City of Baltimore
2017 Greenhouse Gas Emissions Inventory Report

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Abstract

This report provides an analysis of greenhouse gas emissions resulting from activities occurring within Baltimore City during the 2017 calendar year. We estimate emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) measured using the common metric of CO_2 equivalents (CO_2eq), using both a 100-year global warming potential (GWP) and a 20-year GWP. Following the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC), we estimate emissions from six sectors: (1) stationary energy, (2) transportation, (3) waste, (4) industrial processes and product use, (5) agriculture, forestry, and other land use, and (6) other scope 3 emissions. In total, Baltimore City was responsible for the emission of 7,486,783 metric tons CO_2eq when considering a 100-year time horizon, or 8,556,989 metric tons CO_2eq when considering a 20-year time horizon for the global warming impact of CH_4 and N_2O. Baltimore's total CO_2eq emissions are effectively $\sim$14.3% higher when considering the near-term warming potential of CH_4 emissions. Emission totals are dominated by Scope 1 and Scope 2 emissions from the stationary energy sector, which contribute $\sim$72% of the total CO_2eq emissions. $\sim$25% of the total emissions result from transportation within Baltimore, and $\sim$3% of emissions are generated by waste management.

The Baltimore Office of Sustainability has set targets to reduce the city's greenhouse gas emissions by 25% from a 2007 baseline inventory by the year 2020, and by 30% by 2025. In order to evaluate the city's progress toward this target, we also conduct an evaluation of emissions in 2007 relative to emissions in 2017. In order to make a consistent comparison, we re-computed Baltimore City's emissions in 2007 using analogous methods to the 2017 inventory. We find that Baltimore City was responsible for the emission of 8,570,441 tons CO_2eq (100-year GWP), or 10,174,145 tons CO_2eq (20-year GWP) in 2007. Thus, after matching data sources between inventory years, Baltimore City has reduced the 100-year global warming potential of its greenhouse gas emissions by 11.4%, and has reduced the 20-year global warming potential of its greenhouse gas emissions by 14.9% from 2007 to 2017. While these emissions reductions demonstrate significant progress toward the emissions reduction goals, especially when considering a 20-year GWP, the City of Baltimore will need to expedite its future emissions reductions in order to safely achieve the 30% reduction target by 2025.

While there has been an overall reduction in total CO_2eq emissions since 2007, the emissions trend varies significantly by emissions source. A significant decrease ($\sim$68.5%) in CH_4 emissions from the Quarantine Road Landfill between 2007 and 2017 is the primary cause of the larger short-term warming reduction, although much of that decrease is offset by increasing emissions from utility natural gas consumption and fugitive natural gas. Emissions from utility natural gas in the industrial and commercial sectors have increased by $\sim$50.0%, and fugitive natural gas emissions from leaky pipelines within the city limits have risen by $\sim$13.4%, despite a $\sim$23.8% decrease in residential natural gas consumption. Notably, emissions from utility electricity generation for residential buildings has decreased by $\sim$31.9%, and emissions from utility electricity generation for industrial, institutional, and commercial facilities has decreased by $\sim$24.0%. This significant reduction in emissions from electricity generation is driven by a simultaneous decrease in the use of coal power and an increase in the use of natural gas to generate electricity for the regional grid.

Contents

Introduction

Context

In 2009, the City of Baltimore and the Baltimore Office of Sustainability conducted its first greenhouse gas emissions inventory, which analyzed emissions from the 2007 calendar year. Shortly after in 2012, the Baltimore Office of Sustainability set a target of reducing the city's total emissions by 15% from 2010 to 2020 in the Baltimore Climate Action Plan. That target was updated in the 2019 Sustainability Plan when a goal of 25% emissions reductions from the 2007 baseline report by 2020 was set. In the intervening years, greenhouse gas emissions management has become a major environmental priority – and Baltimore City has dedicated itself to many such initiatives. In 2015, Baltimore City became certified through the STAR Communities Rating system, which set baselines for emissions reduction among other environmental improvement goals. In 2017, Mayor Pugh stated a commitment to upholding the Paris Climate Agreement in the wake of President Trump's statement of a nationwide withdrawal, and in 2019, Baltimore was selected for the LEED for Cities and Communities program – in which its progress towards the 2015 STAR Communities goals will be assessed and reasserted. This report exists primarily to assess Baltimore's progress towards the goal of 25% emissions reduction by 2020, but will also show progress towards commitments made in STAR Communities, and will establish a 2017 baseline for LEED for Cities and Communities and other reduction initiatives. Finally, this report will detail the decisions and figures which factor into the final reported values as to lay a clear path for future Baltimore emissions inventories.

Beyond this report, the Baltimore–Washington metropolitan region has become a national testbed for urban greenhouse gas and air quality monitoring, and the results presented here are one piece of a much broader research context. The Baltimore–Washington is now the focus of the National Institutes of Standards and Technology (NIST) Northeast Corridor Urban Test Bed Project [1]. The goal of this project is to determine how cities can best monitor their greenhouse gas emissions and to set best practice guidelines for doing so. The project is a multi-institutional effort, including collaborators from the National Oceanic and Atmospheric Administration (NOAA), University of Maryland, Purdue University, and Northern Arizona University, among other participants. The project not only includes efforts to build state-of-the-art emissions inventories for the region [2] but also includes efforts to monitor emissions from the region using greenhouse gas observations collected in the Earth's atmosphere [3, 4, 5, 6, 7, 8]. In fact, several of NIST's atmospheric observation sites are located in or near Baltimore City, one on Reiserstown Road, one in Clifton Park, and one in nearby Halethorpe, Maryland. Beyond this NIST effort, Baltimore is also a Research Center for Solutions for Energy, AiR, Climate and Health Center (SEARCH) run by Johns Hopkins University and funded by the U.S. Environmental Protection Agency (EPA). As part of this effort, researchers have installed approximately 50 air quality sensors to evaluate disparities in air pollution levels across Baltimore City [9]. These combined efforts put Baltimore at the forefront of national efforts to monitor urban greenhouse gases and air pollution.

Geographic Boundary and Time Span

In this report, we consider all major greenhouse gas emissions associated with activities that occur within the Baltimore City geographic boundary, with the exception of emissions from the Port of Baltimore. Port of Baltimore activities are outside of the jurisdiction of the City of Baltimore, and thus their emissions are excluded from this inventory. We consider Scope 1, Scope 2, and Scope 3 emissions in this report. Scope 1 emissions are defined as emissions that are released within the Baltimore City boundary. Scope 2 and Scope 3 emissions are defined as emissions that are released outside of the Baltimore City boundary, but for the sake of activities occurring within Baltimore City. More specifically, Scope 2 emissions result from the generation of electricity for end-use within Baltimore City, and Scope 3 emissions describe all other emissions released outside of Baltimore City that are due to activities occurring within Baltimore. All emissions in this report occur during the 2017 calendar year, from January 1, 2017 to December 31, 2017. In the appendix of this report, we conduct the same analysis of emissions for the 2007 calendar year.

Greenhouse Gas Inventory Reporting Protocol

In this report, we generally follow the *Global Protocol for Community-Scale Greenhouse Gas Emission Inventories: An Accounting and Reporting Standard for Cities* (GPC) framework put together by the World Resources Institute, C40 Cities Climate Leadership Group, and ICLEI Local Governments for Sustainability [10]. The GPC follows recommendations from the 2006 Intergovernmental Panel on Climate Change (IPCC) *Guidelines for National Greenhouse Gas Inventories*. When discrepancies arise in the GPC, we defer to the IPCC Fifth Assessment Report (AR5) and associated documents from the IPCC for guidance [11]. In some instances, we invoke our professional judgement and scientific experience to suggest alternative ways of characterizing Baltimore emissions (which may deviate from the GPC guidelines) in order to illustrate a broader perspective on the accounting of urban greenhouse gas emissions. However, the GPC framework is always the default reporting protocol in this report. The GPC provides a useful framework for classifying urban emissions, all of which can be grouped into one of six main sectors:

1. Stationary Energy
2. Transportation
3. Waste
4. Industrial Processes and Product Use (IPPU)
5. Agriculture, Forestry, and Other Land Use (AFOLU)
6. Any other emissions occurring outside the geographic boundary as a result of city activities

Each of these six main sectors are further broken down by subsectors, which are listed in Table 0.1. The numbered chapters of this report each correspond to one of these six sectors.

Global Warming Potential of Greenhouse Gases

While there is a diverse mix of anthropogenic greenhouse gases found in our atmosphere, in this report we focus on just the three most dominant greenhouse gases: carbon dioxide (CO_2), methane

Table 0.1: Categorization of Sectors and Sub-sectors by the GPC

Sector	
	Sub-sector
1. Stationary Energy	
1.1	Residential buildings
1.2	Commercial and institutional buildings and facilities
1.3	Manufacturing industries and construction
1.4	Energy industries
1.5	Agriculture, forestry, and fishing activities
1.6	Non-specified sources
1.7	Fugitive emissions from coal
1.8	Fugitive emissions from oil and natural gas
2. Transportation	
2.1	On-road
2.2	Railways
2.3	Waterborne navigation
2.4	Aviation
2.5	Off-road
3. Waste	
3.1	Solid waste disposal
3.2	Biological treatment of waste
3.3	Incineration and open burning
3.4	Wastewater treatment and discharge
4. Industrial Processes & Product Use (IPPU)	
4.1	Industrial processes
4.2	Product use
5. Agriculture, Forestry, & Other Land Use (AFOLU)	
5.1	Livestock
5.2	Land
5.3	Aggregate sources and non-CO_2 sources on land
6. Other Scope 3	
6.1	All Other

(CH_4), and nitrous oxide (N_2O). Each of these three gases have different atmospheric lifetimes and radiation-absorbing strengths, yielding different greenhouse effects from each gas over different timescales. To account for these differences, it is common practice to compare multiple greenhouse gases using a single unit-less metric called the global warming potential (GWP), which indicates the total radiative power of a greenhouse gas relative to carbon dioxide over a given time period. GWPs are the primary metric that the Intergovernmental Panel on Climate Change (IPCC) recommends using to compare the climate effects of different long-lived greenhouse gases. In this report, we use the global warming potentials of methane and nitrous oxide from the IPCC Fifth Assessment Report (AR5) [11].

Global warming potentials are a unitless metric, and can be thought of as a scaling factor to convert tons of CH_4 or tons of N_2O to tons of carbon dioxide equivalents (CO_2eq). These global warming potentials are summarized in Table 0.2, and are used throughout the report to compute emissions of CH_4 and N_2O in units of tons CO_2eq. Note that the GWP of carbon dioxide is 1.0

Table 0.2: IPCC Global Warming Potential of Greenhouse Gases

Greenhouse Gas	20-year GWP	100-year GWP
Carbon Dioxide	1	1
Methane	84	28
Nitrous Oxide	264	265

Data from Table 8.7 of the IPCC AR5 Report. GWP values do not include climate-carbon feedbacks. These values reflect the most current version of the IPCC Assessment Reports (AR5), which included changes to the GWPs of CH_4 and N_2O from previous reports.

over any time period (since it is defined relative to itself), and thus 1 ton CO_2 = 1 ton CO_2eq. At the time of writing, the U.S. Environmental Protection Agency and the Maryland Department of the Environment have not yet updated their greenhouse gas inventory protocol to reflect the current IPCC recommended global warming potentials. Furthermore, both agencies only report CO_2eq emissions using the 100-year GWP. The IPCC AR5 explicitly notes that there is no scientific argument for selecting a 100-year GWP over the other choices, and that "the choice of time horizon is a value judgement [11]." For this reason, we include both the 20-year GWP and the 100-year GWP for each greenhouse gas analyzed. For those interested in short-term climate change impacts, a 20-year time horizon is better representative than a 100-year time horizon. The GWP of methane is 84 over a 20 year time period (meaning that methane is cumulatively 84 times more potent than carbon dioxide during the first 20 years after its emission), or 28 over a 100 year time period. In other words, 1 ton of CH_4 has the same greenhouse effect as 84 tons of CO_2 averaged over the first 20 years after its release, and it has the same greenhouse effect as 28 tons of CO_2 averaged over the first 100 years after its release. The GWP of CH_4 decreases over time because CH_4 has a relatively short lifetime in the atmosphere, with a half-life of about 10 years. Thus, the greenhouse effect of CH_4 is strongest in the first few years after being emitted, and the effect decays over time. However, the effect doesn't decay to zero: when atmospheric CH_4 is destroyed, most of its carbon is oxidized to CO_2. Because CH_4 is predominantly converted to CO_2, the warming effect of CH_4 emissions remains nonzero even after the CH_4 has been removed from the atmosphere. Overall, however, the total greenhouse effect caused by CH_4 emissions is predominantly felt in the first few years after the CH_4 is released, and thus the short-term effects of CH_4 emissions are better represented by the 20-year GWP.

The GWP of nitrous oxide is 264 over a 20 year time period, or 265 over a 100 year time period. Unlike CH_4, emissions of N_2O have a relatively long atmospheric lifetime ($>$ 100 years), and thus the total greenhouse effect of N_2O remains relatively constant over the first century after its release. On a per-molecule basis, N_2O is the most potent greenhouse gas analyzed in this report.

Throughout this report, total emissions of carbon dioxide, methane, and nitrous oxide will be reported together using the common unit of carbon dioxide equivalents (CO_2eq), as defined in Equation 1. Here, M_{CO_2eq} is the mass of all gases expressed in units of CO_2 equivalents, M_{CO_2} is the mass of CO_2, M_{CH_4} is the mass of CH_4, and M_{N_2O} is the mass of N_2O, all in units of metric tons (1 metric ton = 1000 kilograms = 2204.62 pounds). Weighted by global warming potential, M_{CO_2eq} represents the total emissions of all major greenhouse gases in a single metric, in units of metric tons.

$$M_{CO_2eq} = M_{CO_2} + (\text{GWP}_{CH_4} \times M_{CH_4}) + (\text{GWP}_{N_2O} \times M_{N_2O}) \quad (1)$$

Summary of Results

Table 0.3: Categorization of Sectors and Sub-sectors by GPC

Sector	Total CO_2eq (metric tons)	
Sub-sector	20 year GWP	100 year GWP
1. Stationary Energy	**6,063,208**	**5,359,396**
1.1 Residential buildings*	1,379,360	1,375,279
1.2 Commercial and institutional buildings and facilities	3,246,701	3,235,961
1.3 Manufacturing industries and construction	389,717	389,098
1.4 Energy industries	14,902	14,882
1.5 Agriculture, forestry, and fishing activities	–	–
1.6 Non-specified sources	–	–
1.7 Fugitive emissions from coal	–	–
1.8 Fugitive emissions from oil and natural gas*	1,032,528	344,176
2. Transportation	**1,913,890**	**1,909,561**
2.1 On-road	1,782,086	1,780,993
2.2 Railways	–	–
2.3 Waterborne navigation*	3,487	3,328
2.4 Aviation	–	–
2.5 Off-road*	128,317	125,240
3. Waste	**579,891**	**217,825**
3.1 Solid waste disposal	398,610	146,224
3.2 Biological treatment of waste	–	–
3.3 Incineration and open burning	–	–
3.4 Wastewater treatment and discharge	181,281	71,601
4. Industrial Processes & Product Use (IPPU)	**0**	**0**
4.1 Industrial processes	–	–
4.2 Product use	–	–
5. Agriculture, Forestry, & Other Land Use (AFOLU)	**0**	**0**
5.1 Livestock	–	–
5.2 Land	–	–
5.3 Aggregate sources and non-CO_2 sources on land	–	–
6. Other Scope 3	**0**	**0**
6.1 Other	–	–
Total Emissions	**8,556,989**	**7,486,783**

*Sectors marked with an asterisk include emission sources not included in previous emissions inventories.

Residential buildings now includes emissions from home heating oil. Fugitive utility natural gas emissions are now included in the stationary energy sector. Recreational marine vessels are now included in the waterborne navigation sector. Industrial equipment, commercial equipment, construction equipment, railroad equipment, lawn and garden equipment, and golf carts are now included in the off-road transportation sector.

