach, as results are more suited to local policy making. However, any of the four are appropriate as long as the inventory clearly documents the method and assumptions used. **Figure 3-2** provides more detail on the different inventory approaches endorsed by the GPC.

10 The Climate Registry (April 2015). 2015 Climate Registry Default Emissions Factors.

11 U.S. EIA (April 2022). Biofuels and the environment. Retrieved from https://www.eia.gov/energyexplained/biofuels/biofuels-and-the-environment.php

Figure 3-2: On-Road Approaches Recommended by GPC



Source: GPC

For the 2012 inventory, the 'resident activity' method was used to estimate on-road car emissions, which is a bottom-up approach. This was justified by highlighting its benefits and listing the drawbacks of alternatives, as reflective of normal activity in the City of Cambridge. Other emissions sources used a mix of approaches. **Table 3-4** summarizes the 2012 approach to calculating transportation emissions.

Table 3-4: 2012 GPC Approach

Emission Source	Approach Used in 2012	GPC Section
Road – car (fuel) Road – car (elec) Road – bus (fuel) Trackless trolley (elec)	Resident activity Fuel sales Territorial/Geographical Territorial/Geographical	7.3
Heavy and light rail (elec) Commuter rail (diesel)	Territorial/Geographical Territorial/Geographical	7.4

Emission Source	Approach Used in 2012	GPC Section
Water	N/A	7.5
Aviation	N/A	7.6

Note: the 'geographical method' is also sometimes referred to as the 'territorial method.'

For this inventory, the City of Cambridge asked that another approach be calculated. This alternate methodology was intended to provide additional insights on sources of transportation emissions and illuminate additional strategies and levers the City should consider in reducing transportation emissions. The selected alternate approach was to be used for both 2012 and 2019.

Two alternative approaches to estimating on-road emissions were discussed with the City – 'fuel sales' and 'geographical' – and evaluated based on data availability, data quality, data cost, and ease of reproducing in future years.

The 'fuel sales' approach is a top-down approach, where emissions are estimated from total fuel sold within the City boundary. In theory, this approach treats sold fuel as a proxy for transportation activity. The activity data on the volume of fuel sold within the City boundary can be obtained from fuel dispensing facilities and/or distributors, or fuel sales tax receipts. If in-boundary fuel sales figures are unavailable, data may still be available at the regional scale. GPC suggests this data be scaled down using vehicle ownership data or other appropriate scaling factors.

These data are often the easiest to source and is favored by many cities, given the accuracy and availability of the data on a yearly basis. However, given the adjacency of Cambridge to other urban areas, this approach has a major drawback - that changes in the quantity of fuel sold in Cambridge may not be reflective of changes in Cambridge's Transportation sector, but rather depend on choices made by commuters about where to fill up their cars. For this reason, the 'fuel sales' approach was estimated, but only as a back-up alternative approach.

Another alternative is the 'geographical approach.' This is a bottom-up approach, like 'resident activity.' It aims to quantify emissions occurring solely within the City boundary, regardless of the trip's origin or destination, or whether the driver is a resident of the municipality. This makes it well suited to the particular context of the City of Cambridge, where there exists through traffic and a large proportion of commuters into the City, which the resident activity method fails to capture.

To estimate activity for this approach, a model is typically required which estimates the number of vehicles traveling, their origin and destination, their average trip length, the type of vehicle, fuel type, and efficiency. Preliminary discussions with the Boston Region Metropolitan Planning Organization's (MPO) Central Transportation Planning Staff (CTPS) suggest a model reflecting 2016 activity will be available in the coming months that could be used to estimate emissions using this approach.

As a result of the delay in securing data for the 'geographical approach,' this inventory reports emissions for the 'resident activity' and 'fuel sales' approaches, but **strongly recommends the 'geographical approach' is used once the data is available.**

Private On-Road Transportation

The GPC recommends several methodologies for calculating on-road transportation emissions, which were previously outlined in the Approach section above. Both the 'resident activity' and 'fuel sales' approaches were used for this inventory.

The ‘resident activity’ approach estimates emissions from transportation activities carried out by City residents and businesses that garage their vehicles in the City. One of the benefits of the ‘residential activity’ method is that the data is readily available to the City. In addition, this method is a good approach when trying to avoid double counting emissions with other cities in the region. If each city only quantifies the impact of vehicles registered in their city, the complications that arise from allocating cross-boundary trips to multiple jurisdictions can be avoided.

In 2012, the Massachusetts Vehicle Census (MAVC) was used to estimate emissions from vehicles registered in Cambridge. However, because the MAVC only includes data from 2009 to 2014, it could not be used for the completion of this inventory for 2019. Instead, data from the Massachusetts RMV was used to determine raw vehicle counts by vehicle type. Data from the 2012 inventory, provided by the MAVC, was used to estimate the fuel type breakdown by percentage of total vehicles. Due to the lack of available data to determine otherwise, it was assumed that the percentage of diesel, FlexFuel, and hybrid gasoline vehicles remained constant from 2012. It was further assumed that the share of electric vehicles increased at the same rate as the local MOR-EV rebate data provided by the City, and that the percentage of gasoline vehicles decreased as electric vehicles increased.

VMT per day for vehicles of each fuel type were assumed to remain the same as 2012, as no data was available to suggest otherwise. However, overall VMT increased due to an increase in the population of Cambridge.

Fuel efficiencies for each fuel type were projected from CAFE emissions standards using efficiencies in 2012 as the baseline. The fuel economy standards from the Code of Federal Regulations (CFR) were used to calculate projected fuel standards for 2019 with an improvement in efficiency of 23 percent.

Electric Vehicle Charging Station Data

Scope 2 electricity emissions associated with the on-road transportation sub-sector were also quantified. For on-road vehicles, Scope 2 emissions come from electric vehicle charging stations within the City of Cambridge boundaries. In 2012, ChargePoint was the sole operator of electric vehicle charging stations within Cambridge and provided the City with data on the 25 stations it had installed. By 2019, the number of electric vehicle charging stations had grown significantly, estimated at 247 stations within the City limits. ChargePoint data could not be accessed for this inventory; therefore, data on annual electricity consumption for chargers owned by the City of Cambridge were used to estimate the annual average electricity consumption for all 247 stations.

The lack of data on electric vehicle charging stations is a limit of this inventory that will hopefully be improved in future inventories. For example, it was not possible to differentiate between resident and non-resident use, and it was further unclear how many home-based chargers may have been omitted from the data. However, due to the small share of electric vehicles in the private vehicle sector the error associated with emissions from charging stations is minor in the context of the entire inventory. As the share of electric vehicles grows and charging stations proliferate around the City, the acquisition of data must improve to ensure the integrity of future GHG emissions inventories.

Public Transportation

A variety of public transportation modes serve the City of Cambridge: subway heavy rail, commuter heavy rail, light rail, trackless trolleys, and buses. Trackless trolleys and bus emissions were calculated in accordance with Section 7.3 of the GPC. Heavy rail and light rail emissions were quantified in accordance with Section 7.4 of the GPC.