Table 0.4: Categorization of Sectors and Sub-sectors by Scope

Sector	**Scope 1** Total CO_2eq		**Scope 2** Total CO_2eq		**Scope 3** Total CO_2eq	
Subsector	20y GWP	100y GWP	20y GWP	100y GWP	20y GWP	100y GWP
1. Stationary	**3,266,108**	**2,575,107**	**2,797,101**	**2,784,290**	**0**	**0**
1.1	659,312	658,530	720,048	716,750	–	–
1.2	1,169,648	1,168,421	2,077,052	2,067,540	–	–
1.3	389,717	389,098	–	–	–	–
1.4	14,902	14,882	–	–	–	–
1.5	–	–	–	–	–	–
1.6	–	–	–	–	–	–
1.7	–	–	–	–	–	–
1.8	1,032,528	344,176	–	–	–	–
2. Transport	**1,913,890**	**1,909,561**	**0**	**0**	**0**	**0**
2.1	1,782,086	1,780,993	–	–	–	–
2.2	–	–	–	–	–	–
2.3	3,487	3,328	–	–	–	–
2.4	–	–	–	–	–	–
2.5	128,317	125,240	–	–	–	–
3. Waste	**579,891**	**217,825**	**0**	**0**	**0**	**0**
3.1	398,610	146,224	–	–	–	–
3.2	–	–	–	–	–	–
3.3	–	–	–	–	–	–
3.4	181,281	71,601	–	–	–	–
4. IPPU	**0**	**0**	**0**	**0**	**0**	**0**
4.1	–	–	–	–	–	–
4.2	–	–	–	–	–	–
5. AFOLU	**0**	**0**	**0**	**0**	**0**	**0**
5.1	–	–	–	–	–	–
5.2	–	–	–	–	–	–
5.3	–	–	–	–	–	–
6. Other	**0**	**0**	**0**	**0**	**0**	**0**
6.1	–	–	–	–	–	–
Total	**5,759,888**	**4,702,493**	**2,797,101**	**2,784,290**	**0**	**0**

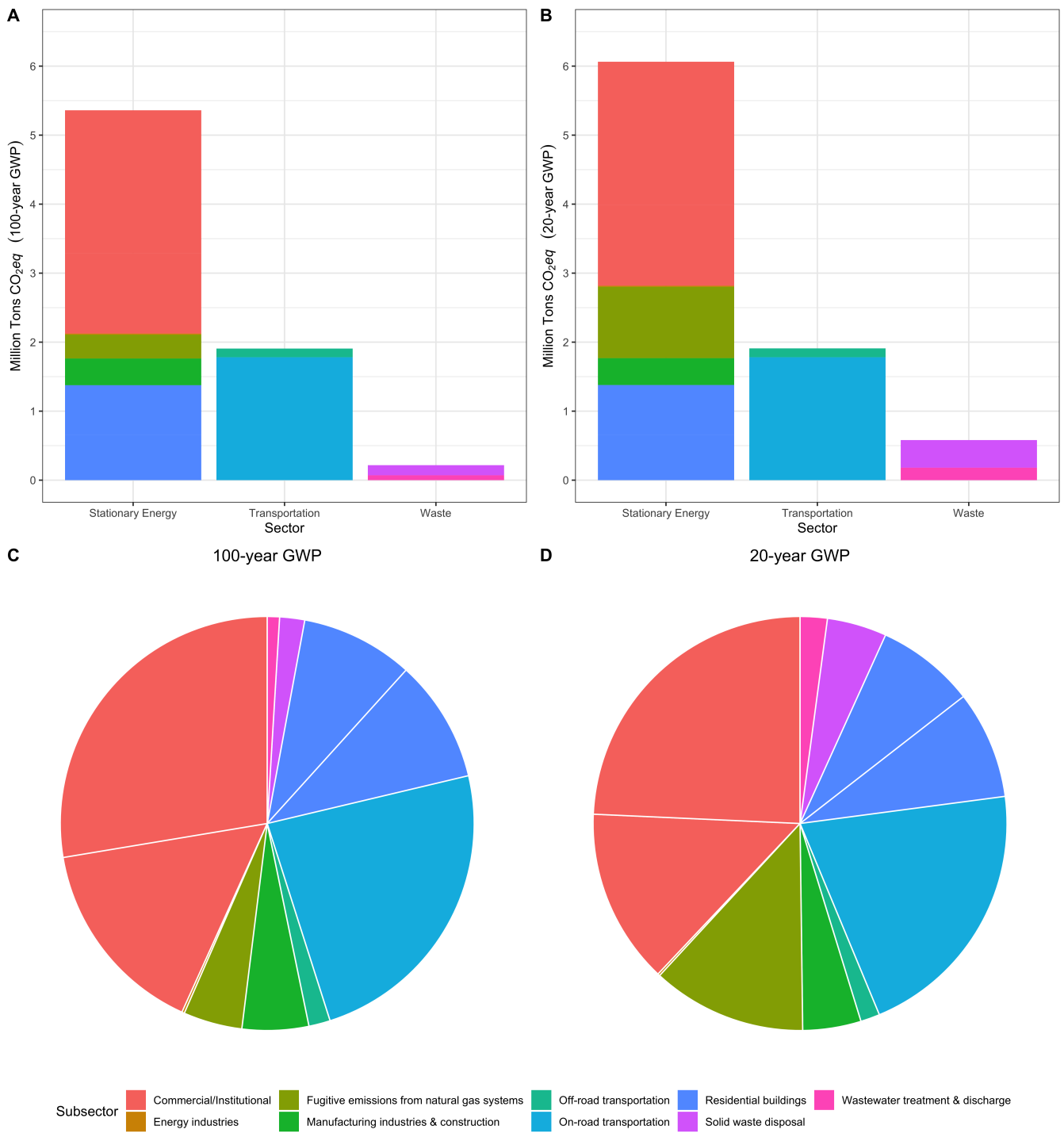

Figure 1: Summary of total CO_2eq emissions in 2017 by sector and subsector. Subfigures **A** and **C** both show the total emissions measured using a 100-year GWP, and Subfigures **B** and **D** both show the total emissions measured using a 20-year GWP. Note that the relative contribution of solid waste disposal and fugitive natural gas emissions to the total CO_2eq emissions is significantly larger when considering a 20-year GWP. Note that the Commercial/Institutional and Residential buildings subsectors are separated into Scope 1 and Scope 2 as well.

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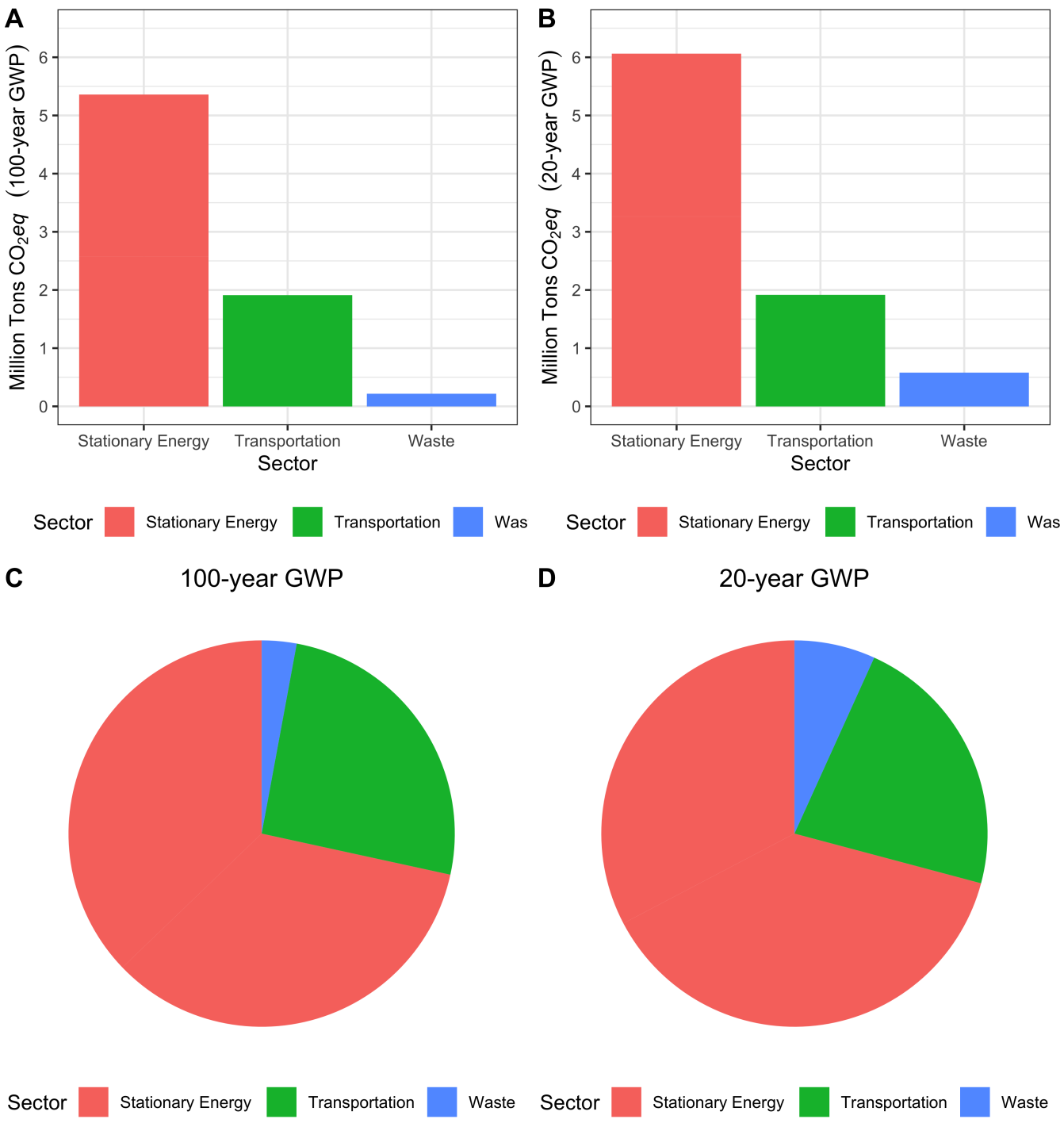


Figure 2: Summary of total CO_2eq emissions in 2017 by GPC sector. While emissions from the waste sector appear to be small relative to transportation and stationary energy emissions, it is important to note that emissions from the Wheelabrator Trash Incinerator and the Curtis Bay Medical Waste Incinerator are not counted toward the waste sector emission totals since they are classified as "Stationary Energy" by the GPC. Emissions from the IPPU, AFOLU, and Other Scope 3 sectors are omitted from this figure since there are no reported emissions from those sectors.

Sector 1 Stationary Energy

Primer on Utility Electricity in Baltimore

The mix of fuels used to generate electricity used in Baltimore has a strong influence on the total CO2*eq* emissions from the electricity sector. Fossil fuels, such as coal, oil, and natural gas, produce significant greenhouse gas emissions when combusted to produce electricity, whereas carbon neutral and renewable energy sources, such as nuclear, solar, wind, and hydro power, produce virtually no greenhouse gas emissions during operation.

The energy utility company Baltimore Gas and Electric (BG&E) is the sole electricity transmission and distribution utility for residential, commercial, and industrial facilities in the City of Baltimore. In 2017, BG&E reported delivery of nearly 6.5 billion kilowatt-hours (kWh) of electricity across residential, industrial, and commercial sectors in the city of Baltimore, as detailed in Table 1.0.1 [12].

Table 1.0.1: Electricity Supply by BGE in 2017

Sector	kWh electricity	% of Total
Residential	1,657,029,183	25.7%
Commercial & Industrial	4,779,868,437	74.3%
Total	6,436,897,620	100%

PJM Interconnection, the regional electricity grid operator, is the primary supplier of electricity to BG&E. Electricity consumers who purchase BG&E's Standard Offer Service (SOS) receive electricity from PJM Interconnection, generated by PJM suppliers. BG&E does not have control over the electricity generation methods that PJM's suppliers use to generate electricity for the regional grid, but BG&E customers do have the option to purchase electricity from an outside supplier. Customers may choose to do this because a non-PJM electricity supplier, for example, may use a higher fraction of renewable energy, or offer a rate that is competitive with the SOS supplied by BG&E. However, BG&E has not provided detailed data on how many customers opted out of the SOS and what their alternative fuel generation mix was, so we base all emissions calculations on the Standard Offer Service. PJM reports the fractional contribution of each electricity generation method to their total grid supply, as well as the CO_2 emission factors (in lbs/MWh, converted here to tons/kWh) of each fuel type, as detailed in Table 1.0.2. Overall, PJM suppliers generate about 35.9% of their electricity from nuclear power, 32.2% from coal, 26.7% from natural gas, 3.9% from renewable sources like wind, hydro, and solar power, and 1.25% from other fossil fuel based sources, including solid waste incinerators like the Baltimore Wheelabrator facility. Baltimore's two major solid waste incinerators, Wheelabrator Baltimore and Curtis Bay Medical Waste Services, both export their generated electricity to the regional PJM grid. In turn, BG&E delivers that solid waste derived electricity across its entire service domain, and not necessarily all within Baltimore

City. Thus, Baltimore City's share of solid waste incinerator emissions are reflected in the PJM grid emission factors, which are a weighted average of the emission factors for each of the electricity production methods used by all PJM suppliers, including Wheelabrator Baltimore and Curtis Bay Medical Waste Services. To adhere to the GPC guidelines and to avoid double counting emissions from Baltimore's solid waste incinerators, we do not report emissions from Wheelabrator Baltimore or Curtis Bay Medical Waste Services separately in the overall totals from Sector 3 Waste, and instead simply acknowledge that these two facilities contribute to the regional grid weighted average CO_2 emission factor reported by PJM and supplied by BG&E. Thus, emissions from the Baltimore's waste incinerators are included in the total emissions from residential, commercial, and industrial electricity generation in Sections 1.1 and 1.2 via the PJM emission factors. Note however that power plants using municipal solid waste as a fuel source to generate electricity for PJM have one of the highest emission factors of all generation methods, including most coal-fired power plants (Table 1.0.2).

Table 1.0.2: PJM Fuel Mix and Corresponding Emission Factors

Fuel Type	Fuel Sub-type	% of Total	CO_2 EF
Nuclear	Nuclear	35.926	0
Coal	Bituminous/Anthracite	27.2697	9.535×10^{-4}
Gas	Natural Gas	26.6702	4.072×10^{-4}
Coal	Sub-Bituminous	3.5384	10.32×10^{-4}
Wind	Wind	2.6277	0
Coal	Waste/Other	1.4121	12.15×10^{-4}
Hydro	Conventional	1.1271	0
Solid Waste	Municipal Solid Waste	0.4668	10.74×10^{-4}
Gas	Captured Landfill Gas	0.3043	0.504×10^{-4}
Solar	Photovoltaic	0.1834	0
Wood	Wood Waste Solids	0.1817	1.538×10^{-4}
Oil	Petroleum Coke	0.1302	12.71×10^{-4}
Gas	Other	0.0393	7.555×10^{-4}
Wood	Black Liquor	0.0386	2.299×10^{-4}
Fuel Cell	Non-Renewable	0.0283	0
Gas	Captured Coal Mine Gas	0.0218	5.272×10^{-4}
Oil	Distillate Fuel Oil	0.019	8.750×10^{-4}
Oil	Residual Fuel Oil	0.0126	11.44×10^{-4}
Other	Other	0.0017	0.694×10^{-4}
Biomass	Other Biomass Gases	0.0009	0.252×10^{-4}
Solid Waste	Tire Derived Fuel	0.0002	9.752×10^{-4}
Total	**Weighted**	**100**	$\mathbf{4.302 \times 10^{-4}}$

CO_2 Emission Factors (EF) in this table are in units of metric tons/kWh, and are rounded. Data from PJM [13].

Notably, PJM does not report an emission factor for CH_4, despite using fuels that emit small amounts of CH_4 during combustion. PJM does report an emission factor for nitrogen oxides (NO_x), which includes NO_2, NO, and some N_2O, but one must be careful to not apply the emission factor for this mixture of nitrogen species to compute N_2O emissions alone. To circumnavigate this problem, we can use the EPA's reported CO_2, CH_4, N_2O emission factors for each fuel that PJM utilizes to

compute the CH_4 and N_2O emission factors that correspond to the reported CO_2 emission factors in PJM's fuel mix [14]. We do this by multiplying PJM's CO_2 emission factor by the EPA's CH_4:CO_2 and N_2O:CO_2 emission factor ratios for each fuel, and then weighting by the percent utilization of each fuel to compute the overall weighted emission factor. Weighted by usage, the fuels that PJM utilizes emit about 12,073 times more CO_2 than CH_4, and about 84,121 times more CO_2 than N_2O. Thus, the CO_2 emission factor from PJM of 4.302×10^{-4} tons CO_2/kWh corresponds to CH_4 and N_2O emission factors of 3.56×10^{-8} tons CH_4/kWh and 5.11×10^{-9} tons N_2O/kWh. These emission factors only indicate emissions resulting directly from fuel combustion, and they do not account for any fugitive emissions during coal mining or natural gas extraction and transport. These overall weighted emission factors for PJM's electricity generation methods are summarized in Table 1.0.3, and utilized in Section 1.1 and Section 1.2.

Table 1.0.3: PJM Electricity Generation Emission Factors

Greenhouse Gas	Emission Factor	Units
CO_2	4.302×10^{-4}	Tons CO_2/kWh
CH_4	3.563×10^{-8}	Tons CH_4/kWh
N_2O	5.114×10^{-9}	Tons N_2O/kWh

Primer on Utility Natural Gas in Baltimore

Baltimore Gas and Electric (BG&E) is the sole supplier of natural gas to residential, commercial, and industrial facilities in the City of Baltimore. In 2017, BG&E reported delivery of over 329 million therms of natural gas to consumers across all sectors in the City of Baltimore [12]. This supply is broken down by sector in Table 1.0.4.

Table 1.0.4: Natural Gas Supply by BGE in 2017

Sector	Natural Gas (therms)	% of Total
Residential	109,907,674	33.4%
Commercial & Industrial	219,216,234	66.6%
Total	329,123,908	100%

The United States Energy Information Administration (EIA) reports a CO_2 emission factor of 5.307×10^{-3} tons CO_2/therm for pipeline natural gas [15]. The U.S. Environmental Protection Agency reports a similar CO_2 emission factor for natural gas combustion, as well as emission factors for methane (1×10^{-7} tons CH_4/therm) and nitrous oxide (1×10^{-8} tons N_2O/therm) [14]. The U.S. EPA only reports CH_4 and N_2O emission coefficients with one significant digit. Each of these emission factors applies only to emissions from natural gas combustion, and does not include fugitive emissions of natural gas from any point in the supply chain. Fugitive emissions of methane from natural gas leaks are considered separately in Section 1.8. These emission factors for delivered natural gas combustion are summarized in Table 1.0.5 and used to compute emissions from natural gas combustion in Section 1.1 and Section 1.2.

Table 1.0.5: Natural Gas Combustion Emission Factors

Greenhouse Gas	Emission Factor	Units
CO_2	5.307×10^{-3}	Tons CO_2/therm
CH_4	1×10^{-7}	Tons CH_4/therm
N_2O	1×10^{-8}	Tons N_2O/therm

1.1 Residential Buildings

1.1.1 Utility Electricity Generation

Calculations in this section utilize information presented in the "Primer on Utility Electricity in Baltimore" section at the beginning of Sector 1 Stationary Energy. From Table 1.0.1, Baltimore Gas and Electric reported 1,657,029,183 kWh of electricity delivered to residential buildings in 2017. In this analysis, we assume that 100% of this electricity is supplied to BG&E by the regional grid operator, PJM Interconnection. This is equivalent to assuming that all BG&E customers purchase the Standard Offer Service. All emissions from this subsector are considered Scope 2 emissions, since BG&E utilizes electricity purchased from power plants outside of Baltimore City. The total CO_2 emissions resulting from the generation of this residential electricity can be computed using the weighted fuel mix emission factor from PJM Interconnection (Table 1.0.3), as calculated below [13].

$$(1{,}657{,}029{,}183 \text{ kWh}) \cdot \left(4.302 \times 10^{-4} \ \frac{\text{tons } CO_2}{\text{kWh}}\right) = 712{,}852 \text{ tons } CO_2$$

Emissions of N_2O and CH_4 can be computed similarly using the emission factors derived from PJM's CO_2 emission factor and the EPA's fuel emission factors.

$$(1{,}657{,}029{,}183 \text{ kWh}) \cdot \left(5.114 \times 10^{-9} \ \frac{\text{tons } N_2O}{\text{kWh}}\right) = 8.5 \text{ tons } N_2O$$

These N_2O emissions from the residential electricity sector are equivalent to 2,236 tons of CO_2 over the next 20-years, or 2,245 tons of CO_2 over the next 100-years.

$$(1{,}657{,}029{,}183 \text{ kWh}) \cdot \left(3.563 \times 10^{-8} \ \frac{\text{tons } CH_4}{\text{kWh}}\right) = 59.1 \text{ tons } CH_4$$

These methane emissions from the residential electricity sector are equivalent to 4,960 tons of CO_2 over the next 20-years, or 1,653 tons of CO_2 over the next 100-years.

The total emissions from Section 1.1.1 are summarized in Table 1.1.6. Overall, emissions of CO_2 dominate the greenhouse gas emissions from residential electricity generation, although emissions of CH_4 and N_2O are non-negligible, especially in the immediate future.

1.1.2 Utility Natural Gas Combustion

Calculations in this section utilize information presented in the "Primer on Utility Natural Gas in Baltimore" section at the beginning of Sector 1 Stationary Energy. From Table 1.0.4, Baltimore Gas and Electric reported 109,907,674 therms of natural gas delivered to the residential sector in 2017. For this analysis, we assume that 100% of the delivered natural gas is combusted and released to the atmosphere. These emissions do not include emissions of methane leaked to the atmosphere

Table 1.1.6: Emissions from Residential Electricity Generation

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	712,852	712,852	712,852
CH_4	59.1	4,960	1,653
N_2O	8.5	2,236	2,245
Total	–	**720,048**	**716,750**

during the transportation, delivery, and usage of the natural gas, which are computed separately in Section 1.8. We can use the CO_2 emission coefficient for natural gas reported by the U.S. EIA to compute the CO_2 emissions from residential natural gas combustion [15]:

$$(109{,}907{,}674 \text{ therms}) \cdot \left(5.307 \times 10^{-3} \ \frac{\text{tons } CO_2}{\text{therm}}\right) = 583{,}280 \text{ tons } CO_2$$

Similarly, we can use the natural gas emission factors of CH_4 and N_2O, as reported by the U.S. EPA, to compute the emissions of CH_4 and N_2O from natural gas combustion [14]:

$$(109{,}907{,}674 \text{ therms}) \cdot \left(1 \times 10^{-7} \ \frac{\text{tons } CH_4}{\text{therm}}\right) = 11.0 \text{ tons } CH_4$$

$$(109{,}907{,}674 \text{ therms}) \cdot \left(1 \times 10^{-8} \ \frac{\text{tons } N_2O}{\text{therm}}\right) = 1.1 \text{ tons } N_2O$$

The total greenhouse gas emissions from Section 1.1.2 are summarized in Table 1.1.7. Overall, direct emissions of CO_2 dominate the greenhouse gas contribution from residential natural gas combustion. These emissions are considered Scope 1 since the combustion of natural gas occurs at residential facilities within Baltimore City.

Table 1.1.7: Emissions from Residential Natural Gas Combustion

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	583,280	583,280	583,280
CH_4	11.0	924	308
N_2O	1.1	290.4	291.5
Total	–	**584,494**	**583,880**

Emissions of CH_4 from natural gas leaks are analyzed separately in Section 1.8.

1.1.3 Home Heating Oil Combustion

According to data from the U.S. Census Bureau, only about 6.15% of homes in Baltimore City are heated using home heating oil (kerosene) [16]. Most of the remaining homes are heated using natural gas ($\sim 63.6\%$) or electricity ($\sim 29.0\%$), and thus their emissions are already accounted for in Section 1.1.2 or 1.1.1, respectively. In order to estimate the amount of heating energy that would be required by the 6.15% of homes that use home heating oil, we can take the therms of residential

natural gas used to heat the 63.6% of homes that are heated by natural gas and scale it by the ratio of those percentages. However, there are end uses of residential natural gas that are generally not substituted by home heating oil, such as fueling stoves and ovens. According to data from the 2015 Residential Energy Consumption Survey by the U.S. EIA, 70.8% of the natural gas utilized by residential homes in the Mid-Atlantic region was used for space heating, and 22.3% was used for water heating [17]. We assume that space heating and water heating are the only two end-uses for home heating oil, and thus, assuming a similar heating efficiency for heating oil and natural gas, home heating oil can be a substitute for 93.1% of residential natural gas usage, according to data from the U.S. EIA RECS Table CE4.2.

The U.S. EPA reports a CO_2 emission coefficient of 7.520×10^{-3} tons CO_2/therm for petroleum fuel (about 42% higher than the emission factor for natural gas) [14]. We can synthesize the information above with this emission factor to estimate the CO_2 emissions from residential combustion of home heating oil in a single expression:

$$\left(\frac{0.0615}{0.636}\right) \cdot (0.931) \cdot (109{,}907{,}674 \text{ therms}) \cdot \left(7.520 \times 10^{-3} \ \frac{\text{tons } CO_2}{\text{therm}}\right) = 74{,}407 \text{ tons } CO_2$$

Similarly, we can estimate the emissions of CH_4 and N_2O from home heating oil combustion using emission factors reported by the U.S. EPA [14]:

$$\left(\frac{0.0615}{0.636}\right) \cdot (0.931) \cdot (109{,}907{,}674 \text{ therms}) \cdot \left(3.0 \times 10^{-7} \ \frac{\text{tons } CH_4}{\text{therm}}\right) = 3.0 \text{ tons } CH_4$$

$$\left(\frac{0.0615}{0.636}\right) \cdot (0.931) \cdot (109{,}907{,}674 \text{ therms}) \cdot \left(6.0 \times 10^{-8} \ \frac{\text{tons } N_2O}{\text{therm}}\right) = 0.6 \text{ tons } N_2O$$

Total estimated emissions from the combustion of home heating oil are summarized in Table 1.1.8. Emissions of CO_2 dominate the greenhouse gas effect caused by home heating oil combustion.

Table 1.1.8: Total Emissions from Home Heating Oil

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	74,407	74,407	74,407
CH_4	2.4	252	84
N_2O	0.5	158	159
Total	–	**74,817**	**74,650**

Summary of Emissions from Section 1.1 Residential Buildings

Adding together emissions from residential electricity production, residential natural gas combustion, and residential home heating oil combustion, the total greenhouse gas emissions from the Residential Buildings sector are summarized in Table 1.1.9.

1.2 Commercial and Institutional Buildings and Facilities

In this section, we consider emissions due to the use of stationary energy by commercial and institutional buildings and facilities. Additionally, due to limited data availability from Baltimore

Table 1.1.9: Total Emissions from Residential Buildings

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	1,370,539	1,370,539	1,370,539
CH_4	73.1	6,136	2,045
N_2O	10.2	2,685	2,695
Total	–	**1,379,360**	**1,375,279**

Sum of emissions from residential electricity usage (Table 1.1.6), residential natural gas combustion (Table 1.1.7), and home heating oil combustion (Table 1.1.8).

Gas and Electric, we also include utility electric and utility natural gas emissions from the industrial sector in this section. Available data from BG&E only reports utility usage in two categories: 1) residential and 2) industrial and commercial [12]. Thus, since industrial utility usage cannot be disentangled from commercial utility usage, we analyze both sectors together in this section. With more detailed data from BG&E, one could reassign a portion of natural gas and electricity emissions from this section to the appropriate industrial section (1.3 Manufacturing, 1.4 Energy, 1.5 Agriculture, Forestry, and Fishing Activities, or 1.6 Non-specified) in order to more accurately represent the ICLEI GPC-recommended sub-categorization of emissions, but the overall totals for the Stationary Energy sector would not change.

Note, however, that industrial emissions that are not caused by electric utility and natural gas utility usage, such as emissions from non-natural gas fuel combustion by the manufacturing and energy industries, are analyzed separately in Sections 1.3 through 1.6. The only industrial emissions that are included in Section 1.2 Commercial and Institutional Buildings and Facilities are from utility electricity and natural gas usage.

In Section 1.2.1, we compute emissions resulting from the generation of electricity used by commercial, institutional, and industrial buildings and facilities. These are considered Scope 2 emissions, since the electricity is generated by PJM Interconnection outside of Baltimore City. In Section 1.2.2, we compute emissions resulting from the combustion of natural gas by commercial, institutional, and industrial buildings and facilities. In Section 1.2.3, we analyze emissions from commercial and institutional point sources, excluding any point source emissions caused by natural gas combustion to avoid double counting Section 1.2.2.

1.2.1 Utility Electricity Generation

Calculations in this section utilize information presented in the "Primer on Utility Electricity in Baltimore" section at the beginning of Sector 1 Stationary Energy. Emissions from this subsector are computed using the same methodology and emission factors that were used in Section 1.1.1. Baltimore Gas and Electric reported 4,779,868,437 kWh of electricity delivered to industrial and commercial facilities in 2017 (Table 1.0.1). CO_2 emissions from the generation of this electricity can be computed using the weighted fuel mix emission factor from PJM Interconnection (Table 1.0.3), as calculated below.

$$(4{,}779{,}868{,}437 \text{ kWh}) \cdot \left(4.302 \times 10^{-4} \ \frac{\text{tons } CO_2}{\text{kWh}}\right) = 2{,}056{,}295 \text{ tons } CO_2$$

Emissions of N_2O and CH_4 can be computed similarly using the emission factors derived from PJM's CO_2 emission factor and the EPA's fuel emission factors.

$$(4{,}779{,}868{,}437 \text{ kWh}) \cdot \left(5.114 \times 10^{-9} \frac{\text{tons } N_2O}{\text{kWh}}\right) = 24.4 \text{ tons } N_2O$$

These N_2O emissions from the industrial and commercial electricity sector are equivalent to 6,452 tons CO_2eq over a 20-year time horizon or 6,477 tons CO_2eq over a 100-year time horizon.

$$(4{,}779{,}868{,}437 \text{ kWh}) \cdot \left(3.563 \times 10^{-8} \frac{\text{tons } CH_4}{\text{kWh}}\right) = 170.3 \text{ tons } CH_4$$

These CH_4 emissions from the industrial and commercial electricity sector are equivalent to 14,305 tons of CO_2 over the next 20-years, or 4,768 tons of CO_2 over the next 100-years. Each of these emissions are considered Scope 2 emissions, since they occur from the use of electricity generated outside of the city boundary. Total emissions from Section 1.2.1 are summarized in Table 1.2.10.

Table 1.2.10: Total Emissions from Industrial and Commercial Electricity Generation

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	2,062,160	2,062,160	2,062,160
CH_4	170.3	14,305	4,768
N_2O	24.4	6,452	6,477
Total	–	**2,077,052**	**2,067,540**

1.2.2 Utility Natural Gas Combustion

Calculations in this section utilize information presented in the "Primer on Utility Natural Gas in Baltimore" section at the beginning of Sector 1 Stationary Energy. From Table 1.0.4, Baltimore Gas and Electric reported 219,216,234 therms of natural gas across the industrial and commercial sector in 2017. As was done in Section 1.1.2, we assume that 100% of the delivered natural gas is combusted and released to the atmosphere. These emissions do not include fugitive emissions of CH_4 leaked to the atmosphere during the transportation and delivery of the natural gas, which are computed separately in Section 1.8. We can use the CO_2 emission coefficient for natural gas reported by the U.S. EIA to compute the total emissions from industrial, institutional, and commercial natural gas combustion [15]:

$$(219{,}216{,}234 \text{ therms}) \cdot \left(5.307 \times 10^{-3} \frac{\text{tons } CO_2}{\text{therm}}\right) = 1{,}163{,}381 \text{ tons } CO_2$$

Similarly, we can use the natural gas emission factors for CH_4 and N_2O from the U.S. EPA to compute the emissions of CH_4 and N_2O from industrial and commercial natural gas combustion [14]:

$$(219{,}216{,}234 \text{ therms}) \cdot \left(1 \times 10^{-7} \frac{\text{tons } CH_4}{\text{therm}}\right) = 21.9 \text{ tons } CH_4$$

$$(219{,}216{,}234 \text{ therms}) \cdot \left(1 \times 10^{-8} \frac{\text{tons } N_2O}{\text{therm}}\right) = 2.2 \text{ tons } N_2O$$

The total emissions from Section 1.2.2 are summarized in Table 1.2.11.

Table 1.2.11: Total Emissions from Industrial and Commercial Natural Gas Combustion

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	1,163,381	1,163,381	1,163,381
CH_4	21.9	1,840	613
N_2O	2.2	581	583
Total	–	**1,165,803**	**1,164,578**

1.2.3 Commercial and Institutional Point Sources

The 2017 EPA National Emissions Inventory (NEI) reports significant greenhouse gas emissions from the commercial and institutional point sources listed in Table 1.2.12 [18]. These point source emission sites include hospitals, universities, and research institutions in Baltimore City. According to the EPA NEI, most of these emissions are due to the combustion of natural gas and distillate oil. Thus, to avoid double counting the emissions due to natural gas combustion by commercial and institutional facilities, as computed in Section 1.2.2, Table 1.2.13 summarizes the subset of point source emissions in Table 1.2.12 that are not caused by natural gas combustion. We use the values in Table 1.2.13 when computing total greenhouse gas emissions in this report, but we include Table 1.2.12 to illustrate the total magnitude of emissions by point source.

Table 1.2.12: Emissions from Commercial and Institutional Point Sources (All Fuels)

Site Name	Tons CO_2	Tons CH_4	Tons N_2O
Johns Hopkins Hospital	113,144	6.1	2.7
Johns Hopkins University – Homewood	33,568	1.6	0.5
NIH Bayview Acquisition, LLC	11,976	0.2	0.2
Johns Hopkins Bayview Medical Center	10,965	0.2	0.2
Morgan State University	9,720	0	0
St. Agnes Hospital	6,618	0.1	0.04
U of MD Medical Center Midtown Campus	5,874	0.1	0.1
University of Maryland – Baltimore	188	0	0
University of Maryland Medical Center	347	0.02	0
Total	**192,401**	**8.5**	**3.8**

Data from 2017 EPA National Emissions Inventory [18]. Values reported in this table are rounded.

Summary of Emissions from Section 1.2 Commercial and Institutional Facilities

Adding together emissions from industrial and commercial electricity production and natural gas combustion, the total greenhouse gas emissions from stationary energy usage in the Commercial and Institutional Buildings and Facilities sector are summarized in Table 1.2.14.

Table 1.2.13: Emissions from Commercial and Institutional Point Sources (Non-Natural Gas)

Site Name	Tons CO_2	Tons CH_4	Tons N_2O
Morgan State University	2,352	0	0
Johns Hopkins Hospital	532	0	0
University of Maryland Medical Center	347	0	0
NIH Bayview Acquisition, LLC	221	0	0
University of Maryland – Baltimore	188	0	0
U of MD Medical Center Midtown Campus	88	0	0
Johns Hopkins Bayview Medical Center	82	0	0
St. Agnes Hospital	33	0	0
Total	**3,842**	**0**	**0**

Data from 2017 EPA National Emissions Inventory [18]. Values reported in this table are rounded. Values in this table are a subset of the values in Table 1.2.12, with emissions from natural gas removed to avoid double counting Section 1.2.2.

Table 1.2.14: Total Emissions from Commercial and Industrial Facilities

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	3,223,518	3,223,518	3,223,518
CH_4	192.3	16,150	5,383
N_2O	26.6	7,033	7,060
Total	–	**3,246,701**	**3,235,961**

Sum of emissions from industrial, commercial, and institutional electricity generation (Table 1.2.10), industrial, commercial, and institutional natural gas combustion (Table 1.2.11), and commercial and institutional point sources (Table 1.2.13).

1.3 Manufacturing Industries and Construction

1.3.1 Manufacturing and Construction Point Sources

The 2017 U.S. EPA National Emissions Inventory reports greenhouse gas emissions from point sources in the manufacturing and construction industry, as reported in Table 1.3.15 [18]. These manufacturing and construction plants all lie within the Baltimore City limits and have significant greenhouse gas emission contributions. To avoid double counting the emissions due to natural gas combustion by industrial, commercial, and institutional facilities, as computed in Section 1.2.2, Table 1.3.16 summarizes the subset of point source emissions in Table 1.3.15 that are not caused by natural gas combustion. We use the values in Table 1.3.16 when computing total greenhouse gas emissions in this report, but we include Table 1.3.15 to illustrate the total magnitude of emissions by point source. Note that only a small fraction of manufacturing and construction point source emissions ($< 4\%$) result from natural gas combustion.

Table 1.3.15: Emissions from Manufacturing Plants (All Fuels)

Plant Name	Tons CO_2	Tons CH_4	Tons N_2O
W.R. Grace & Co.	112,008	2.1	0.2
American Sugar Refining	108,117	2.1	0.2
National Gypsum Company	94,410	1.8	0.2
United States Gypsum Company	18,763	0.3	0.03
PQ Corporation	14,206	0.2	0.02
P. Flanigan and Sons	11,135	4.0	0.9
Synagro-Patapsco Pelletizer	8,889	0.2	0.2
GAF Materials Corporation	7,366	0.1	0.1
Mid-Atlantic Baking	4,640	0.09	0.09
H & S Bakery	4,592	0.09	0.09
USALCO, LLC	4,194	0.07	0.07
Kaydon Ring & Seal, Inc.	3,983	0	0
ReConserve of MD	3,771	0.07	0.07
Crispy Bagel Company	2,425	0.04	0.04
Automatic Rolls of Baltimore	1,556	0.03	0.03
Sherwin-Williams Company	1,326	0	0.2
The Baltimore Sun	1,043	0.02	0.02
U.S. Concrete Products	487	0.1	0
P & J Contracting Company, Inc.	65	0	0
Key Recycling, LLC	13	0	0
Total	**402,991**	**11.3**	**2.5**

Data from 2017 EPA National Emissions Inventory [18]. Values reported in this table are rounded.