The commuter rail engines use diesel fuel to operate while the buses use both diesel and CNG for fuel depending on the route. The subway, light rail, and trackless trolleys operate on electricity. Diesel and CNG emission factors were provided by The Climate Registry and the electricity emission factor was from ISO New England.

Emissions estimates are primarily based on the percent of VMT within the City compared to the overall system wide VMT. **Table 3-5** provides a summary of the Cambridge route miles versus the system route miles, which has remained the same since 2012. Off-road modes were calculated in terms of route miles, while on-road modes were calculated using VMT. System-wide route miles and VMT are from the National Transit Database (NTD) fuel and energy data, and they represent the length of all routes of that mode type.

Table 3-5: Public Transportation Route Miles and VMT for Cambridge and MBTA System Wide

Transit Type	System Route Miles	Cambridge Route Miles	Cambridge Percent
Subway (Red Line in Cambridge)	39.1	4.2	10.7%
Light Rail (Green Line E Branch in Cambridge)	22.8	0.4	1.8%
Commuter Rail (Fitchburg Line)	438.5	3.4	0.8%
Transit Type	**System VMT**	**Cambridge VMT**	**Cambridge Percent**
Trackless Trolley	582,121	342,166	58.8%
Bus	26,303,896	1,014,196	3.9%

Bus

To estimate the amount of diesel and CNG used by MBTA buses within the City of Cambridge, the percentage of revenue bus VMT within the City was multiplied by the system-wide diesel and CNG emissions by buses from 2019. An even mixture of diesel and CNG buses across all routes was assumed due to variations in operations.

Bus VMT was estimated using General Transit Feed Specification (GTFS) schedule data from March 2019 and GIS data for the MBTA system. The GTFS data was downloaded from MBTA archives online. GIS data was used to determine which routes traveled through Cambridge and the length of those portions.

To determine the frequency of each bus route, the trip table from the GTFS package was analyzed. Each row of data in the trip table represents an individual bus trip throughout the course of the day and contains information on which schedule the bus is following in the form of a service ID as well as which route the bus is following in the form of a route ID.

Data in the trip table was grouped by route ID and service ID to determine the number of trips per day for each route and service type. Three service types with different frequencies were identified: Weekday, Saturday, and Sunday. Once the data was grouped by route ID and service ID, each bus route had three service types with an associated number of trips per day. In circumstances where there were multiple values for the same service type, the maximum value was chosen for a conservative estimate. Route IDs not identified in the GIS analysis of bus routes traveling through Cambridge were eliminated from the analysis at this point.

It was then determined that there were 251 Weekday service days, 52 Saturday service days, and 62 Sunday service days in 2019. The difference between the number of Saturday and Sunday service days is due to holidays on weekdays that were assigned Sunday service types. Using the number of service days in the year, the annual number of trips were determined for each route using the formula below.

$$Annual\ Trips = (Weekday\ Trips \times 251) + (Saturday\ Trips \times 52) + (Sunday\ Trips \times 62)$$

With the annual number of trips identified for each bus route, as well as the length of the route identified through the GIS analysis, the estimated VMT for each bus route was calculated using the formula below.

$$Annual\ VMT = Route\ Length \times Annual\ Trips$$

Total VMT for all buses was calculated by summing the annual VMT for each bus route. This total was used to determine the percentage of bus VMT occurring within the geographical limits of the City of Cambridge, which was then multiplied by the electricity and CNG emissions of the entire bus network. This final value represents the emissions from buses in Cambridge running on electricity and CNG.

Table 3-6 presents the bus and trackless trolley routes used in the GTFS analysis to determine Cambridge frequency-weighted route distance. It is unknown which routes were included in the 2012 analysis, although analysis of the previous inventory data suggests demand responsive routes were included.

Table 3-6: MBTA Bus and Trackless Trolley Routes Serving Cambridge

Bus Routes			
Route Number	Total Length (mi)	Cambridge Length (mi)	Cambridge Percent of Total Length
1	4.4	1.9	44
47	5.3	1.0	20
62	10.8	0.5	4
64	5.4	1.6	30
66	3.9	0.6	14
67	5.1	0.5	9
68	2.1	2.1	100
69	2.6	2.6	100
70	10.1	1.3	13
70A	11.7	1.3	11
74	4.4	2.6	59
75	4.7	2.8	61
76	15.9	0.5	3
77	1.8	1.8	100
78	6.0	3.0	49
79	3.9	0.7	19

Bus Routes			
Route Number	Total Length (mi)	Cambridge Length (mi)	Cambridge Percent of Total Length
80	6.4	0.4	6
83	3.6	2.1	58
84	3.3	0.5	14
85	2.3	1.2	50
86	6.9	1.6	23
87	5.1	0.3	6
88	2.4	0.4	17
91	2.8	1.0	34
96	4.6	1.5	34
325	7.0	0.2	2
350	8.7	0.7	8
351	21.4	0.5	2
352	18.0	0.2	1
354	18.2	0.2	1
627	21.1	0.5	2
701	3.5	1.3	37
725	4.3	2.5	57
747	7.0	3.0	42
Trackless Trolley Routes			
Route Number	Total Length (mi)	Cambridge Length (mi)	Cambridge Percent of Total Length
71	5.6	3.9	49
72	4.9	2.1	100
73	2.8	4.3	51

Commuter Rail

To estimate the amount of diesel fuel consumed by the Commuter Rail within the City of Cambridge, the total system-wide diesel fuel consumption in 2019 was multiplied by the percentage of the Commuter Rail track length contained within Cambridge.

Electricity-Based Heavy Rail, Light Rail, and Trackless Trolley

Transit electricity usage associated with the Red Line, Green Line, and trackless trolleys was retrieved from the NTD fuel and energy use data. With electricity usage already broken down by mode, the percentage of electric usage that should be allotted from each mode to Cambridge was then determined using the same track length methods described for buses and commuter rail emissions.

Transportation Emissions

As shown in **Table 3-7**, this 2019 GHG inventory estimates that the Transportation sector in the City of Cambridge emitted 141,495 $MTCO_2e$ using the 'resident activity' methodology and 235,154

MTCO$_2$e using the 'fuel sales' methodology. As can be seen in both methods, private on-road transportation represents the greatest source of emissions for the transportation sector in Cambridge. Using the 'resident activity' methodology, it is estimated that private transportation is the source of 132,580 MTCO$_2$e, or 93.7 percent of total transportation emissions. Using the 'fuel sales' approach, the estimate for private transportation is 226,239 MTCO$_2$e, or 96.2 percent of total transportation emissions.