1.4 Energy Industries

1.4.1 Energy Industry Point Sources

The EPA National Emissions Inventory reports several power plants in Baltimore City that emit greenhouse gases to generate electricity via fossil fuel combustion. Emissions from these power plants are detailed in Table 1.4.18, and the non-natural gas portion of these emissions are detailed in Table 1.4.19 [18]. Non-natural gas emissions are reported separately in order to avoid double counting emissions from utility natural gas consumption that were reported in Sections 1.1 and 1.2.

However, the emissions from some of the energy industry facilities in Tables 1.4.18 and 1.4.19 are due to fossil fuel combustion for the purpose of generating electricity to export to the PJM grid. Following the GPC guidelines, we do not count these emissions toward the overall totals in this report, since including these emissions would double count the emissions from electricity generation and consumption in Sections 1.1 and 1.2. The PJM grid emission factors from Table 1.0.3 already take into account the weighted contribution of the electricity generating facilities in Tables 1.4.18 and 1.4.19. These facilities are removed in Table 1.4.20, which leaves only emissions from non-electricity generating fuel terminals within Baltimore. Following the GPC framework, we only report the totals from Table 1.4.20 in the overall totals in this report (Table 1.4.21), but we include Tables 1.4.18 and 1.4.19 in this report for reference.

Table 1.3.16: Emissions from Manufacturing Plants (Non-Natural Gas)

Plant Name	Tons CO_2	Tons CH_4	Tons N_2O
W.R. Grace & Co.	112,008	2.1	0.2
American Sugar Refining	108,117	2.1	0.2
National Gypsum Company	94,410	1.8	0.2
United States Gypsum Company	18,763	0.3	0.03
PQ Corporation	14,206	0.2	0.02
P. Flanigan and Sons	11,135	4.0	0.9
Synagro-Patapsco Pelletizer	8,889	0.2	0.2
GAF Materials Corporation	1,319	0.02	0.02
Mid-Atlantic Baking	4,640	0.09	0.09
H & S Bakery	3,673	0.07	0.07
USALCO, LLC	2,576	0.07	0.07
Kaydon Ring & Seal, Inc.	2,523	0	0
ReConserve of MD	3,771	0.07	0.07
Crispy Bagel Company	849	0.02	0.02
Automatic Rolls of Baltimore	1,556	0.03	0.03
U.S. Concrete Products	487	0.1	0
P & J Contracting Company, Inc.	65	0	0
Key Recycling, LLC	13	0	0
Total	**388,242**	**11.1**	**2.1**

Data from 2017 EPA National Emissions Inventory [18]. Values reported in this table are rounded. Values in this table are a subset of the values in Table 1.3.15, with emissions from natural gas removed to avoid double counting Section 1.2.2.

Table 1.3.17: Total Emissions from Manufacturing Industries

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	388,242	388,242	388,242
CH_4	11.1	931	310
N_2O	2.1	544	546
Total	–	**389,717**	**389,098**

1.5 Agriculture, Forestry, and Fishing Activities

None reported.

1.6 Non-Specified Sources

None reported.

Table 1.4.18: Emissions from Energy Industry Point Sources (All Fuels)

Facility Name	Tons CO_2	Tons CH_4	Tons N_2O
Veolia Energy – Spring Gardens	53,734	1.0	0.1
Constellation Energy Group – Westport	19,898	0.4	0.04
Veolia Energy – Central Ave Steam Plant	19,638	0.4	0.04
Constellaton Power – Gould Street Station	10,273	0.2	0.02
Buckeye Terminals	9,113	0.3	0.1
NuStar Terminals Operations Partnership	7,865	0.2	0.1
Trigen Energy – Inner Harbor East	6,103	0.2	0.04
Petroleum Fuel & Terminal Company	5,471	0.1	0.01
Veolia Energy – Saratoga Plant	5,034	0.09	0.03
Veolia Energy – Cherry Hill	4,144	0.08	0.02
Constellation Energy Group – Philadelphia Rd	1,900	0.08	0.01
CITGO / ARC - Terminal	1,151	0	0
Sunoco Terminal	316	0	0
Center Point Terminal	43	0	0
Total	**138,896**	**2.8**	**0.5**

Data from 2017 EPA National Emissions Inventory [18]. Values reported in this table are rounded.

Table 1.4.19: Emissions from Energy Industry Point Sources (Non-Natural Gas)

Facility Name	Tons CO_2	Tons CH_4	Tons N_2O
Veolia Energy – Spring Gardens	53,734	1.0	0.1
Constellation Energy Group – Westport	19,898	0.4	0.04
Veolia Energy – Central Ave Steam Plant	19,638	0.4	0.04
Constellaton Power – Gould Street Station	10,273	0.2	0.02
Buckeye Terminals	9,113	0.3	0.1
NuStar Terminals Operations Partnership	3,726	0.1	0.1
Constellation Energy Group – Philadelphia Rd	1,900	0.08	0.01
CITGO / ARC - Terminal	1,151	0	0
Petroleum Fuel & Terminal Company	476	0	0
Sunoco Terminal	316	0	0
Veolia Energy – Saratoga Plant	178	0	0
Center Point Terminal	43	0	0
Total	**120,445**	**2.4**	**0.4**

Data from 2017 EPA National Emissions Inventory [18]. Values reported in this table are rounded. Values in this table are a subset of the values in Table 1.4.18, with emissions from natural gas removed to avoid double counting Section 1.2.2.

1.7 Fugitive Emissions from Mining, Processing, Storage, and Transportation of Coal

None reported.

Table 1.4.20: Emissions from Energy Industry Point Sources (Non-electricity producing)

Facility Name	Tons CO_2	Tons CH_4	Tons N_2O
Buckeye Terminals	9,113	0.3	0.1
NuStar Terminals Operations Partnership	3,726	0.1	0.1
CITGO / ARC - Terminal	1,151	0	0
Petroleum Fuel & Terminal Company	476	0	0
Sunoco Terminal	316	0	0
Center Point Terminal	43	0	0
Total	**14,825**	**0.4**	**0.2**

Data from 2017 EPA National Emissions Inventory [18]. Values reported in this table are rounded. Values in this table are a subset of the values in Table 1.4.19, with emissions from natural gas removed to avoid double counting Section 1.2.2, and emissions that result from utility electricity generation removed to avoid double counting utility electricity consumption from the grid in Sections 1.1 and 1.2. Emissions from this Table are only emissions from Section 1.4 that are reported in the overall totals in this report.

Table 1.4.21: Total Emissions from Energy Industries

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	14,825	14,825	14,825
CH_4	0.4	31.4	10.5
N_2O	0.2	46.1	46.3
Total	–	**14,903**	**14,882**

1.8 Fugitive Emissions from Oil and Natural Gas Systems

1.8.1 Natural Gas Leaks from BG&E Infrastructure

The direct emission of CO_2 from natural gas combustion, as discussed in Sections 1.1.2 and 1.2.2, is not the only source of greenhouse gas emissions from natural gas. Due to a combination of routine operations, aging infrastructure, and occasional equipment malfunctions, there are significant leaks of methane to the atmosphere during the transportation and distribution of natural gas. In particular, we focus on leaks from natural gas pipelines and local distribution infrastructure within the city limits. While there are also significant leaks from upstream supply chain processes like production and retrieval from geological reservoirs, and long-distance transport of natural gas through inter-state pipelines, we do not analyze the fugitive emissions occurring outside of Baltimore City [19]. It is difficult to isolate Baltimore's contribution to the these net upstream fugitive emissions, and furthermore, the net national fugitive emissions are not well quantified. Additionally, these upstream fugitive emissions lie outside of the jurisdiction of the City of Baltimore, so we focus on the fugitive emissions occurring within city limits. In short, we consider Scope 1 fugitive CH_4 emissions in this report, but not Scope 2. Note that fugitive emissions of natural gas were not considered as a greenhouse gas emission source in the previous 2010 and 2014 Baltimore emissions inventories.

Numerous studies have attempted to quantify natural gas leaks from urban infrastructure, including studies focused on the Baltimore-Washington region [20, 21, 22]. However, no study thus far has quantified the natural gas leak rate within the city of Baltimore alone. Ren et. al. (2018) have

estimated natural gas leak rates of $1.1 \pm 0.6\%$ and $2.1 \pm 1\%$ from aircraft flight campaigns over the Baltimore-Washington region in February of 2015 and February of 2016 [21]. Notably, these leak rates are influenced by natural gas infrastructure across the broad Baltimore-Washington region, including the suburbs, and may not represent the leak rate in other months of the year. McKain et. al. (2015) have estimated an average leak rate of $2.7 \pm 0.6\%$ during a 12 month ground-based monitoring study in the Boston, Massachusetts urban region [22]. Although this study was focused on the city of Boston, we predict that a similar leak rate would be measured in Baltimore City in an analogous study, especially considering the similarities between the two historical mid-sized northeast harbor cities. Plant et. al. (2019) have estimated CH_4 emission fluxes over the Baltimore-Washington region using aircraft observations and gridded emission inventories, and found results that are broadly consistent with both McKain et. al. and Ren et. al. Plant et. al. did not attempt to compute a natural gas leak rate since it would require difficult and imperfect aggregation of natural gas supply data over a large geographic region, but their work is useful for validating the results of McKain et. al. and Ren et. al., and also for demonstrating that the most recent gridded EPA inventory underestimates emissions of natural gas by a factor of about 10. Thus, in lieu of a natural gas leak rate specific to Baltimore City, we take the mean of the available estimated leak rates and only specify one significant digit, yielding an effective leak rate of 2%.

As reported in Table 1.0.4, Baltimore Gas and Electric reported delivery of 329,123,908 therms of natural gas across all sectors in Baltimore City. Assuming a 2% leak rate, the reported 329,123,908 therms correspond to the 98% of natural gas that was safely delivered, meaning that 6,716,814 therms of natural gas would be released to the atmosphere. The U.S. EPA reports the average carbon content of pipeline natural gas to be 14.43×10^{-4} tons C/therm [23]. Assuming a standard natural gas composition of 95% methane, the effective CH_4 emission factor for pipeline natural gas leaks can be computed as follows:

$$(0.95) \cdot \left(14.43 \times 10^{-4} \ \frac{\text{tons C}}{\text{therm}}\right) \cdot \left(\frac{16.04 \text{ tons } CH_4}{12.01 \text{ tons C}}\right) = 1.83 \times 10^{-3} \ \frac{\text{tons } CH_4}{\text{therm}}$$

The remaining 5% of the natural gas mixture, comprised primarily of ethane, propane, and other trace gases, would also be released to the atmosphere. However, since this report only analyzes CO_2, CH_4, and N_2O, these other greenhouse gas emissions are unreported.

Using this emission factor, we can compute the mass of CH_4 released to the atmosphere in the 2% of leaked natural gas:

$$\left(\frac{0.02}{0.98}\right) \cdot (329{,}123{,}908 \text{ therms}) \cdot \left(1.83 \times 10^{-3} \ \frac{\text{ton } CH_4}{\text{therm}}\right) = 12,292 \text{ tons } CH_4$$

These CH_4 emissions are equivalent to 1,032,528 tons CO_2 over the next 20 years, or 344,176 tons CO_2 over the next 100 years. The total emissions from fugitive natural gas systems are summarized in Table 1.8.22. Relative to the city's total greenhouse gas emissions, these fugitive methane emissions are strikingly large: $\sim$11.9% when considering the greenhouse effect over the next 20 years.

Summary of Emissions from Sector 1 Stationary Energy

The sum of emissions from residential buildings (Section 1.1), industrial, commercial, and institutional facilities (Section 1.2), manufacturing industries and construction (Section 1.3), energy industries (Section 1.4), and fugitive natural gas emissions (Section 1.8) are summarized in Table

Table 1.8.22: Total Emissions from Fugitive Natural Gas Systems

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	–	–	–
CH_4	12,292	1,032,528	344,176
N_2O	–	–	–
Total	–	**1,032,528**	**344,176**

1.8.23 and Figure 1.1. The difference between the fractional contribution of BG&E natural gas to total stationary energy emissions in Figures 1.1C and 1.1D in particular indicates the significance of fugitive natural gas emissions in the short term.

Table 1.8.23: Total Emissions from Stationary Energy Usage

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	4,997,124	4,997,124	4,997,124
CH_4	12,569	1,055,776	351,926
N_2O	39.0	10,308	10,347
Total	–	**6,063,208**	**5,359,396**

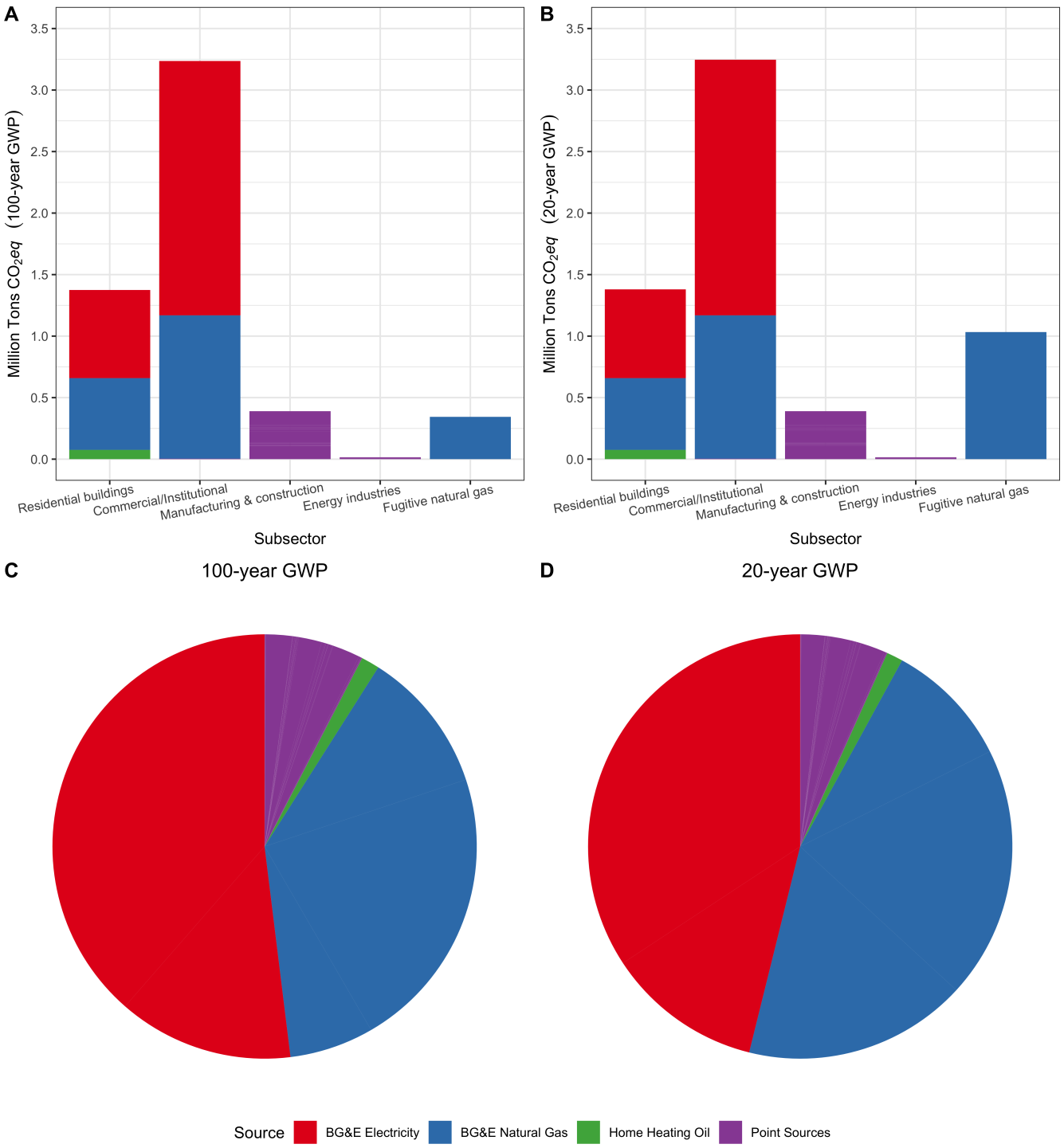


Figure 1.1: Summary of emissions from the stationary energy sector by subsector and emission source. Individual point source facilities are separated by faint dashed lines.

Sector 2 Transportation

2.1 On-Road

In 2017, the State Highway Administration (SHA) of the Maryland Department of Transportation reported a total of 3,601 million vehicle miles driven in the City of Baltimore, with 1,144 million of these miles driven on the interstate highways [24]. This estimate is derived by multiplying the number of vehicles on various roadways within Baltimore City by the number of miles driven on those roadways. All vehicle miles under the SHA definition are driven within the Baltimore city limits.

The total greenhouse gas emissions from these on-road transportation miles depend on the vehicle types, fuel economy, and the type of fuels utilized across all vehicles operating in the City of Baltimore. In this section, we present three different estimates of on-road transportation emissions, each of which is derived from a computational model using local, state, and federal roadway data. In Sections 2.1.1 and 2.1.2, we report analyses done by the Maryland Department of the Environment (MDE) and the U.S. Environmental Protection Agency, respectively. Both the MDE and the EPA utilize the EPA MOVES (MOtor Vehicle Emission Simulator) model, but with different model configurations and input data, and thus, differing solutions. This is the same model used in the 2010 and 2014 City of Baltimore emissions inventories, although the model settings and input data may slightly vary depending on data availability and current EPA recommendations. In Section 2.1.3, we analyze on-road transportation emissions data from a data product called DARTE, which was released by the Oak Ridge National Laboratory in 2019 [25]. At the end of Section 2.1, we summarize the results of the three estimates and specify which method is likely best representative of Baltimore City transportation.

2.1.1 Maryland Department of the Environment using EPA MOVES

The State of Maryland 2017 Greenhouse Gas Emission Inventory prepared by the Maryland Department of the Environment reports greenhouse gas emissions from the on-road transportation sector in Section 4.4 of their report [26]. MDE aggregates vehicle and mileage data from the Maryland Department of Transportation (MDOT) State Highway Administration (SHA) to use as input for the U.S. EPA MOVES (MOtor Vehicle Emission Simulator) model. MDE used input files and a model configuration for MOVES that are specific to Maryland traffic patterns by county (including separate analyses for Baltimore City and Baltimore County), lending confidence to their modeling estimate. MOVES is the primary recommended method by the EPA for estimating greenhouse gas emissions from the on-road transportation sector. MDE's MOVES analysis estimates a total of 1.78 million tons of CO_2 emitted from the combustion of gasoline, diesel, compressed natural gas (CNG), and E85 ethanol for on-road transportation in the City of Baltimore, summarized by fuel type in Table 2.1.1. Note that gasoline emissions contribute to a large majority of the total emissions.

MDE reports emissions of CO_2 for each county in Maryland, including Baltimore City, but they

Table 2.1.1: Emissions from On-road Transportation by Fuel Type (MDE Estimate)

Fuel Type	Tons CO_2	Tons CH_4	Tons N_2O
Gasoline	1,408,506	19.3	0.17
Diesel	361,590	0.25	0.04
E85	6,895	–	–
CNG	3,399	–	–
Total	**1,780,390**	**19.5**	**0.21**

do not provide the same county-level analysis for on-road emissions of CH_4 and N_2O. However, we can use the MDE's analysis of CO_2 emissions by county in order to compute Baltimore City's fractional contribution to the State of Maryland totals. Overall, 6.34% of Maryland gasoline emissions come from Baltimore City, and 5.87% of Maryland diesel emissions come from Baltimore City. We can scale MDE's reported state-wide emissions of CH_4 and N_2O from gasoline and diesel by these percentages to compute Baltimore City's contribution to the total CH_4 and N_2O emissions in Maryland. Doing so yields 19.5 tons of CH_4 and 0.21 tons of N_2O from on-road transportation. These emissions are summarized by fuel type in Table 2.1.1 and by global warming potential in Table 2.1.2. Note that nearly all greenhouse gas emissions from on-road transportation are released as CO_2.

Table 2.1.2: Total Emissions from On-road Transportation (MDE Estimate)

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	1,780,390	1,780,390	1,780,390
CH_4	19.5	1,640	547
N_2O	0.21	57	57
Total	–	**1,782,086**	**1,780,993**

2.1.2 U.S. EPA using EPA MOVES

The 2017 U.S. EPA National Emissions Inventory reports an estimate of on-road traffic emissions from light and heavy duty vehicles that use gasoline, diesel, and other fuels while idling and driving on roads, highways, and ramps. The U.S. EPA uses the MOVES model to compute emissions for Baltimore City with input data from state and local transportation agencies. These emissions are summarized by vehicle type, vehicle duty, and fuel type in Table 2.1.3. Note that the MDE's estimate did not specify this same breakdown by vehicle type in their report, but they did use this same vehicle class categorization scheme. While the EPA NEI estimate of total emissions is higher than the MDE estimate of total emissions, it is unclear whether that same relationship holds for each vehicle type in the absence of data which summarize emissions by vehicle type from the MDE.

Total emissions from the EPA NEI estimate of on-road transportation are summarized in Table 2.1.4 by global warming potential. Note that nearly all greenhouse gas emissions from on-road transportation are released as CO_2.

Table 2.1.3: On-Road Vehicle Emissions by Vehicle Type (EPA NEI Estimate)

Fuel Type	Vehicle Duty	Vehicle Type	Tons CO_2	Tons CH_4	Tons N_2O
Gasoline	Light	Passenger Car	968,386	17.8	19.4
Gasoline	Light	Passenger Truck	687,202	19.4	18.3
Diesel	Heavy	Combination Long-haul Truck	207,659	13.7	0.3
Gasoline	Light	Light Commercial Truck	125,736	3.5	2.8
Diesel	Heavy	Single Unit Short-haul Truck	84,192	5.0	0.3
Diesel	Heavy	Combination Short-haul Truck	62,644	2.2	0.1
Diesel	Heavy	Transit Bus	23,088	1.0	0.1
Gasoline	Heavy	Single Unit Short-haul Truck	22,715	0.4	0.5
Diesel	Heavy	Intercity Bus	9,805	0.2	0.02
Diesel	Light	Passenger Truck	8,028	0.5	0.04
Diesel	Light	Light Commercial Truck	7,678	0.7	0.03
Gasoline	Light	Motorcycle	6,041	0.7	0.09
Diesel	Heavy	Refuse Truck	5,609	0.2	0.01
Diesel	Light	Passenger Car	5,153	0.6	0.01
Diesel	Heavy	Single Unit Long-haul Truck	4,728	0.3	0.01
E85	Light	Passenger Truck	3,679	0.2	0.06
Diesel	Heavy	School Bus	2,215	0.2	0.01
E85	Light	Passenger Car	1,403	0.1	0.02
Gasoline	Heavy	Single Unit Long-haul Truck	1,173	0.02	0.02
Gasoline	Heavy	Refuse Truck	829	0	0
E85	Light	Light Commercial Truck	665	0	0.01
Gasoline	Heavy	Transit Bus	460	0	0
Gasoline	Heavy	Motor Home	258	0	0
Diesel	Heavy	Motor Home	133	0	0
Gasoline	Heavy	School Bus	3.5	0	0
Gasoline	Heavy	Combination Short-haul Truck	2.5	0	0
Total	**Total**	**Total**	**2,233,738**	**66.4**	**42.0**

Table 2.1.4: Total Emissions from On-road Transportation (EPA NEI Estimate)

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	2,233,738	2,233,738	2,233,738
CH_4	66.4	5,579.7	1,859.9
N_2O	42.0	11,080	11,122
Total	–	**2,250,397**	**2,246,719**

2.1.3 On-road Transportation Emissions via DARTE

Oak Ridge National Laboratory has published a gridded on-road transportation CO_2 emission data set called the Database of Road Transportation Emissions (DARTE), which has 1 kilometer × 1 kilometer grid resolution spanning the continental United States [25]. DARTE includes emissions from five vehicle types: passenger cars, passenger trucks (SUVs, minivans, pickups), buses, single-unit trucks, and combination trucks. This vehicle type classification scheme is notably coarser than the classification scheme employed in the EPA MOVES model, as detailed in Table 2.1.3.

By summing only the grid points in or near the Baltimore City boundary, we can compute an estimate of the total on-road transportation emissions resulting from transportation activities in Baltimore City. However, with only 1-kilometer grid resolution, there are a significant number of grid points that lie just outside of the city boundary. Since each grid point represents a square 1 km $\times$ 1 km area, and the coordinates of each grid point lie at the centroid of that square area, each grid point that lies just outside of the city boundary at least partially includes an area within the city boundary, and thus we must be careful about how we count grid points around the Baltimore City boundary.

In other words, each data point that lies just outside of the city boundary represents a 1 km^2 area that is partially inside and partially outside of the Baltimore City boundary. The emissions associated with each grid point represent the sum of all emissions occurring within that 1 km^2 area, assuming that the emissions are distributed evenly across the entire 1 km^2 area. To illustrate why this is potentially misleading, one could imagine a 1 km^2 area with a heavily trafficked road running through one corner and with no other roads within the area; this grid point would appear to indicate significant emissions occurring at the center of the 1 km^2 area, even though 100% of the emissions are due to the heavily trafficked road running through the corner edge of the square area. Thus, to address the issue of being unable to precisely assign emissions occurring around the perimeter of Baltimore City to one side of the boundary or the other, we compute both an upper bound and lower bound solution and argue that the true answer, according to DARTE data, must lie in between the upper and lower bounds.

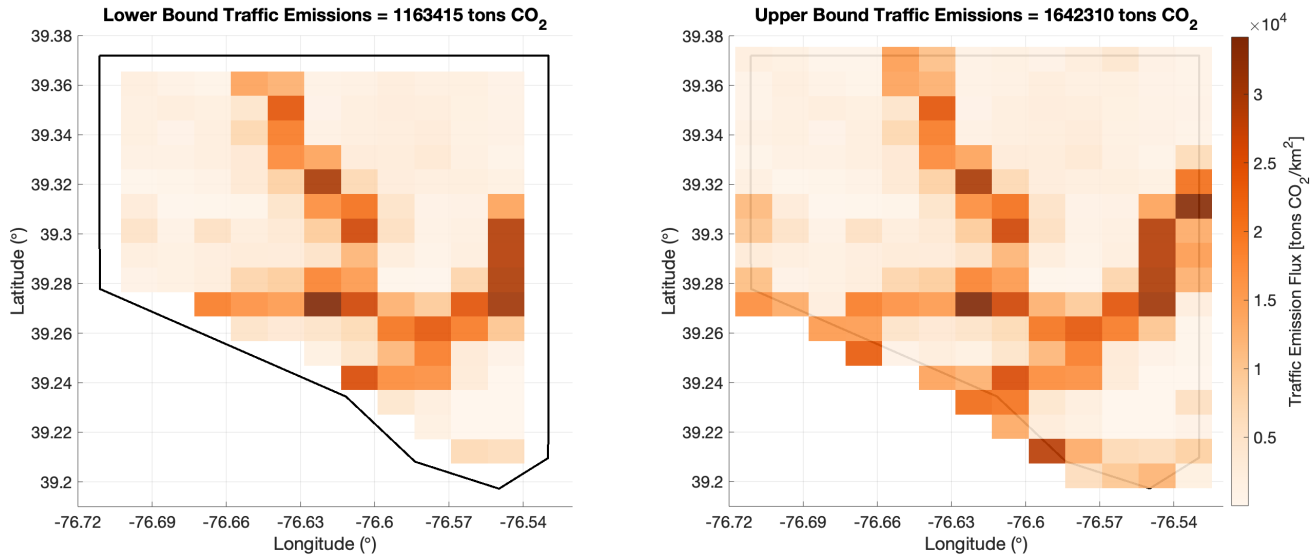


Figure 2.1: Lower and upper bound traffic emissions estimates using DARTE data. Black line indicates the Baltimore City boundary.

To compute the lower bound for on-road emissions from Baltimore City traffic, we take the conservative assumption that none of the DARTE data points whose centroid lies just outside of the Baltimore City boundary represent traffic emissions from within the city. On the other end, we can compute the upper bound by taking the liberal assumption that each grid point whose centroid lies just outside of the city boundary represents emissions that originate entirely from within the portion of the 1 km^2 area that lies within the Baltimore City boundary. We would consider this a modest upper bound. Computing the sum of all emissions occurring within and on the Baltimore City boundary, the lower bound method suggests a total 1,163,415 tons CO_2 and the upper bound

method suggests a total of 1,642,310 tons CO_2 (a net difference of 478,895 tons). In reality, the true total, according to DARTE data, most likely lies in between these two extremes. Crudely, we could assume that 50% of the emissions represented by grid points that are partially within the Baltimore City boundary originate from within the city. This assumption is equivalent to computing the mean of the upper and lower bounds, yielding an point estimate of 1,402,863 tons CO_2.

However, even if we take the upper bound estimate of the DARTE data, the total on-road emissions estimated by DARTE are still significantly lower than the MOVES estimates by the U.S. EPA and the Maryland Department of the Environment. One plausible explanation for this would be that the total traffic emissions are highly sensitive to the specified boundary. To illustrate this high sensitivity, suppose we were to count the emissions from one pixel outside of the upper bound estimate in Figure 2.1. This would be analogous to expanding the Baltimore City traffic boundary by 1-kilometer in each cardinal direction, which we would consider an aggressive upper bound. Doing so yields a total traffic emissions estimate of 2,395,054 tons CO_2 – significantly higher than the 1,642,310 tons CO_2 in the modest upper bound estimate.

Relatively small ($\sim$ 1-km) changes to the boundary definition yield widely differing total traffic estimates, with more than a factor of 2 difference between the lower bound and the aggressive upper bound estimates. For this reason, we do not use numerical estimates derived from DARTE data in the final on-road transportation totals. However, we still include this analysis to illustrate the spatial distribution of traffic emissions in the City of Baltimore. Although the resolution is coarse and the total magnitude of each grid point may be biased from true Baltimore traffic emissions, the general spatial pattern of high emission areas vs. low emission areas is most likely representative of where on-road traffic emissions are occurring. For instance, most of the hot spots in Figure 2.1 contain major highways that run through Baltimore, including Interstate 95, Interstate 83, and U.S. Route 40.

Summary of Emissions from Section 2.1 On-Road Transportation

We report three different methods for estimating on-road transportation emissions in Sections 2.1.1, 2.1.2, and 2.1.3. As was argued in Section 2.1.3, we do not use the estimates derived from DARTE data in the grand totals of this report due to the high sensitivity of integrated DARTE emissions to the traffic boundary definition. Thus, we are left with two estimates of on-road transportation emissions derived from the EPA MOVES model: one from the Maryland Department of the Environment and one from the U.S. EPA National Emissions Inventory.

The EPA NEI reports on-road traffic emissions that are 26% higher than what the MDE estimates, a difference of over 460,000 tons CO_2eq. Since both agencies used the same computational model, the explanation for their differing answers lies in their choice of input data files and model parameter settings. Most notably, the EPA NEI computes on-road transportation emissions using the same default MOVES model parameters for each geographic region included in the NEI. The EPA also acknowledges that the default data cannot be guaranteed to be most current or best available for any particular region. MDE, on the other hand, utilized local data in place of the default MOVES data when available. In particular, MDE utilized roadway data from the Maryland SHA, vehicle age data from the Maryland Motor Vehicle Administartion (MVA), vehicle technology and emission inspection compliance from the Vehicle Emission Inspection Program (VEIP), and other vehicle and traffic data from various Maryland state departments and programs. Thus, since MDE used more precise local data than the EPA NEI in their MOVES model analysis, their overall on-road emissions estimate is likely more accurate for Baltimore City, so we use the estimate from MDE when calculating overall GHG emission totals in this report. The MDE estimate of on-road

transportation emissions is summarized in Table 2.1.5.

Table 2.1.5: Total Emissions from On-Road Transportation

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	1,780,390	1,780,390	1,780,390
CH_4	19.5	1,640	547
N_2O	0.21	57	57
Total	–	**1,782,086**	**1,780,993**

2.2 Railways

None reported: Data unavailable.

2.3 Waterborne Navigation

We do not consider emissions from the Port of Baltimore in this report, since port activities lie outside of the jurisdiction of the City of Baltimore.

2.3.1 Recreational Marine Vessels

The Maryland Department of the Environment and the EPA National Emissions Inventory report recreational waterborne navigation emissions occurring within Baltimore City [26, 18]. These emissions are summarized by gasoline type and engine type in Table 2.3.6.

Table 2.3.6: Emissions from Recreational Marine Vessels

Fuel Type	Tons CO_2	Tons CH_4
Gasoline - 2 Stroke	2,064	2.4
Gasoline - 4 Stroke	671	0.4
Diesel	513	0.01
Total	**3,248**	**2.8**

Table 2.3.7: Total Emissions from Waterborne Navigation

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	3,248	3,248	3,248
CH_4	2.8	239	79.5
N_2O	–	–	–
Total	–	**3,487**	**3,328**

2.4 Aviation

None reported. The Baltimore-Washington International Airport (BWI) lies outside of the Baltimore City limits in Anne Arundel county.

2.5 Off-Road

As in Section 2.1, we provide two different analyses of off-road transportation emissions: one by the U.S. EPA and one by the MDE. Both estimates were derived using the MOVES-NONROAD model, a component of the EPA MOVES model designed to estimate off-road transportation emissions. In Section 2.5.1 we show the EPA NEI estimate, and in Section 2.5.2 we show the MDE estimate. At the end of Section 2.5, we summarize the two results and specify which analysis is likely most representative of off-road transportation emissions in Baltimore City.

2.5.1 EPA NEI Nonroad Emissions

The U.S. EPA National Emissions Inventory reports non-road greenhouse gas emissions from off-road mobile sources that use gasoline, diesel, and other fuels. These emissions are estimated by the EPA using the MOVES-NONROAD model. These emissions are summarized by equipment type and fuel type in Table 2.5.8.

Table 2.5.8: Off-road Emissions by Equipment and Fuel Type (EPA Estimate)

Emission Source	Fuel Type	Tons CO_2	Tons CH_4
Industrial Equipment	Gasoline	3,139	1.0
Industrial Equipment	Diesel	24,993	0.6
Industrial Equipment	Other	22,279	10.0
Lawn and Garden Equipment	Gasoline	27,206	24
Lawn and Garden Equipment	Diesel	1,326	0.04
Lawn and Garden Equipment	Other	58	0
Commercial Equipment	Gasoline	12,445	8.9
Commercial Equipment	Diesel	9,549	0.3
Commercial Equipment	Other	1,585	8.9
Construction Equipment	Gasoline	530	0.4
Construction Equipment	Diesel	19,948	0.4
Construction Equipment	Other	58	0.03
Railroad Equipment	Gasoline	7	0
Railroad Equipment	Diesel	124	0.01
Golf Carts	Gasoline	456	0.34
Total	**Total**	**123,702**	**54.9**

2.5.2 MDE Nonroad Emissions

The Maryland Department of the Environment (MDE) also reports emissions from a variety of non-road motorized vehicles and equipment. These emissions are estimated by MDE using the EPA MOVES-NONROAD model. These emissions are summarized by equipment type in Table 2.5.9.