Table 3-7: Cambridge 2019 Transportation Emissions

Category	Subcategory		Resident Activity Approach		Fuel Sales Approach	
			MT CO_2e	Percent of Total	MT CO_2e	Percent of Total
Public Transportation	All On-Road Public Transportation	MBTA Buses	485	0.3%	485	0.2%
		Trackless Trolley	851	0.6%	851	0.4%
	All Rail Public Transportation	Red Line (Subway Heavy Rail)	6,216	4.4%	6,216	2.6%
		Green Line E Branch (Light Rail)	258	0.2%	258	0.1%
		Fitchburg Line (Commuter Rail)	1,105	0.8%	1,105	0.5%
	All Public Transportation		8,915	6.3%	8,915	3.8%
Private Transportation	On-Road Private		132,580	93.7%	226,239	96.2%
Total Transportation Emissions			**141,495**	**100%**	**235,154**	**100%**

While the percentage of on-road emissions is fairly similar between the two methodologies, the total emissions calculated is significantly different – approximately 90,000 MTCO$_2$e – reinforcing the importance of the approach selected. This is because the 'fuel sales' methodology is a top-down approach, meaning fuel consumption is used as a proxy for travel behavior instead of using detailed activity data, and includes a lot of opportunity for error. For example, statewide fuel sales data scaled down using vehicle ownership does not account for differences in resident behavior between municipalities. Vehicle owners in Cambridge, while representing 0.96 percent of the vehicles registered in the state, likely represent a smaller percentage of vehicle miles traveled due to the availability of transit, denser land use, and lifestyle differences. It is because of this that the resident activity method is considered more accurate.

Overall, despite the differences in cumulative emissions calculated between the two methodologies, the similar patterns of emissions reduction indicate a promising trajectory in reducing Cambridge's emissions in the transportation sector.

2012 Emissions Inventory Comparison

Using the 'resident activity' approach, albeit with some variation in data sources, it is estimated that transportation emissions have decreased 13 percent, from 162,938 $MTCO_2e$ in 2012 to 141,495 $MTCO_2e$ in 2019. Per capita emissions have decreased 21 percent, from 1.51 $MTCO_2e$ in 2012 to 1.19 $MTCO_2e$ in 2019. The larger decrease in per capita emissions when compared to total emissions can be attributed to an increase in population.

Following the 'fuel sales' approach, it is estimated that transportation emissions have decreased 14 percent, from 274,418 $MTCO_2e$ in 2012 to 235,846 $MTCO_2e$ in 2019. Per capita emissions have decreased 22 percent, from 2.54 $MTCO_2e$ in 2012 to 1.98 $MTCO_2e$ in 2019. Detailed comparisons are shown in **Table 3-8** and **Table 3-9.**

Table 3-8: Comparison of Cambridge Transportation Emissions 2012-2019 (Resident Activity)

Category	Subcategory		2012 Emissions (MT CO_2e)	2019 Emissions (MT CO_2e)	Percent Change
Public Transportation	All On-Road Public Transportation	MBTA Buses	3,061	485	-84%
		Trackless Trolley	1,118	851	-24%
	All Rail Public Transportation	Red Line (Subway Heavy Rail)	7,088	6,216	-12%
		Green Line E Branch (Light Rail)	310	258	-17%
		Fitchburg Line (Commuter Rail)	967	1,105	14%
	All Public Transportation		12,544	8,915	-29%
Private Transportation	On-Road Private		149,815	132,580	-12%
Total Transportation Emissions			**162,358**	**141,495**	**-13%**

Table 3-9: Comparison of Cambridge Transportation Emissions 2012-2019 (Fuel Sales)

Category	Subcategory		2012 Emissions (MT CO_2e)	2019 Emissions (MT CO_2e)	Percent Change
Public Transportation	All On-Road Public Transportation	MBTA Buses	3,061	485	-84%
		Trackless Trolley	1,118	851	-24%
	All Rail Public Transportation	Red Line (Subway Heavy Rail)	7,088	6,216	-12%
		Green Line E Branch (Light Rail)	310	258	-17%
		Fitchburg Line (Commuter Rail)	967	1,105	14%
	All Public Transportation		12,544	8,915	-29%
Private Transportation	On-Road Private		261,874	226,239	-14%
Total Transportation Emissions			**274,418**	**235,154**	**-14%**

There were two modes that had significant emissions reductions from the 2012 inventory to the 2019 inventory: buses and on-road private transportation. Buses saw a reduction in estimated emissions of 68 percent for both the 'resident activity' and 'fuel sales' approaches. On-road private transportation saw a reduction in estimated emissions of 12 percent with the 'resident activity' approach and 14 percent with the 'fuel sales' approach. Despite the larger percentage reduction in estimated emissions from buses, the reduction from on-road private transportation drove the overall reduction in emissions because it is the source of over 90 percent of emissions for both methodologies. The drivers of the estimated emissions reductions for both modes are described in more detail below.

Bus Emissions Reductions

There are two main drivers to the reduction in emissions from buses. The first driver is the complete switch from diesel to biodiesel fuel. In 2012, MBTA buses in Cambridge used an estimated 196,859 gallons of diesel, which was the source of over 60 percent of the City's GHG emissions. The United States Energy Information Administration states the U.S. government considers biodiesel to be carbon-neutral because the plants which are the sources of biodiesel absorb CO_2 as they grow. For this reason, emissions from biodiesel in 2019 were determined to be zero. Emissions tied to biodiesel should be revisited in future inventories as their environmental impact and full life-cycle emissions become clearer.

The second driver in emissions reductions for buses was a difference in calculating vehicle miles traveled (VMT) from buses between the two inventories. Frequency-weighted VMT was calculated, which incorporates the number of trips buses take along each route. This is a more accurate representation of bus VMT because buses on short routes may generate more VMT than buses on long routes depending on the frequency of trips for each route. **Table 3-10** shows the difference in system-wide and Cambridge frequency-weighted on-road public transportation VMT between the 2012 inventory and the 2019 inventory.

Table 3-10: On-Road Public Transportation Vehicle Miles Traveled Comparison

	2012 (miles/year)	2019 (miles/year)	Percent Change
System-Wide Frequency-Weighted VMT			
MBTA Bus	40,933,537	26,303,896	-36%
Trackless Trolley	1,601,904	582,121	-64%
Cambridge Frequency-Weighted VMT			
MBTA Bus	1,439,502	1,014,196	-30%
Trackless Trolley	898,589	342,166	-62%

There were no data sources provided for 2012, but from investigation of various sources and back-calculations, it was determined that the 2012 inventory included demand responsive VMT as well as purchased transit VMT. An MAPC calculation of system-wide frequency-weighted trip miles in 2017 confirmed a system-wide value closer to the 20 million value calculated for 2019. It is assumed the same calculation was used for Cambridge frequency-weighted VMT. Despite the significant difference in VMT use in each inventory, the switch to biodiesel still had the largest impact in reducing the emissions from buses.

Private On-Road Transportation Emissions Reductions

Reductions in private on-road transportation emissions were exclusively driven by an improvement in vehicle fuel efficiencies. The improvements due to fuel efficiencies were slightly offset by an increase in VMT. To demonstrate the impact of the improved fuel efficiencies in 2019, **Table 3-11** shows the interplay between fuel efficiency and VMT in regard to emissions.