Table 2.5.9: Off-road Emissions by Equipment and Fuel Type (MDE Estimate)

Emission Source	Fuel Type	Tons CO_2	Tons CH_4
Industrial Equipment	Gasoline	3,149	1.0
Industrial Equipment	Diesel	25,133	0.6
Industrial Equipment	Other	22,280	10.1
Lawn and Garden Equipment	Gasoline	27,198	24
Lawn and Garden Equipment	Diesel	1,325	0.04
Lawn and Garden Equipment	Other	58	0
Commercial Equipment	Gasoline	12,441	8.9
Commercial Equipment	Diesel	9,546	0.3
Commercial Equipment	Other	1,584	8.9
Railroad Equipment	Gasoline	7	0
Railroad Equipment	Diesel	124	0
Golf Carts	Gasoline	455	0.3
Total	**Total**	**103,302**	**54.2**

Summary of Emissions from Off-road Mobile Sources

The off-road mobile emission estimates from the EPA in Table 2.5.8 and from the MDE in Table 2.5.9 are generally consistent with one another. However, MDE does not include emissions from construction equipment, while the EPA does. For this reason, we use the nonroad emissions estimate from the EPA in Section 2.5.1 when computing off-road transportation emission totals in this report. These emissions are summarized by global warming potential in Table 2.5.10.

Table 2.5.10: Total Emissions from Off-road Mobile Sources (EPA NEI Estimate)

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	123,702	123,702	123,702
CH_4	54.9	4,615	1,538
N_2O	–	–	–
Total	–	**128,317**	**125,240**

Summary of Emissions from Sector 2 Transportation

The sum of emissions from on-road transportation (Section 2.1), railways (Section 2.2), waterborne navigation (Section 2.3), and off-road transportation (Section 2.5) are summarized in Table 2.5.11. Note that emissions of CO_2 dominate the total CO_2eq emissions from the Transportation sector, with the majority of emissions coming from on-road vehicles. It is also important to note that emissions from the transportation sector reported here are somewhat lower than reality, since we do not report emissions from railway transportation due to unavailable data for that subsector.

Table 2.5.11: Total Emissions from Transportation

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	1,907,340	1,907,340	1,907,340
CH_4	77.3	6,493	2,164
N_2O	0.2	56	57
Total	–	**1,913,890**	**1,909,561**

Sector 3 Waste

3.1 Solid Waste Disposal

3.1.1 Quarantine Road Landfill

Due to the operations of the Wheelabrator Trash Incinerator (Section 3.3), only about 1/5th of municipal waste generated in Baltimore ends up in a landfill. Nearly all of this non-combusted waste, in addition to ash from the Wheelabrator incinerator, ends up in the Quarantine Road Landfill, which is currently over 80% full and is expected to reach full capacity by 2026 [27].

The Maryland Department of the Environment conducted an analysis of landfill emissions in their 2017 Greenhouse Gas Inventory report [26]. In their analysis, they use the Landfill Gas Emissions Model (LandGEM), an EPA tool developed to estimate greenhouse gas emissions from landfills. LandGEM estimates emissions of CO_2 and CH_4, but not N_2O. These emissions of CO_2 and CH_4 from the Quarantine Road Landfill are summarized in Table 3.1.1. These emissions are notably higher than the reported 2010 and 2014 emissions from previous inventories; this is most likely due to different estimation methods used in those inventories, which used simple and uncertain emission factors rather than more sophisticated estimation methods like LandGEM.

Note that the Quarantine Road landfill is the largest point source of CH_4 in Baltimore City. Since CH_4 emissions dominate the greenhouse gas emissions from landfills, the chosen time horizon of the global warming potential has a large impact on the total CO_2 equivalent emissions from solid waste disposal. There is a significantly larger global warming effect from landfill emissions over the next 20 years, as shown in Table 3.1.1.

3.2 Biological Treatment of Waste

None reported.

Table 3.1.1: Emissions from the Quarantine Road Landfill

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	20,031	20,031	20,031
CH_4	4,507	378,579	126,193
N_2O	–	–	–
Total	–	**398,610**	**146,224**

3.3 Incineration and Open Burning

3.3.1 Wheelabrator Trash Incinerator

Wheelabrator Baltimore is a municipal waste disposal facility that collects municipal waste from the City of Baltimore and nearby counties and incinerates it to generate electricity, which is both utilized on-site and exported to the local utility BG&E. In 2017, the Maryland Department of the Environment reported 640,664 tons of CO_2, 226 tons of CH_4, and 29.7 tons of N_2O emitted by the Wheelabrator facility [26]. MDE indicates that these emissions were estimated using a Continuous Emissions Monitoring System (CEMS), adding confidence to these emissions estimates. However, as discussed in Section 1, Wheelabrator Baltimore exports the electricity it generates via municipal solid waste combustion to the regional grid supplier, PJM. Thus, to avoid double counting emissions from the Wheelabrator facility in the PJM grid emission factor in Sector 1, and in other municipal greenhouse gas inventories within PJM's supply area, we do not include the measured emissions from Wheelabrator Baltimore in the waste totals in this report. This is the GPC recommended protocol for reporting emissions caused by the combustion of municipal solid waste at electricity generation plants. However, we include an analysis and discussion of emissions from Wheelabrator Baltimore here for reference. The total emissions from Wheelabrator Baltimore are summarized by global warming potential in Table 3.3.2. Note that the Wheelabrator Trash Incinerator is one of the largest point sources of N_2O in Baltimore City.

Table 3.3.2: Emissions from the Wheelabrator Trash Incinerator

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	640,664	640,664	640,664
CH_4	226	18,984	6,328
N_2O	29.7	7,841	7,871
Total	–	**667,489**	**654,863**

The U.S. EPA often reports two separate emissions from trash incineration: a biogenic component (including food waste, paper products, and other organic matter) and a non-biogenic component (including plastics and fossil fuel derived materials). The EPA argues that biogenic emissions from trash incineration do not need to be included in greenhouse gas emission inventories because the combustion of organic waste simply returns CO_2 that plants previously absorbed through photosynthesis back to the atmosphere. However, we include both components in our analysis, and we argue that it would be misleading not to do so. The combustion of biogenic waste releases CO_2 directly into the atmosphere, whereas not combusting the biogenic waste would require it to be sent

to a landfill. In the landfill, it would naturally decompose and release CH_4 and CO_2 over the next several decades, and those emissions would need to be counted in Section 3.1.

Greenhouse gas emissions are not avoided by diverting municipal waste away from landfills and incinerating it instead; both waste management methods produce significant greenhouse gas emissions. One notable difference is that the incineration of municipal solid waste releases primarily CO_2 to the atmosphere, with relatively small amounts of CH_4 and N_2O, whereas decomposition in a landfill releases primarily CH_4, which is 84 times more potent than CO_2 in the first 20 years after it's emission (Table 0.2). Additionally, greenhouse gas emissions occur immediately when waste is incinerated, whereas emissions are slowly released over several decades when organic waste decomposes in a landfill.

Incineration of biogenic municipal waste does not nullify the greenhouse gas emissions from the combustion of that waste, but rather, it changes the time scale and magnitude of the emissions. Incinerating municipal solid waste sends emissions of CO_2 to the atmosphere immediately upon incineration, but prevents emissions of CH_4, a more potent greenhouse gas, from landfill decomposition over the next few decades. It is generally accepted that solid waste incineration produces fewer greenhouse gas emissions than dumping waste in a landfill [28]. However, emissions of CH_4 from landfills can be captured and burned (like natural gas) to produce energy, whereas emissions of CO_2 from waste incineration cannot be captured and utilized. While there is an ongoing debate about the net environmental and public health impacts of incinerating municipal solid waste versus sending it to a landfill, it is clear that the waste management technologies that are utilized by municipalities play a key role in determining which is less harmful to both the environment and human health.

Wheelabrator Electricity Exports

In 2017, the Wheelabrator Baltimore waste-to-power facility self-reported a total export of 336,878 MWh of electricity to the regional grid operator, PJM Interconnection [29]. This net electricity export equates to only ∼5% of the 6,436,898 MWh of total electricity consumed by BG&E customers within the City of Baltimore in 2017 (Table 1.0.1), which suggests that Wheelabrator Baltimore is not a significant source of electricity for the City of Baltimore. With the total CO_2eq emissions in Table 3.3.2, we can compute an "effective" emission factor per kilowatt-hour for the Wheelabrator Baltimore facility:

$$\left(\frac{654{,}863 \text{ tons } CO_2}{336{,}878{,}000 \text{ kWh}}\right) = 1.944 \times 10^{-3} \ \frac{\text{tons } CO_2eq}{\text{kWh}}$$

It is important to note that Wheelabrator Baltimore's effective emission factor of 1.944×10^{-3} tons CO_2/kWh is about 4.5 times larger that the PJM grid average emission factor of 4.302×10^{-4} tons CO_2/kWh. In other words, for each kilowatt-hour of electricity generated, Wheelabrator Baltimore emits 4.5 times more CO_2 per kWh than the average power plant that supplies electricity to PJM. However, it is important to take this effective emission factor with a grain of salt, since it may not include electricity generated and used on site by the Wheelabrator facility. If Wheelabrator Baltimore uses a significant amount of the electricity it generates to power its facility, the overall emission factor would be lower since the total electricity generated is larger than the total electricity exported. For this reason, we refer to Wheelabrator Baltimore's emission factor of 1.944×10^{-3} tons CO_2/kWh as an *effective* emission factor, indicating that only electricity that is exported counts toward the emission factor. The emission factors from PJM may not be effective (exported only) emission factors, but rather the total generation emission factors; it is unclear how much electricity

is used on site by PJM suppliers. However, in the absence of an accounting error by Wheelabrator Baltimore or the Maryland Department of the Environment, even an effective emission factor that is half of the exported 1.944×10^{-3} tons CO_2/kWh would make Wheelabrator Baltimore's use of municipal solid waste one of the least efficient and most highly polluting fuel types on the grid, comparable to coal-fired power plants (Table 1.0.2).

3.3.2 Curtis Bay Medical Waste Services

Curtis Bay Medical Waste Services, located within the Baltimore City limits, is the nation's largest medical waste incinerator. In 2017, the U.S. EPA National Emissions Inventory reported emissions from the Curtis Bay facility as shown in Table 3.3.3. However, as with the Wheelabrator Baltimore facility, the Curtis Bay Medical Waste Incinerator exports the net electricity it generates to the regional PJM grid. Thus, we also do not include emissions from Curtis Bay Medical Waste Services in the overall emissions totals in Sector 3 Waste to avoid double counting emissions that were encapsulated in the effective PJM grid emission factor in Sector 1 Stationary Energy. However, we still include a summary of the emissions from the Curtis Bay incinerator here for reference.

Table 3.3.3: Emissions from the Curtis Bay Medical Waste Incinerator

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	26,100	26,100	26,100
CH_4	1.1	92.3	30.8
N_2O	0.44	115.6	116
Total	–	**26,308**	**26,247**

Summary of Emissions from Section 3.3 Incineration and Open Burning

The sum of emissions from the Wheelabrator Trash Incinerator (Section 3.3.1) and and the Curtis Bay Medical Waste Incinerator (Section 3.3.2) are summarized in Table 3.3.4. While CO_2 emissions dominate the total CO_2eq emissions from this section, there are substantial CH_4 and N_2O emissions as well, especially when one considers the resulting greenhouse effect over the next 20 years. Note that none of the emissions from the Wheelabrator facility or the Curtis Bay facility are included in the overall emissions totals in Sector 3 Waste, as discussed above.

Table 3.3.4: Total Emissions from Incineration and Open Burning (*)

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	666,764	666,764	666,764
CH_4	227	19,076	6,359
N_2O	30.1	7,956	7,987
Total	–	**693,797**	**681,109**

Sum of Wheelabrator Trash Incinerator emissions (Table 3.3.2) and Curtis Bay Medical Waste Incinerator emissions (Table 3.3.3). (*) Note that none of these emissions are counted in the overall totals for Sector 3 Waste, as discussed above and in Section 1.

3.4 Wastewater Treatment and Discharge

There are two wastewater treatment plants that serve the Baltimore City population: the Patapsco Wastewater Treatment Plant and the Back River Wastewater Treatment Plant. According to the City of Baltimore Wastewater Facilities Division, the Patapsco facility treated 22,225 million gallons of wastewater and the Back River facility treated 41,769 million gallons of wastewater from the City of Baltimore in 2017, as summarized in Table 3.4.5 [30].

Table 3.4.5: Gallons of Wastewater Treated

Treatment Facility	Gallons Wastewater	% of Total
Patapsco	$22{,}225 \times 10^6$	34.7%
Back River	$41{,}769 \times 10^6$	65.3%
Total	$\mathbf{63{,}994 \times 10^6}$	**100%**

There are a variety of methods that are commonly used to make estimates of greenhouse gas emissions from wastewater treatment. One commonly used method is a population based estimate, using a per capita emissions factor. Another viable method, given the availability of data indicating the volume of treated wastewater (Table 3.4.5), uses a wastewater volume emissions factor. Most inventory frameworks, including the EPA, IPCC, and GPC, recommend the use of population-based wastewater emission estimates. This recommendation is generally based on the complexity of alternative methods, and because the data and/or expertise needed for a detailed site-specific analysis is not always available. Given this recommendation, we follow the U.S. EPA method used by the MDE to estimate Baltimore City's emissions from wastewater treatment [26].

The MDE reports state-wide emissions of CH_4 and N_2O from wastewater treatment. Their calculations are based on the population of the State of Maryland, and one could estimate Baltimore City's contribution to state totals by scaling their estimates by the population ratio of Baltimore City to Maryland State. MDE bases their calculations on a state population estimate of 6,052,177 in 2017. According to data from the U.S. Census Bureau, Baltimore City had a population of about 610,481 people in 2017 [31]. Scaling MDE's state estimates by this population ratio (610,481/6,052,177 $\sim$ 10.1%), and assuming that none of Baltimore City's population uses a personal septic system, we calculate that Baltimore City was responsible for emission of 1,960 tons CH_4 and 63 tons N_2O during wastewater treatment. Note that this estimate would not include waste contribution from Baltimore visitors or people who work in Baltimore but live elsewhere.

Following the U.S. EPA's method of calculating emissions from wastewater treatment yields rather high emissions of CH_4 and rather low emissions of N_2O, relative to alternative methods. For completeness, we discuss some alternative methods of computing wastewater emissions below, but use the EPA guided estimate calculated above in the final totals for the waste sector and for the overall inventory. Note that these values are higher than the wastewater emissions in the previous 2010 and 2014 Baltimore emissions inventories. This is primarily due to the use of smaller emissions factors from the 2006 IPCC report in the previous inventories, and not necessarily because wastewater emissions have increased significantly. These emissions are summarized in Table 3.4.8.

Alternative Methods for Computing Wastewater Treatment Emissions

To illustrate the range of estimates for wastewater treatment emissions that could apply to Baltimore City, we summarize here some alternative methods from the literature for estimating emissions from wastewater treatment. These estimates utilize the gallons of treated wastewater data in Table

3.4.5 along with emission factors reported in the literature. We consider emissions factors from two literature studies: one long-term study of a municipal wastewater treatment plant in the Netherlands by Daelman et. al., and one critical review of multiple wastewater treatment emissions studies by Nguyen et. al. [32, 33]. The emission factors from these studies are summarized in Table 3.4.6, and are normalized by the population size and the average amount of wastewater treated during the study period, lending confidence to the applicability of these emission factors at Maryland municipal wastewater treatment plants. Using these emission factors with the gallons of wastewater treated data in Table 3.4.5, the total emissions from each plant are summarized by emission factor method in Table 3.4.7.

Table 3.4.6: Summary of Literature Emission Factors for Wastewater Treatment

Method	Plant Type	CO_2 E.F.	CH_4 E.F.	N_2O E.F.
Daelman et. al.	–	$^{*}2.18 \times 10^{-7}$	1.25×10^{-8}	6.06×10^{-9}
Nguyen et. al.	AAO	6.62×10^{-7}	6.81×10^{-10}	3.71×10^{-9}
Nguyen et. al.	SRB	1.31×10^{-6}	1.51×10^{-9}	1.59×10^{-8}

Emission factors (E.F.) here have units of metric tons/gallon of wastewater
* CO_2 emission factor for indirect emissions only (e.g. facility energy usage)

When following the Daelman et. al. method, note that emissions of CO_2 are entirely due to electricity and natural gas usage to power the treatment plant, and the CO_2 emission factor reported here is corrected from the literature value to account for the difference in the electrical grid CO_2 efficiency between Baltimore City and the Netherlands study region. Only the Nguyen et. al. study provides an estimate of direct CO_2 emissions from wastewater treatment. In order for there to truly be no direct CO_2 emissions from wastewater treatment, the wastewater treatment plant environment would have to be anoxic (without oxygen). This is unlikely to be the case, so we should expect nonzero emissions of CO_2 from wastewater treatment. The Nguyen et. al. study suggests that about 10% of CO_2 emissions from wastewater treatment are direct emissions, which yields an estimate of about 7,000 tons of CO_2 emitted directly from wastewater treatment in Baltimore City. Note that we did not include direct emissions of CO_2 in the totals of this report, following the EPA methodology for estimating wastewater treatment emissions.

There are two different types of wastewater treatment technologies described in the Nguyen et. al. review study, and each technology has a different set of emission factors. The anaerobic-anoxic-oxic (AAO) process is a biological nutrient removal technique that uses three tanks to sequentially flow wastewater through an anaerobic zone, an anoxic zone, and an oxic zone for removing pollutants. Wastewater is cycled between the anoxic and oxic tanks to ensure complete nutrient removal. Alternatively, the sequencing batch reactor (SBR) process is a biological nutrient removal process that occurs in a single reactor and utilizes an anoxic and aerobic treatment cycle, followed by a settling and decanting step. Differences in the aeration steps, biochemical additives, and reaction sequences cause different amount of CO_2, CH_4, and N_2O to be released at different steps within the two treatment processes.