Table 3-11: Impact of Fuel Efficiency and VMT on Emissions (Resident Activity)

Private On-Road Transportation	2012	2012 with 2019 Fuel Efficiency	2019
Annual Vehicle Miles Traveled City-Wide	326,736,419	326,736,419	360,360,742
Average Fuel Efficiency (mpg)	22.19	27.04	27.04
Emissions (MT CO_2e) (Resident Activity)	162,358	136,447	143,159

The center column of **Table 3-11** – 2012 with 2019 Fuel Efficiency – uses 2012 VMT and applies the improved 2019 average fuel efficiency of 27.04 mpg. There is a corresponding reduction in emissions of approximately 25,000 MTCO_2e. This is what the emissions would be if residents of Cambridge drove the same amount in 2019 as they did in 2012. In actuality, VMT increased in the years between inventories, offsetting some of the emissions reductions achieved through the improved fuel efficiency. Emissions in 2019 for private on-road transportation are about 7,000 $MTCO_2e$ higher in 2019 than they would have been if VMT remained constant between 2012 and 2019 while fuel efficiency improved.

A decrease in emissions despite an increase in VMT raises the question of how much electric vehicles (EVs) are contributing to the emission reduction. **Table 3-12** shows a detailed breakdown of VMT by fuel type within the private on-road transportation category.

Table 3-12: Private On-Road VMT Comparison by Fuel Type

	2012 VMT	2019 VMT	Raw Change	Percent Change	Percent of Total VMT
Passenger and Commercial Vehicles	362,890,853	397,415,937	34,525,084	10%	100%
Gasoline	332,848,805	363,294,303	30,445,498	9%	91.4%
Diesel	4,954,418	5,378,373	423,955	9%	1.4%
FlexFuel	5,703,923	6,156,578	452,655	8%	1.5%
Gasoline (Hybrid)	19,368,099	21,254,747	1,886,647	10%	5.3%
Electric	15,608	1,331,936	1,331,936	8,434%	0.3%

As can be seen, EVs saw an incredible amount of growth between 2012 and 2019. However, their overall VMT is still only 0.3 percent of the total private on-road VMT in Cambridge. This indicates that the majority of emissions reductions come from improvements in the fuel efficiency of gasoline powered vehicles.

4

Waste

Waste emissions are generated from solid waste disposal at landfills, the biological treatment of organic waste (i.e., composting or anaerobic digestion), the incineration of waste, and wastewater treatment. For this GHG inventory, all Waste sector emissions are considered Scope 3 emissions, since all waste and wastewater are processed outside of the inventory boundary (i.e., outside of the City of Cambridge).

Data Sources

Municipal solid waste (MSW) in Cambridge is collected for disposal through municipal curbside pickup programs or by private haulers operating within the City's boundary. Solid waste data from the City's municipal curbside pickup program was provided by the Cambridge Department of Public Works (DPW), including separated organic waste. Private hauler data for commercial properties were estimated using 2019 Labor Force and Unemployment Data from the Executive Office of Labor and Workforce Development (EOLWD),[12] which was converted to waste units using employee waste disposal rates by industry (tons of disposal per employee per year) from CalRecycle.[13] Private hauler data for multi-family housing in the City were estimated by applying the annual tonnage per resident (calculated from the municipal curbside pickup program data and the portion of the City's 2019 total population served by the program) to the portion of the population not served by the program.

All wastewater produced in the City is directed to the Deer Island Treatment Plant in Winthrop, MA operated by the Massachusetts Water Resource Authority (MWRA). MWRA is the main source of data used to calculate the GHG emissions from wastewater generation in Cambridge.

---

12 Massachusetts Department of Unemployment Assistance, Economic Research Department. Labor Force and Unemployment Data. Retrieved from https://lmi.dua.eol.mass.gov/LMI/LaborForceAndUnemployment

13 CalRecycle. Disposal and Diversion Rates for Business Groups. Retrieved from https://www2.calrecycle.ca.gov/WasteCharacterization/BusinessGroupRates

Solid Waste Disposal

MSW collected in the City of Cambridge is either incinerated to produce energy (60 percent) or landfilled (40 percent). This breakdown differs slightly from the state average. According to the Massachusetts 2019 Solid Waste Data Update, approximately 78 percent of MSW is incinerated, compared to 22 percent sent to landfill. However, these numbers do not account for MSW disposed of out of state, where a lot of MSW from Cambridge is sent. The 60/40 split provides a more accurate account of disposal sites specific to the City of Cambridge.

An estimated 35 percent of resident-generated MSW in Cambridge is collected as part of municipal curbside pickup programs, while the remaining 65 percent is collected by private haulers that are contracted by larger multi-family complexes. All commercial MSW collection is performed by private haulers.

To calculate the emissions associated with solid waste disposal, the City must determine the amount of MSW (i.e., the "activity data") collected by the municipal curbside pickup program, as well as the amount of waste collected by private haulers in the City boundary. In addition to these totals, information on where/how the MSW is disposed is also needed.

As noted, municipal curbside program data were provided through waste collection and disposal records supplied by the Cambridge DPW, which maintains detailed records on the tonnage of MSW collected by individual trucks serving the City. The DPW also collects waste data related to other municipal operations, such as pavement and street cleaning operations and catch basin debris that is collectively referred to as "mixed waste." As such, total MSW collected by municipal services is a combination of curbside pickup and mixed waste. In 2019, 14,380 tons of MSW were collected by municipal hauling services. It is important to note that while the DPW also collects detailed information on the curbside recycling program, this data is not included in total MSW tonnage since minimal emissions are generated from the disposal of recycled materials.

Raw MSW tonnage data from private hauler collection was not able to be obtained, and was therefore estimated for the purposes of this inventory as outlined in the preceding section and described in more detail below.

Labor Force and Unemployment Data for the City of Cambridge for 2019 were obtained from EOLWD's website[14] using the following steps.

1. "Select Area Type" drop-down: Select "City or Town"
2. "Select Specific Geographic Area" drop-down: Select your community
3. "Select a Year" drop-down: Select your inventory year
4. "Select the Time Period" drop-down: Select "Annual Report"
5. "Select the Ownership" drop-down: Select "All ownership types"
6. "Select an Industry or Industry Sector" drop-down: Select "Total, All Industries"
7. "Select the Category" option: Select "Category and all sub-categories"
8. Select the link to "Download and save the data as a Comma Separated Value (CSV) File"

[14] Massachusetts Department of Unemployment Assistance, Economic Research Department. Labor Force and Unemployment Data. Retrieved from https://lmi.dua.eol.mass.gov/LMI/LaborForceAndUnemployment

To avoid double counting, only the three-digit NAICS codes were considered for this inventory (note that the data download described above initially includes multiple tiers of NAICS codes). To facilitate grouping of industries, NAICS codes and titles were then matched to "principal business activities" of buildings as defined by the U.S. Energy Information Administration (EIA). Average monthly employment per employer establishment (i.e., building) for each primary building activity was calculated using this data.

Primary Building Activities were used to group employment by sub-sector industry, including only those PBAs applicable to the City of Cambridge. This process resulted in an estimate of the number of employees in the City in 2019, divided into simplified groups. These groupings included the following:

Commercial and Institutional Buildings

- Education
- Food Sales
- Food Service
- Health Care Inpatient
- Health Care Outpatient
- Lodging
- Mercantile Retail (other than mall)
- Mercantile Enclosed and Strip Malls
- Office
- Public Assembly
- Public Order And Safety
- Religious Worship
- Service
- Warehouse And Storage

Manufacturing Industries & Construction

- Food
- Printing and Related Support
- Chemicals
- Machinery
- Computer and Electronic Products
- Electrical Equip., Appliances, Components
- Miscellaneous

Total 2019 MSW disposal associated with commercial, institutional, and manufacturing properties and collected by private haulers (126,252 tons) was calculated by applying specific disposal rates by industry (tons per employee per year) to the estimated number of employees in the City by industry, and then summing the calculated disposal totals across industries. For example, for the Education industry, a rate of 0.38 tons/employee/year was multiplied by 30,914 (the number of persons employed by the Education industry in the City in 2019) to arrive at a total of 10,293 tons MSW disposed. **Table 4-1** and **Table 4-2** show the methodology for estimating solid waste tonnage collected by private haulers for 2019.

Table 4-1: Estimation Methodology for Commercial and Institutional Solid Waste Collected by Private Haulers

Commercial & Institutional Buildings by NAICS Code	Number of Employees in Cambridge, 2019	Curbside Disposal Rates (Tons per Employee per Year)	2019 Total Tons per Year	CalRecycle Reference
Education	30,914	0.38	11,747	Education
Food Sales	1,731	0.94	1,627	Retail Trade - Food & Beverage Stores
Food Service	8,240	1.57	12,937	Restaurants
Health Care Inpatient	3,573	0.57	2,037	Medical & Health
Health Care Outpatient	2,641	0.57	1,506	Medical & Health
Lodging	4,976	1.4	6,966	Hotels & Lodging
Mercantile Retail (other than mall)	1,812	1.74	3,153	Retail Trade - All Other
Mercantile Enclosed and Strip Malls	1,322	1.74	2,300	Retail Trade - All Other
Office	67,266	1.105	74,329	AVERAGE of *Services - Management, Administrative, Support & Social* AND *Services - Professional, Technical, & Financial*
Public Assembly	1,625	1.94	3,153	Arts, Entertainment, & Recreation
Public Order And Safety	755	0.3	227	Public Administration
Religious Worship	788	0.6	473	Services - Management, Administrative, Support & Social
Service	1,133	1.02	1,156	AVERAGE of *Services - Management, Administrative, Support & Social* AND *Services - Professional, Technical, & Financial* AND

Commercial & Institutional Buildings by NAICS Code	Number of Employees in Cambridge, 2019	Curbside Disposal Rates (Tons per Employee per Year)	2019 Total Tons per Year	CalRecycle Reference
				Services - Repair & Personal
Warehouse And Storage	3,096	0.57	1,765	Durable Wholesale & Trucking
All Commercial & Institutional Buildings	**129,872**		**123,376**	

Table 4-2: Estimation Methodology for Manufacturing Solid Waste Collected by Private Haulers

Manufacturing Industries & Construction by NAICS Code	Number of Employees in Cambridge, 2019	Curbside Disposal Rates (Tons per Employee per Year)	2019 Total Tons per Year	CalRecycle Reference
Food	770	1.23	947	Manufacturing - Food & Nondurable Wholesale
Printing and Related Support	31	1.23	38	Manufacturing - Food & Nondurable Wholesale
Chemicals	1,487	1.23	1,829	Manufacturing - Food & Nondurable Wholesale
Machinery	7	0.44	3	Manufacturing - All Other
Computer and Electronic Products	71	0.31	22	Manufacturing - Electronic Equipment
Electrical Equip., Appliances, Components	0	0.31	0.	Manufacturing - Electronic Equipment
Miscellaneous	89	0.44	39	Manufacturing - All Other
All Manufacturing Industries & Construction Buildings	**2,455**		**2,878**	

The disposal rates were obtained from CalRecycle, derived from its 2014 Waste Characterization Study. Although these disposal rates were established in 2014, they remain the best estimates in the waste industry for associating employment with waste generation. This is an area where more research and analysis are needed.

In addition to commercial facilities, private haulers are also contracted to collect MSW from large multi-family housing developments. To estimate the amount of residential MSW collected by private haulers in 2019 , a disposal rate per resident was calculated by multiplying the City's total population in 2019 (116,632) by 65 percent (i.e., the percent of the population served by the municipal curbside program), and then dividing the resulting value by the total MSW collected by the municipal curbside program in 2019 (12,938 tons). The calculated residential MSW disposal rate (0.17 tons MSW per resident per year) given municipal data was then applied to the remaining 35 percent of the City's population (40,821) to reflect residential MSW tonnage collected by private haulers (6,967 tons).

Combining the private haul MSW collection estimates for commercial properties and large multi-family housing developments, total waste collected by private haulers in 2019 was determined to be 133,219 tons.

The City's 2012 Community-Wide GHG Emissions Inventory estimated total MSW collected by private haulers based on the square footage of commercial space in Cambridge and a factor for how many metric tons of waste is generated per square-foot. The 2019 update attempts to improve upon the accuracy of this estimate by using industry-specific employee disposal rates.

This change in approach is responsible, in part, for a substantial increase in total private haul MSW collection. For comparison, the 2012 inventory reported 67,107 tons of private haul MSW collection. Applying the 2019 approach, the 2012 value would have been 104,491 tons.

As mentioned above, approximately 60 percent of MSW is sent for combustion, with the remaining 40 percent sent to landfill. In Massachusetts, incinerated waste is used to produce electricity in waste-to-energy facilities. According to the GPC, incinerated waste used to generate energy is a stationary energy (Scope 1) source. However, since there are no waste-to-energy facilities in Cambridge, these emissions were not included under Scope 1 stationary energy emissions. Instead, emissions generated as a result of incineration outside of City boundaries are considered Scope 3 emissions.

Biological Treatment

The biological treatment of waste refers to composting and/or anaerobic digestion of organic waste, such as food or yard waste. Anaerobic digestion is the process through which bacteria break down organic matter in the absence of oxygen, creating biogas in the form of methane that can be used for energy. The City's DPW provides curbside collection of organic waste from residents, 100 percent of which is sent to an anaerobic digestion facility in Charlestown to create either methane or fertilizer. The mass of solid waste disposed through biological treatment and the method of treatment (i.e., composting vs. anaerobic digestion) was provided by the DPW for 2019. In this year, 1,756 tons of organic waste were biologically treated.

Wastewater

Wastewater in the City is generated by residents, businesses, and industrial processes. All wastewater produced in the City is directed to the Deer Island Treatment Plant in Winthrop, MA. The

Massachusetts Water Resource Authority (MWRA) operates the Deer Island facility and is the main source of data used to calculate the GHG emissions from wastewater generation in Cambridge.