We discuss both treatment technologies to illustrate that not all wastewater treatment plants operate using the same chemical engineering techniques, and that different treatment techniques result in different emissions factors. The Patapsco Wastewater Treatment Plant utilizes an SBR-like treatment process, whereas the Back River Wastewater Treatment Plant more closely resembles the AAO process. However, it is important to note that there are complexities to the engineering designs of both plants that may cause the true emissions to differ from what either set of emission factors predict. For example, a wastewater treatment plant could utilize CH_4 capture technology to

capture and flare CH_4, releasing it as CO_2, which would significantly reduce its total CO_2eq emissions. Alternatively, antiquated plant technologies could make wastewater treatment less efficient, yielding higher operating costs and/or greenhouse gas emissions. As wastewater treatment systems are continually updated, it is important to ensure that these upgrades minimize the production of greenhouse gases and close off pathways where greenhouse gases can escape from the treatment chambers. Installing greenhouse gas monitoring equipment on treatment plant outlets, when possible, would allow emissions can be tracked in real time, and would provide a highly accurate measure of wastewater treatment emissions for future inventories.

Table 3.4.7: Summary of Wastewater Treatment Emissions by Facility and Emission Factor Method

Plant	Method	Tons CO_2	Tons CH_4	Tons N_2O	Tons CO_2eq 20-yr GWP	Tons CO_2eq 100-yr GWP
Patapsco	Daelman	4,849	278	135	63,707	48,294
Back River	Daelman	9,113	522	253	119,728	90,762
Total	**Daelman**	**13,961**	**799**	**388**	**183,435**	**139,056**
Patapsco	Nguyen	14,723	15.1	82.4	37,739	36,973
Back River	Nguyen	54,865	63.2	664	232,616	235,493
Total	**Nguyen**	**69,588**	**78.4**	**746**	**273,232**	**269,589**
Total	**EPA/MDE**	–	**1,960**	**63.1**	**181,281**	**71,601**

Note that both volume-based emissions estimates following Daelman et. al. and Nguyen et. al. yield higher total CO_2eq estimates than the EPA/MDE method used in the totals for this report, primarily driven by larger estimates of N_2O emissions. Both literature methods suggest that the EPA methodology for estimating N_2O emissions may yield a significant underestimate, by a factor of about 6-12. Considering the high global warming potential of N_2O, this potential underestimate could yield an overall underestimate on the order of 80,000–180,000 tons CO_2eq. However, the literature emission factors also suggest that the EPA methodology may yield a significant overestimate of CH_4 emissions, by a factor of about 2-25. This potential overestimate could inflate CO_2eq emissions by about 30,000–50,000 tons CO_2eq for a 100-year GWP, or 100,000–160,000 tons CO_2eq for a 20-year GWP. However, it is unclear which of the three estimates in Table 3.4.7 is most reliable for each greenhouse gas, and there have been few literature studies to date that could resolve these discrepancies. We opt to follow the EPA's population-based methodology in order to remain consistent with MDE's state inventory, but it is important to acknowledge that any of the above estimates of wastewater treatment emissions carry a relatively high amount of uncertainty.

Table 3.4.8: Total Emissions from Municipal Wastewater Treatment

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	–	–	–
CH_4	1,959.7	164,615	54,872
N_2O	63.13	16,666	16,730
Total	–	**181,281**	**71,601**

Summary of Emissions from Sector 3 Waste

Emissions from Solid Waste Disposal (Section 3.1), Incineration and Open Burning (Section 3.3), and Wastewater Treatment and Discharge (Section 3.4) are summarized in Table 3.4.9 Figure 3.1. Note that emissions from the Wheelabrator Trash Incinerator are not included in Table 3.4.9 or the overall emission totals to avoid double counting imported electricity emissions in Section 1.

As summarized in Table 3.4.9, over the next 20 years, emissions of CH_4 and N_2O together contribute almost as much to the greenhouse effect from Baltimore City waste as CO_2 alone. Emissions from the waste sector in particular underscore the importance of including non-CO_2 greenhouse gases in municipal inventories. Furthermore, emissions of CH_4 from municipal waste management highlight the importance of considering a 20-year global warming time horizon instead of a 100-year time horizon, with an effective difference of nearly 300,000 tons of CO_2 between the two time intervals.

Table 3.4.9: Total Emissions from All Waste

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	20,031	20,031	20,031
CH_4	6,467	543,194	181,065
N_2O	63.1	16,666	16,729
Total	–	**579,891**	**217,825**

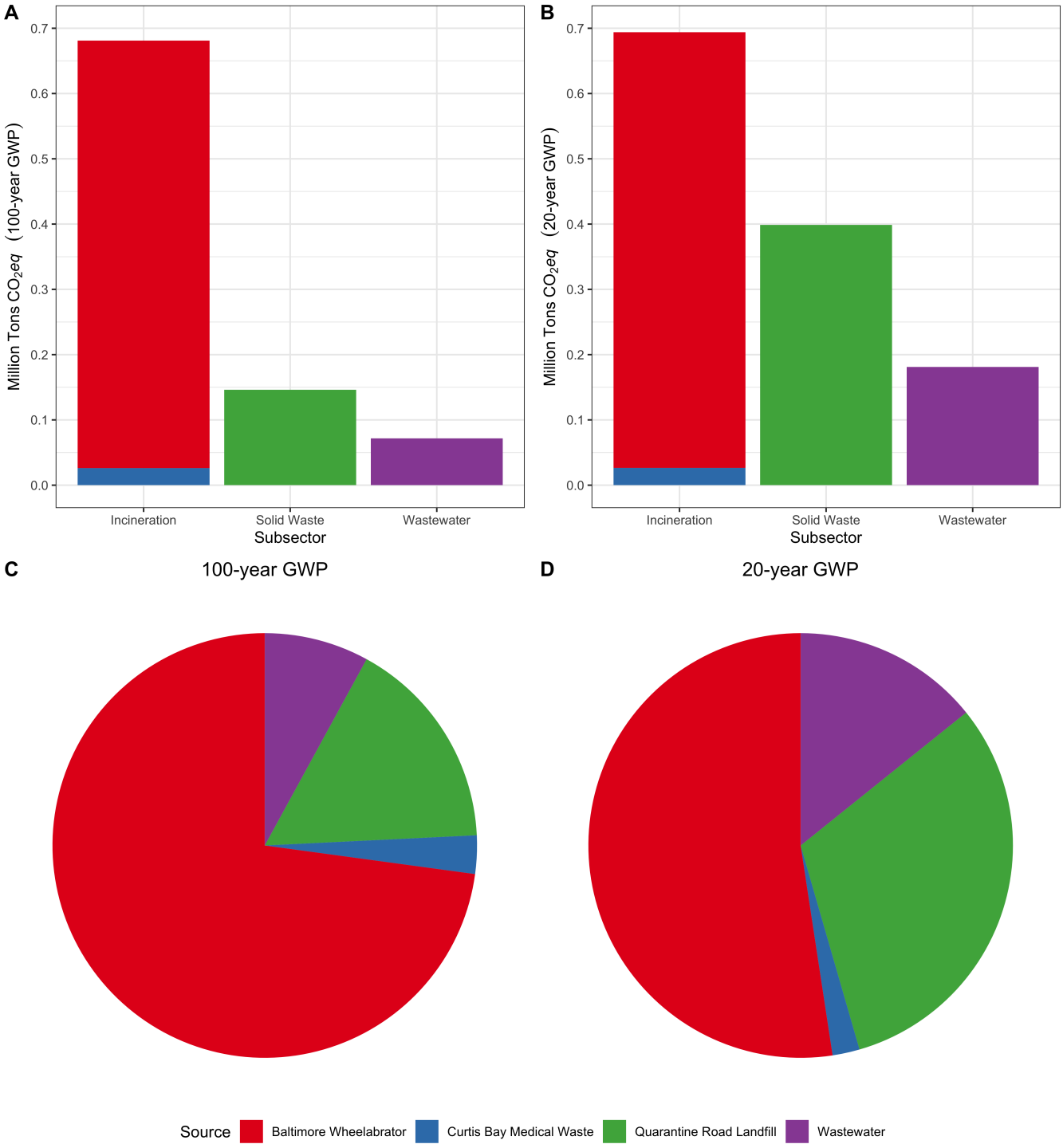


Figure 3.1: Summary of waste emissions by site. Note that emissions from the Baltimore Wheelabrator and Curtis Bay Medical Waste facilities are included in this figure for illustrative purposes, but are excluded from the overall emissions totals in Sector 3 Waste and in the overall report totals.

Sector 4 Industrial Process and Product Use (IPPU)

There are no emissions reported in this sector. Emissions from energy usage for industrial processes and product use are included in Sector 1 Stationary Energy.

4.1 Industrial Processes

None reported.

4.2 Product Use

None reported.

Summary of Emissions from Sector 4 IPPU

Table 4.2.1: Total Emissions from Industrial Process and Product Use

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	–	–	–
CH_4	–	–	–
N_2O	–	–	–
Total	–	**0**	**0**

Sector 5 Agriculture, Forestry, and Other Land Use (AFOLU)

There are no significant Scope 1 emissions from agriculture, forestry, or other land use activities within the City of Baltimore. One could compute the Scope 3 emissions resulting from agricultural activities that produce food and other products for the City of Baltimore, but we do not include those emissions in this report since they are not covered in the GPC [10].

5.1 Livestock

None reported.

5.2 Land

None reported.

5.3 Aggregate Sources and Non-CO_2 Sources on Land

None reported.

Summary of Emissions from Sector 5 AFOLU

Table 5.3.1: Total Emissions from Agriculture, Forestry, and Other Land Use

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	–	–	–
CH_4	–	–	–
N_2O	–	–	–
Total	–	**0**	**0**

Sector 6 Other Scope 3 Emissions

6.1 Other

None reported.

Summary of Emissions from Sector 6 Other Scope 3

Table 6.1.1: Total Emissions from Other Scope 3

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	–	–	–
CH_4	–	–	–
N_2O	–	–	–
Total	–	**0**	**0**

End of 2017 Inventory

Click to jump back to tables and figures summarizing overall emissions totals in 2017.

A Appendix: Re-analysis of 2007 Baltimore City GHG Inventory

Motivation for Re-analysis of 2007 Emissions

In 2009, the Baltimore Office of Sustainability released the city's first greenhouse gas emissions inventory. This inventory of the 2007 calendar year followed the ICLEI protocol at the time, but several of their emissions estimates and the calculation methods that were utilized notably differ from the methodology in the 2017 inventory from this report. The results of the original 2007 inventory are summarized in Table A1. In this Appendix, we re-analyze Baltimore City's emissions in 2007 following the same methodology that was utilized in the 2017 inventory above, when possible, and using analogous methodology when limited data availability prevents the use of the same methodology. For most of the upcoming sections, one can refer to the analogous section in the 2017 inventory (Section 1, Section 2, and Section 3) for a more detailed discussion of the emissions calculations.

Table A1: Summary of Previous 2007 GHG Inventory

Sector	Emissions (tons CO_2eq)
Industrial	2,382,109
Residential	2,166,818
Commercial	2,157,649
Transportation	2,254,410
Waste	265,088
Total	**9,226,075**

The emissions summarized in this table are from the original 2007 City of Baltimore GHG inventory, released in 2009.

Summary of 2007 Emissions Inventory Re-analysis

Here we summarize the results of the following appendix sections, each of which correspond to the GPC sectors with nonzero emissions (A.1 Stationary Energy, A.2 Transportation, and A.3 Waste). Table A2 summarizes the total emissions in 2007 by sector and subsector, as defined by the GPC. In total, we find that Baltimore City was responsible for the emission of 8,570,441 tons CO_2eq (100-year GWP), or 10,174,145 tons CO_2eq (20-year GWP). Considering the short-term warming impacts of these emissions effectively decreases the original estimate of 2007 emissions (which used a 100-year GWP) by ∼7.1%, or about 655,600 tons CO_2eq (Table A1). This downward revision of the original 2007 inventory is driven by significantly decreased estimates of emissions

from the industrial and commercial sectors, a slightly decreased estimate of residential emissions, and an increased estimate of waste emissions. The emission factors from PJM used in the current inventory to estimate emissions from the industrial, residential, and commercial sectors may not have been available when the original 2007 inventory was compiled.

Table A2: 2007 Emissions by GPC sectors and subsectors

Sector	Total CO_2eq (metric tons)	
Sub-sector	20 year GWP	100 year GWP
1. Stationary Energy	**6,480,584**	**5,843,200**
1.1 Residential buildings	1,987,150	1,979,961
1.2 Commercial and institutional buildings and facilities	3,513,855	3,497,467
1.3 Manufacturing industries and construction	–	–
1.4 Energy industries	–	–
1.5 Agriculture, forestry, and fishing activities	–	–
1.6 Non-specified sources	68,683	62,140
1.7 Fugitive emissions from coal	–	–
1.8 Fugitive emissions from oil and natural gas	910,896	303,632
2. Transportation	**2,195,859**	**2,189,330**
2.1 On-road	2,089,280	2,082,751
2.2 Railways	–	–
2.3 Waterborne navigation	4,090	4,090
2.4 Aviation	–	–
2.5 Off-road	102,489	102,489
3. Waste	**1,497,702**	**537,912**
3.1 Solid waste disposal	1,307,220	463,524
3.2 Biological treatment of waste	–	–
3.3 Incineration and open burning	–	–
3.4 Wastewater treatment and discharge	190,482	74,388
4. Industrial Processes & Product Use (IPPU)	**0**	**0**
4.1 Industrial processes	–	–
4.2 Product use	–	–
5. Agriculture, Forestry, & Other Land Use (AFOLU)	**0**	**0**
5.1 Livestock	–	–
5.2 Land	–	–
5.3 Aggregate sources and non-CO_2 sources on land	–	–
6. Other Scope 3	**0**	**0**
6.1 Other	–	–
Total Emissions	**10,174,145**	**8,570,441**

Table A3 summarizes the emissions from each emissions source that appears in both 2007 and 2017 inventories, including the percent change in emissions from 2007 to 2017. Note that some of the values from the 2017 inventory that appear in Table A3 are slightly modified to allow for a direct comparison of only the components in each emissions source that appear in both inventories. In particular, not all point sources from the 2017 EPA NEI also appear in the 2008 EPA NEI, in which case only the point sources that appear in both national inventories are compared. Additionally, MDE does not provide an analysis of Baltimore City on-road transportation emissions in their 2006

Table A3: Nested Comparison of 2007 Emissions to 2017 Emissions (100-year GWP)

Sector	2007 CO_2eq	2017 CO_2eq	% change
Utility Natural Gas (I&C)	776,308	1,164,578	+50.0%
Fugitive Utility Natural Gas	303,632	344,176	+13.4%
On-Road Transportation*	2,082,751	2,246,719	+7.9%
Other Point Sources	62,140	66,498	+7.0%
Wheelabrator Incinerator**	619,224	654,863	+5.8%
Off-Road Transportation*	102,489	104,680	+2.1%
Wastewater Treatment	74,388	71,601	–3.7%
Waterborne Navigation	4,090	3,328	–18.6%
Curtis Bay Incinerator**	32,495	26,247	–19.2%
Utility Natural Gas (Res.)	766,179	583,880	–23.8%
Utility Electricity (I&C)	2,721,159	2,067,540	–24.0%
Utility Electricity (Res.)	1,053,106	716,750	–31.9%
Home Heating Oil	160,676	74,650	–53.5%
Solid Landfill Waste	463,524	146,224	–68.5%
Total	**8,570,441**	**7,590,623**	**–11.4%**

*Values for On-Road and Off-Road Transportation emissions in this Table are both taken from the EPA NEI to allow direct comparison between inventory years using analogous data products. Note that in the overall 2017 inventory sum, the on-road transportation estimate from MDE is used instead of the EPA NEI estimate. MDE did not provide an estimate for on-road transportation emissions from Baltimore City in the 2006 state inventory. The 2017 off-road value in this table does not include "Construction equipment", which was not included in the 2008 NEI. **Emissions from the Wheelabrator and Curtis Bay incinerators are included here to indicate their net trend from 2007 to 2017, but are both excluded from overall totals.

report, so we use the 2017 and 2008 EPA NEI estimates of on-road transportation to estimate the trend in on-road transportation emissions, despite using the 2017 MDE estimate in the overall 2017 inventory totals.

In total, after correcting the emission values from the final 2017 analysis to ensure that both the 2007 and 2017 values are derived using the same methodology and data sources (Table A3), we calculate a net 11.4% decrease in emissions from 2007 to 2017. It is not shown in Table A3, but the same comparison results in a 14.9% reduction in emissions when using a 20-year GWP instead of a 100-year GWP. Note that if one were to calculate the net emissions change without matching the data sources that are used, and instead simply used the inventory totals in Tables 0.3 and A2, one would compute emissions decreases of 12.6% and 15.9% (100-year and 20-year GWP, respectively). The apparent discrepancy that arises when the data sources are required to match between inventory years is driven by the 2017 Transportation emissions sector. In the overall inventory totals, we use the 2017 MDE estimate of on-road and off-road transportation emissions; there is no analogous MDE estimate for 2007, and so we use the EPA NEI estimates of transportation emissions in 2008 and 2017 when computing the percent change in emissions from 2007 to 2017.

Figure A.1 illustrates the magnitudes and relative contributions of each emission source by sector, and also illustrates the significance of considering a 20-year global warming potential instead of a 100-year global warming potential. In particular, note that the total share of solid waste disposal emissions and fugitive natural gas emissions significantly increases when considering the near-term

GWP.

Figures A.2 and A.3 illustrate the 10-year changes in emissions by sector and subsector, first using a 20-year GWP and then using a 100-year GWP. Most notably, the total emissions from solid waste disposal at the Quarantine Road Landfill decreased significantly from 2007 to 2017. Emissions from both residential and industrial, institutional, and commercial facilities decreased over the 10-year period, primarily driven by the decrease in coal usage and increase in natural gas usage in the PJM regional electricity grid (A.4). The emissions reduction from a cleaner electricity grid is partially offset by an increase in natural gas usage, both in utility consumption and in fugitive emissions. As natural gas consumption increases, the net impact of the associated fugitive emissions also increases, especially in the near-term.

While there may appear to be a reduction in transportation emissions if one were to compare the 2017 summary tables (Table 0.3) to the 2007 summary tables (Table A2), it's important to note that the 2017 on-road transportation data shown in Figures A.2 and A.3 comes from MDE's estimate, while the 2007 data comes from the EPA NEI, which is notably higher than MDE's estimate in 2017 (as discussed in Section 2.1). EPA NEI estimates are used for both inventory years in Table A3, which allows for a fair direct comparison of on-road transportation emissions between 2007 and 2017. EPA NEI data suggest a 7.9% increase in on-road transportation emissions from 2007 to 2017. One would not see this increase if one were to compare the 2017 MDE estimate to the 2008 EPA NEI estimate, since the two agencies used different model settings and data inputs in their MOVES model analyses.