The Deer Island Treatment Plant releases no methane in the wastewater treatment process. Methane is captured and diverted to co-generation systems where it is used to heat buildings and generate electricity via steam turbine generators. Emissions generated as a result of methane capture and co-generation occurring outside of Cambridge's boundaries are considered Scope 3 emissions.

There are indirect N_2O emissions from the wastewater treatment plant that must be accounted for. These N_2O emissions primarily result from treated effluent being discharged into the ocean. To determine the amount of N_2O emissions attributed to this process, the total population of Cambridge served by the Deer Island Treatment Plant is needed, as well as the per capita protein consumption value. For this inventory, a value of 34.1 kg/person/year was used based on guidance from the U.S. EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 -2017, Table 7-16.

Estimating Greenhouse Gas Emissions

Solid Waste Disposal

GHG emissions associated with solid waste disposal include CO_2, CH_4, and N_2O. In the City of Cambridge, approximately 40 percent of collected MSW is sent to landfill and 60 percent of MSW is incinerated to produce energy.

For waste sent to landfill, methane emissions were calculated using Equations 8.1, 8.3, and 8.4 of the GPC. Equation 8.3 is used to calculate total CH_4 emissions. This is known as the Methane Commitment Model, which assigns landfill emissions based on waste disposed in a given year. The Methane Commitment Model takes a lifecycle and mass-balance approach and calculates landfill emissions based on the amount of waste disposed that year, regardless of when the emissions actually occur (since a portion of emissions are released every year after the waste is disposed). Alternatively, a First Order of Decay method can be used but requires historical waste disposal data that is not readily available for the City of Cambridge.

GHG emissions from the incineration of MSW were calculated using Equations 8.6, 8.7 and 8.8 of the GPC, as well as default factors from GPC Tables 8.4, 8.5, and 8.6. The mass of incinerated waste in total and each fraction of matter type i (paper, textiles, food, etc.) are used to determine the emissions.

Resulting CO_2, CH_4, and N_2O emissions across equations are summed, and then multiplied by their GWPs to calculate CO_2e emissions from landfilled waste and incinerated waste.

Emissions Factors Used

For waste sent to landfill, Equations 8.1, 8.3, and 8.4 require the user to input values for each variable based on the characteristics of the waste and landfill. For Equation 8.1, Degradable Organic Carbon (DOC) is calculated based on the proportion of certain types of waste (e.g., food, paper, wood, etc.) in the waste stream. For the 2019 Community-wide GHG Emissions Inventory, default factors were used from the Massachusetts Department of Environmental Protection (MassDEP) Summary of Waste Combustor Class II Recycling Program Waste Characterization Studies (Includes 2010, 2013 & 2016 Data). Specifically, data from the "2016 Detailed Fall & Winter" tab of the workbook were used.

The City's 2019 Waste Characterization Study could not be used for Equation 8.1, as certain City waste categories could not be mapped to the GPC waste categories. For example, the 2019 characterization study did not quantify materials that could be included under the GPC waste category of "Garden Waste and Plant Debris" and various paper materials could not be parsed out with reasonable accuracy from the City's general "Recyclables" category.

Equation 8.3 calculates CH_4 emissions based on the mass of solid waste sent to landfill (MSW), the methane generation potential (L_0), the fraction of methane recovered from the landfill (f_{rec}), and the oxidation factor (OX). For this inventory, the following assumptions were made, which are in accordance with GPC values.

- The f_{rec} was assumed to be 0.0 because it could not be determined to which landfills the City's waste was sent.
- An OX of 0.1 was selected because the landfills to which the City's waste was sent are likely to be managed.

L_0 is calculated based on a methane correction factor (MCF), the DOC calculated as part of equation 8.1, the fraction of DOC that is ultimately degraded (DOC_F), and the fraction of methane in landfill gas (F). In accordance with the GPC, the following values were used.

- A value of 1.00 was used for MCF since the landfills to which the City's waste was sent are likely to be managed.
- A default value of 0.6 was used for DOC_F.
- A default value of 0.5 was used for F.

The default fraction of 16/12 was also used as the input for the Stoichiometric Ratio Between Methane and Carbon.

For the incineration of waste, Equation 8.6 estimates non-biogenic CO_2 emissions, Equation 8.7 estimates CH_4 emissions, and Equation 8.8 estimates N_2O emissions. As mentioned, the City's DPW estimates that 60 percent of MSW generated in Cambridge is incinerated. Equation 8.6 calculates CO_2 emissions based on the following:

- Tonnage of waste incinerated,
- Fraction of waste consisting of type i matter (WF_i),
- Dry matter content in the type i matter (dm_i),
- Fraction of carbon in the dry matter of type i matter (CF_i),
- Fraction of fossil carbon in the total carbon component of type i matter ($FCF)_{,i}$),
- Oxidation fraction or factor (OF_i), and
- Matter type of the solid waste incinerated (i) (e.g., paper, textile, food waste, etc.).

The following values were used in accordance with GPC Equation 8.6.

- WF values were identical to the proportions of certain types of waste (e.g., food, paper, wood, etc.) in the waste stream used in Equation 8.1 and based on state-level compositions.
- Defaults values for dm and CF were pulled from 2006 IPCC Guidelines, Vol. 5, Ch. 2, Table 2.4.
- Default values for FCF were pulled from 2006 IPCC Guidelines, Vol. 5, Ch. 2, Table 2.5.
- Default Values for OF were pulled from GPC Table 8.4 and equivalent to 100 percent for all waste types.

Equation 8.7 calculates CH_4 emissions based on the amount of solid waste of type i incinerated (IW_i), aggregate CH_4 emission factor (in g CH_4/ton of waste type i), Conversion factor from grams to tons, and the type of waste incinerated (i). The following values and assumptions were used for Equation 8.7.

- Waste categories were identical to the proportions of certain types of waste (e.g., food, paper, wood, etc.) in the waste stream used throughout the inventory, based on state-level compositions.
- CH_4 emission factor was pulled from GPC Table 8.5, assuming "Continuous Incineration: Stoker."
- 10^{-6} was used as a conversion factor.

Equation 8.8 calculates N_2O emissions based on the Amount of solid waste of type i incinerated (IW_i), Aggregate N_2O emission factor (in g N_2O /ton of waste type i), and the type of waste incinerated (i). The following values and assumptions were used for Equation 8.7.

- Waste categories were identical to the proportions of certain types of waste (e.g., food, paper, wood, etc.) in the waste stream used throughout the inventory, based on state-level compositions.
- N_2O emission factor was pulled from GPC Table 8.6, assuming "MSW: continuous and semi-continuous incinerators."

Biological Treatment

CH_4 and N_2O emissions associated with the biological treatment of solid waste were calculated using GPC Equation 8.5. Equation 8.5 estimates direct emissions resulting from two treatment types - compositing and anaerobic digestion. CH_4 and N_2O emissions are calculated based on the mass of organic waste treated by biological treatment type i (m), CH_4 and N_2O emissions factors based upon treatment type, the treatment type used, and the total tons of CH_4 recovered in the inventory year if a gas recovery system is in place (R). The following values and assumptions were used for Equation 8.5.

- 100 percent of organic waste collected by the City is sent to an anaerobic digestion facility.
- The default biological treatment emission factors from GPC Table 8.3 were used. "Wet waste" emission factors were used for anaerobic digestion at biogas facilities (composting is not applicable) for both CH_4 and N_2O.
- A 100 percent methane recovery is assumed for the anaerobic digestion facility.

Resulting CH_4 and N_2O emissions were multiplied by their GWPs to calculate CO_2e emissions from the biological treatment of waste.

Wastewater

For this community-wide Inventory, only N_2O emissions need to be considered, as CH_4 emissions are captured through the wastewater treatment process at the Deer Island WWTP. Equation 8.11 estimates indirect N_2O emissions from wastewater effluent, based on the total population served by the water treatment plant, annual per capita protein consumption, a factor to adjust for non-consumed protein ($F_{NON\text{-}CON}$), the fraction of nitrogen in protein (F_{NPR}), a factor for industrial and commercial co-discharged protein into the sewer system ($F_{IND\text{-}COM}$), nitrogen removed with sludge

(N_{SLUDGE}), an emission factor for N_2O emissions discharged to wastewater, and the conversion of kg N_2O-N into kg N_2O.

Key variables used to complete Equation 8.11 can be found in the U.S. EPA Inventory of U.S. Greenhouse Gas Emissions and Sink (1990-2017), including:

- Annual per capita protein consumption: 34.1 kg/person/year.
- Factor to adjust for non-consumed protein: 1.40 (for countries with garbage disposals).
- A default value of 0.16 for Fraction of Nitrogen in Protein.
- A default value of 1.25 for Factor for Industrial and Commercial Co-discharged Protein.
- A default value of 0 for Nitrogen Removed from Sludge.
- A default value of 0.005 for Emission Factor for N_2O Emissions from Discharged Wastewater.
- Conversion of kg N_2O-N into kg of N_2O at 44/28, or 1.57.

It was assumed that 100 percent of the City's residents are serviced by the Deer Island WWTP. According to the *2015-2019 American Community Survey 5-Year Estimates*, the City's total population in 2019 was 116,632.

Waste Emissions

It is estimated that the Waste sector in the City of Cambridge emitted 103,619 MT CO_2e in 2019. Waste emissions are generated from solid waste disposal at landfills, the biological treatment of organic waste (i.e., composting or anaerobic digestion), the incineration of waste, and wastewater treatment. **Table 4-3** presents Waste sector emissions from 2019 by sub-sector. For this GHG inventory, it is important to note that all Waste sector emissions are considered Scope 3 emissions, since all waste and wastewater is processed outside of the inventory boundary (i.e., outside of Cambridge).

Table 4-3: Cambridge 2019 Waste Emissions, by Subsector

Sub-sector	2019 Emissions (MT CO_2e)	Percent of Total
Solid Waste Disposal	99,014	95.6%
Biological Treatment of Waste	0	0.0%
Incineration and Open Burning	2,286	2.2%
Wastewater Treatment and Discharge	2,319	2.2%
Total Waste Emissions (Scope 3)	**103,619**	**100%**

Solid waste disposal (i.e., waste sent to landfill) was responsible for 96 percent of Waste sector emissions in 2019, primarily due to the methane released from landfills. Out of all municipal solid waste collected in the City of Cambridge, 40 percent is sent to landfill and 60 percent is sent to incineration facilities. Landfilled waste results in methane emissions as materials decompose in the anaerobic (non-oxygen) environment of a landfill. As a greenhouse gas, methane has a global warming potential that is 25 times more potent than carbon dioxide.

Comparatively, emissions from waste incineration and the wastewater treatment process are very small, each comprising 2.2 percent of total waste emissions.

Incineration of waste results in CO_2, CH_4, and N_2O emissions as the waste is burned. In Massachusetts, incinerated waste is used to produce electricity in waste-to-energy facilities. As landfilled waste produce CH_4 over the long-term, incineration generally provides effective mitigation of GHG emissions from the Waste sector through landfill avoidance.

Wastewater treatment results in process and fugitive emissions of methane and/or nitrogen oxide (N_2O). However, the Deer Island Treatment Plant releases no methane during the wastewater treatment process. Methane is captured and diverted to co-generation systems where it is used to heat buildings and generate electricity via steam turbine generators. Therefore, indirect N_2O emissions are responsible for all of Cambridge's wastewater treatment emissions. These N_2O emissions primarily result from treated effluent being discharged into the ocean. Total N_2O emissions from wastewater treatment and discharge were estimated to be 8.75 MT N_2O in 2019. With a global warming potential that is 265 times more potent than carbon dioxide, the CO_2 equivalent of these N_2O emissions becomes 2,319 MT CO_2e.

Zero emissions were estimated for the biological treatment of waste. All of the City's residential organic waste that is collected curbside is sent to an anaerobic digestion facility, where bacteria break down organic matter in the absence of oxygen to produce energy. While methane is produced during this process, it was assumed that the anaerobic digestion facility recovered 100 percent of the methane produced.

2012 Emissions Inventory Comparison

It is estimated that Waste sector emissions have increased by 7.6 percent from 2012 to 2019 in the City of Cambridge. However, this increase is primarily attributable to an alternative accounting approach employed for 2019 that more accurately reflects solid waste collections from commercial buildings and large multi-family residences by private haulers. This methodology is explained in detail in the Data Sources section of this chapter.

Note that Cambridge's Organics Diversion Program was not fully implemented until 2018. This waste stream did not generate emissions in 2019, as all materials are sent to an anaerobic digestion facility in North Andover that recovers 100 percent of methane gases.

5

Conclusion

The City of Cambridge and local organizations have long supported the scientific consensus that climate change is a real global phenomenon that is caused by anthropogenic greenhouse gas emissions and puts the health and vitality of Cambridge at risk. The 2019 Community-wide Greenhouse Gas Emissions Inventory helps the City of Cambridge benchmark community-wide emissions and provides a necessary foundation that enables Cambridge to track progress towards emission reduction goals. It also helps the City to engage specific market sectors in actions to reduce emissions.

Summary of Community-wide GHG Emissions

This community-wide GHG emissions inventory estimates that the City of Cambridge emitted 1,413,026 MT CO_2e in calendar year 2019. Emissions from the Buildings and Energy Production (or Stationary Energy) sector were responsible for 82.7 percent of this total, followed by the Transportation sector at 10 percent and the Waste Sector at 7.3 percent. Looking at the results by sub-sector, the largest sources of emissions in the City of Cambridge were commercial and institutional buildings (37.4 percent), residential buildings (20.4 percent), and energy producing facilities (12.7 percent).

Using the Scopes framework, 89 percent of total 2019 emissions can be directly attributed to the City as Scope 1 and 2 emissions, while 11 percent of emissions are associated City activities but are considered Scope 3 emissions because they occur outside of City limits. However, it is important to note that this inventory does not include the full gamut of Scope 3 categories described by the GPC, and therefore likely undercounts total Scope 3 emissions.

Summary of 2012 Emissions Inventory Comparison

It is estimated that total community-wide GHG emissions increased 8 percent between 2012 and 2019, from 1,308, 249 MT CO_2e to 1,413,026 MT CO_2e. As shown in **Table 5-1**, the overall increase in GHG emissions was primarily attributable to the residential buildings (+9 percent) and commercial and institutional buildings (+29 percent) sub-sectors. New construction, particularly involving high energy-intensity uses, such as in the life sciences and technology economic sectors, are a primary cause of these increases. Additional energy consumption from new construction was offset by energy efficiency improvements enabled through programs, including the City's Building Energy Use Disclosure Ordinance.

Table 5-1: Comparison of Cambridge Community-wide Emissions 2012-2019

Sector	Sub-sector	2012 Emissions (MT CO_2e)	2019 Emissions (MT CO_2e)	Percent Change
Buildings and Energy Production	Residential Buildings	264,858	288,407	+9%
	Commercial & Institutional Buildings	410,178	528,953	+29%
	Manufacturing Industries & Construction	179,026	170,870	-5%
	Energy Industry (i.e., Energy Producing Facilities)	194,907	179,682	-8%
Transportation	On-Road Transportation	153,993	133,916	-13%
	Railways	8,945	7,579	-15%
Waste	Solid Waste Disposal	92,051	99,014	+8%
	Incineration	2,145	2,286	+7%
	Wastewater Treatment and Discharge	2,146	2,319	+8%
Total Emissions		**1,308,249**	**1,413,026**	**+8%**

Emissions generated by manufacturing industries, energy producing facilities, on-road transportation, and railways all experienced a decrease between five and 15 percent over this time period. Waste sector emissions increased for each sub-sector, with the exception of the biological treatment of waste, which did not generate emissions in 2019 (and was not included in the baseline report, therefore lacking a comparison point). The increase in wastewater treatment and discharge emissions resulted from an increase in the City of Cambridge's population between 2012 and 2019. Waste emissions from solid waste disposal and incineration increased from 2012 to 2019 due to an alternative accounting methodology, as described in **Chapter 4, Waste** above.

Considerations for Future Inventories

The benefits and value of emissions inventories grows significantly when the inventories are conducted frequently. Increasing the frequency of inventories increases the granularity of conclusions that can be drawn from observed trends and outlying values. Large gaps of time in between inventories makes it increasingly difficult to identify the causes of changes in behavior.

Inventories shine a large amount of light on where emissions come from and long-term trends in the community. However, it is also important to understand the blind spots inherent in conducting inventories. One such blind spot of an emissions inventory is that it is always historical, meaning the conclusions drawn from an inventory will be about past years. To account for this lack of present-day analysis, real-time data collection methods should be implemented that can provide up-to-date data for interim tracking of policy impacts.

One example of real-time data collection is traffic counters at key intersections. The City of Cambridge currently has counters set up at 13 intersections which collect information on every mode of transportation traveling through the intersection at 15-minute increments all day for the entire year. This information could provide excellent data on the effectiveness of policies aiming to reduce VMT or encourage mode shift. These data can then be used to estimate emissions reductions until the next inventory is conducted.

It is important to note that these data cannot take the place of an inventory. For instance, a policy may be passed that seeks to reduce vehicle ownership. Data in the form of vehicle registrations could be used to track its effectiveness and indicate after some years that vehicle ownership has in fact decreased and the policy was successful. However, what that data may not show is that all those former vehicle owners have replaced their trips with ride-hailing services, increasing their VMT and in turn increasing GHG emissions. This would provide a feedback loop to the City to show that the policy was effective in its main aim of reducing vehicle ownership, but that reduction did not contribute to a reduction in GHG emissions as the City had hoped it would. For this reason, emissions inventories and real-time data collection and analysis must both occur, complementing each other and working to inform effective policy creation.

Data sources, availability, and accuracy all constrain the ability of an inventory to provide truly nuanced analysis, particularly when it comes to informing policy decisions. It is essential that professionals with in-depth planning, policy, and engineering knowledge fill the gaps present in any inventory or proxy data analysis.

Stationary Energy

Unlike electricity and natural gas, fuel oil in the City of Cambridge is supplied by many different private companies. For the purposes of this and previous inventories, residential fuel oil consumption was estimated based on the number of housing units in Cambridge by type, and a percentage of units determined to be heated with fuel oil from the *2015-2019 American Community Survey 5-Year Estimates*. For the commercial buildings sector, fuel oil use estimates were based on the total number of employees, establishments by PBA, and the average expected energy use per employee for each

PBA. Using customer data instead of estimating consumption would improve the accuracy of future inventories.

Transportation

Incorporating analysis of additional modes of transportation would add another level of insight to future inventories. Micromobility, active transportation, and on-demand ride hailing services all influence emissions from the Transportation sector in various ways. Analyzing activity in these modes would further inform policy decisions as Cambridge continues to reduce its GHG emissions.

Approach. It is strongly recommended that the transport model being developed by the Boston Region MPO is used to develop a geographical approach to estimating GHG emissions from on-road transportation. This will provide a much better estimate of the transportation activity within the City and will complement the analysis conducted in this report using the 'resident activity' and 'fuel sales' approaches, especially given the particular context of Cambridge's adjacency to other major urban areas. Discussions with CTPS suggest a model reflecting 2016 activity will be available in the coming months.

Electric Vehicle Charging Station Data. The lack of data on electric vehicle charging stations is a limit of this inventory that will hopefully be improved in future inventories. For example, it was not possible to differentiate between resident and non-resident use, and it was further unclear how many home-based chargers may have been omitted from the data. However, due to the small share of electric vehicles in the private vehicle sector the error associated with emissions from charging stations is minor in the context of the entire inventory. As the share of electric vehicles grows and charging stations proliferate around the City, the acquisition of data must improve to ensure the integrity of future GHG emissions inventories.

Waste

As noted, employee disposal rates were obtained from CalRecycle, derived from its 2014 Waste Characterization Study. Although these remain the best estimates in the waste industry for associating employment with waste generation, they are neither current nor geographically relevant. The accuracy of future inventories would be better served if such data were up-to-date and local/regional. The City of Cambridge can work with MassDEP and other partners to improve the research in this area.

This 2019 Community-wide GHG Emissions Inventory used default inputs to characterize the MSW generated within the City of Cambridge. The City's 2019 Waste Characterization Study could not be used, as its outputs were not compatible with GPC Equation 8.1. Future inventories should leverage Cambridge-specific characterization results, and the City should conduct future characterization studies in a manner that is consistent with the GPC's equation for calculating DOC.