Overall, the largest emission sources in Baltimore City in 2007 remain the largest emission sources in 2017, despite notable reductions by some sources. However, the use of utility natural gas in Baltimore has significantly increased since 2007, along with associated fugitive natural gas emissions (which are predominantly methane). We assumed a 2% leak rate associated with utility natural gas consumption, but it is possible that the leak rate within Baltimore City is significantly larger than 2%, especially considering the aging infrastructure used to transport natural gas. BG&E plans to continually modernize their natural gas storage and transport system, but reports of natural gas leaks have been rising since at least 2011, with over 8,000 natural gas leaks repaired by BG&E in 2017 [34].

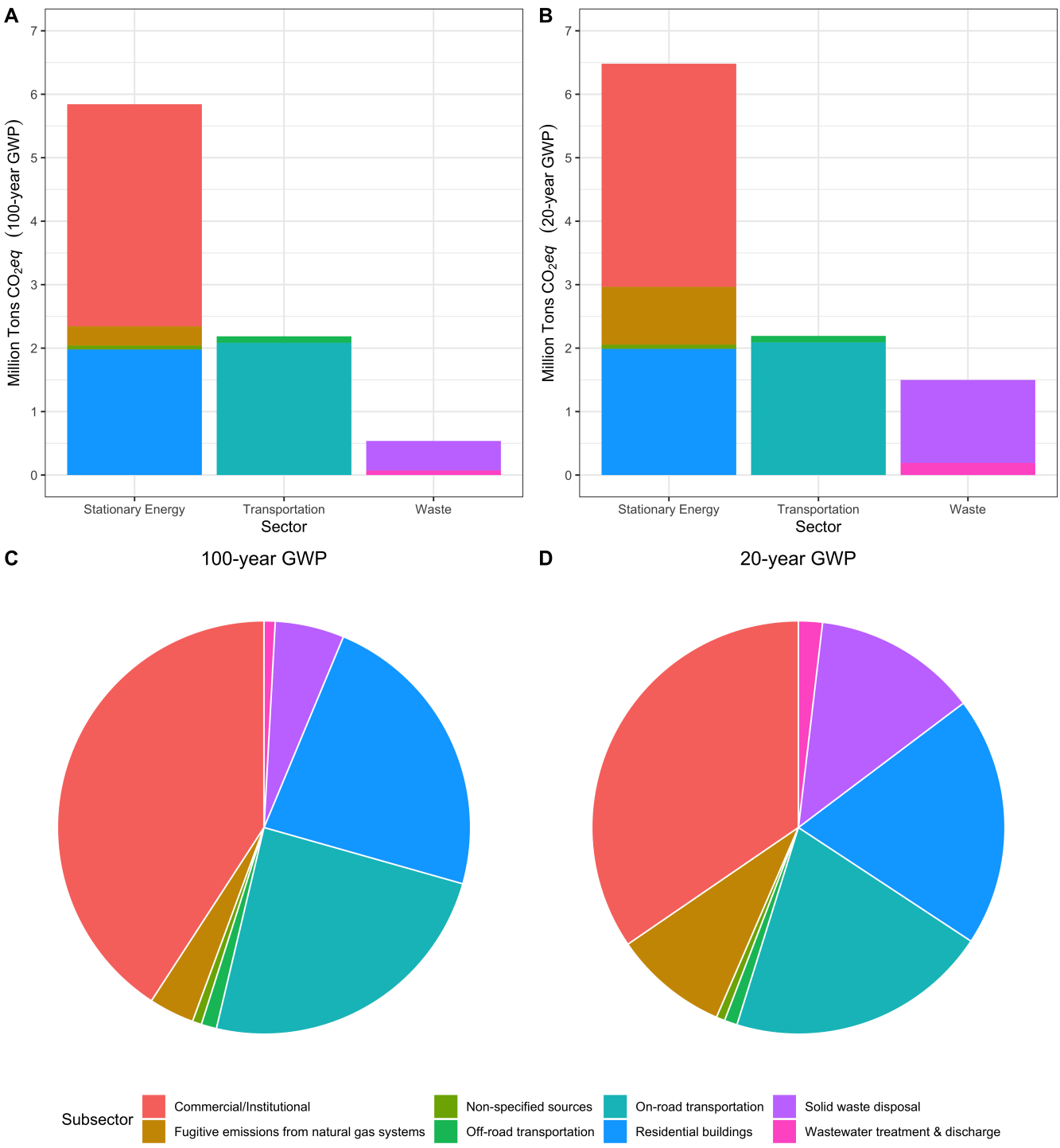


Figure A.1: Summary of total CO_2eq emissions in 2007 by sector and subsector.

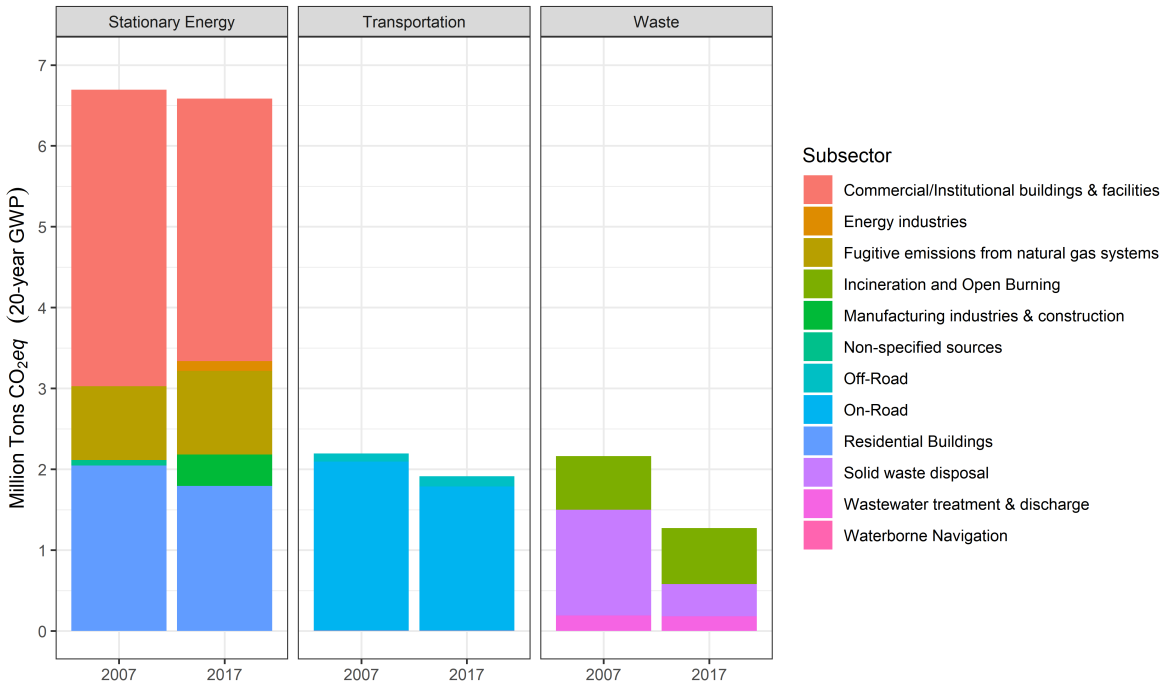


Figure A.2: Comparison of 2007 emissions to 2017 emissions by sector (20-year GWP)

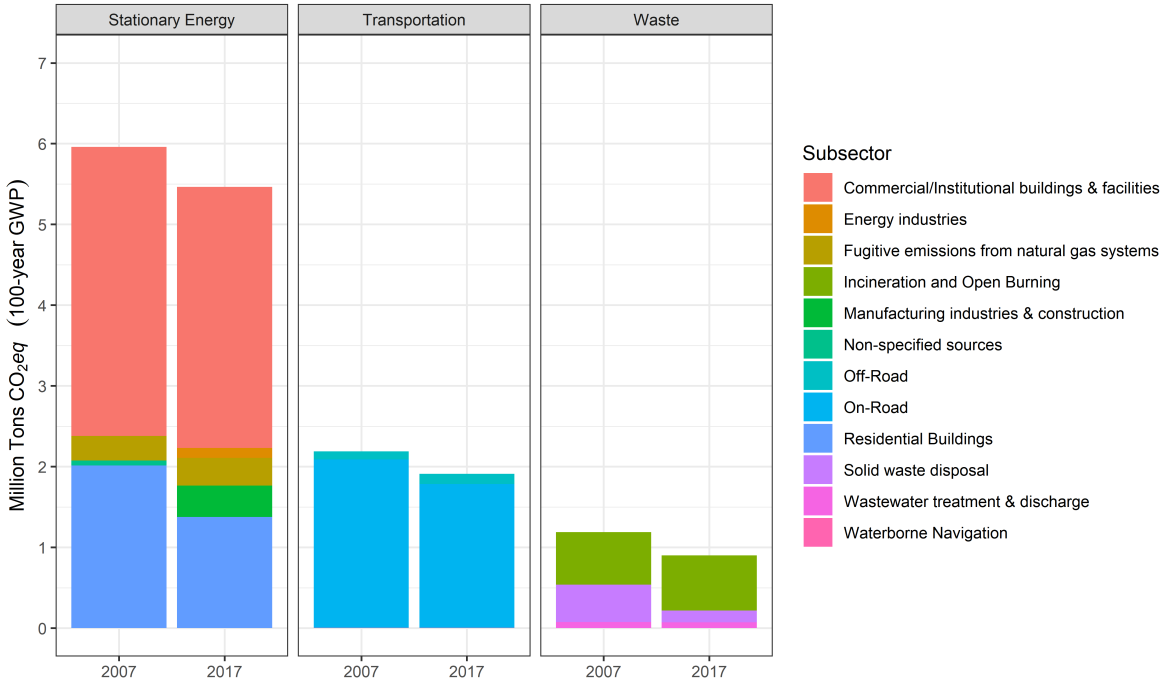


Figure A.3: Comparison of 2007 emissions to 2017 emissions by sector (100-year GWP)

A.1 Stationary Energy

As was done for the 2017 inventory, we can compute emissions from utility electricity and natural gas usage in the residential, industrial, and commercial sectors using supply data from the local utility, Baltimore Gas & Electric, and emission factors from the U.S. EPA and the regional electricity grid supplier, PJM Interconnection. PJM reports a fuel usage weighted CO_2 emission factor. As was done in 2017, EPA reported emissions factors for the fuels used in PJM's fuel mix were used to compute the CH_4 and N_2O emission factors that correspond to the PJM-reported CO_2 emission factor. These emission factors for electricity generation by PJM are summarized by greenhouse gas in Table A5, and utility supply data from BG&E is summarized in Table A4 [12, 13]. The emission factors for natural gas combustion can be found in Table 1.0.5.

Table A4: 2007 Electricity and Natural Gas from BG&E

Sector	Electricity (kWh)	Natural Gas (therms)
Residential	1,857,082,770	144,223,487
Industrial & Commercial	4,798,569,858	146,130,023
Total	**6,655,652,628**	**290,353,510**

Table A5: PJM Electricity Generation Emission Factors in 2007

Greenhouse Gas	Emission Factor	Units
CO_2	5.632×10^{-4}	Tons CO_2/kWh
CH_4	5.81×10^{-8}	Tons CH_4/kWh
N_2O	8.45×10^{-9}	Tons N_2O/kWh

A.1.1 Utility Electricity

Using the emission factors from PJM Interconnection for each fuel used in grid electricity generation, the weighted emission factor for electricity generated by PJM in 2007 is 0.5632 tons CO_2/MWh [13, 14]. This CO_2 emission factor is about 30.9% higher than the Scope 2 electricity emission factor in 2017, largely due to the coincident decrease in coal usage and increase in natural gas usage for regional grid electricity generation between 2007 and 2017. The trend in electricity generation methods between 2007 and 2019 in summarized in Figure A.4, which shows a sharp decline in coal usage along with a sharp incline in natural gas usage.

Using the 2007 BG&E supply data in Table A4 and the corresponding PJM emission factors in Table A5, we can calculate the total emissions from Scope 2 electricity generation for both the residential and the industrial/commercial sectors, as summarized in Table A6.

A.1.2 Utility Natural Gas

For this analysis, we assume that the chemical composition of utility natural gas has not changed significantly from 2007 to 2017. Thus, we can use the same emission factors for natural gas combustion as was done the 2017 analysis (Table 1.0.5). We can then compute the total greenhouse gas emissions from utility natural gas combustion using those emission factors and the utility natural gas usage data in Table A4. This calculation is summarised in Table A7.

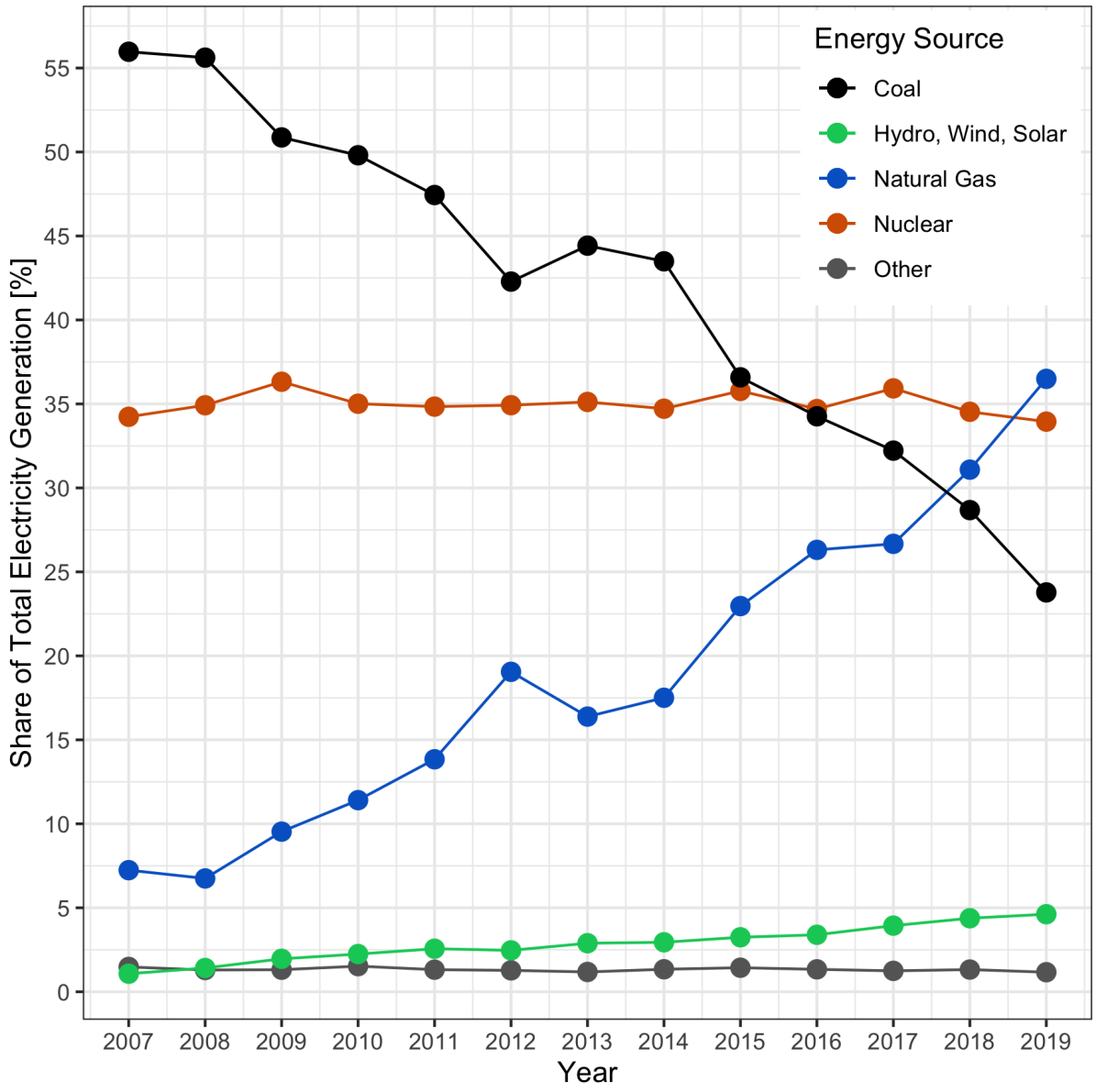


Figure A.4: Time series trend in fuels used by PJM to generate electricity for utility suppliers

A.1.3 Fugitive Utility Natural Gas

We compute the fugitive emissions of natural gas CH_4 in 2007 by using the same 2% utility natural gas leak rate and the CH_4 emission factor from the 2017 analysis. These fugitive emissions are summarized by global warming potential in Table A8.

$$\left(\frac{0.02}{0.98}\right) \cdot (290{,}353{,}510 \text{ therms}) \cdot \left(1.83 \times 10^{-3} \frac{\text{ton CH}_4}{\text{therm}}\right) = 10,844 \text{ tons CH}_4$$

A.1.4 Home Heating Oil

We follow the same approach as we did in Section 1.1.3 to estimate emissions from the combustion of home heating oil using data from the U.S. Census Bureau [16]. However, the U.S. Census Bureau

Table A6: Total Emissions from Utility Electricity in 2007

Greenhouse Gas	Sector	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	Residential	1,045,924	1,045,924	1,045,924
CH_4	Residential	108	9,064	3,021
N_2O	Residential	15.7	4,145	4,161
Total	Residential	–	**1,059,132**	**1,053,106**
CO_2	I&C	2,702,594	2,702,594	2,702,594
CH_4	I&C	279	23,419	7,806
N_2O	I&C	40.6	10,718	10,759
Total	I&C	–	**2,736,732**	**2,721,159**
Total	**Total**	–	**3,795,864**	**3,774,265**

Table A7: Total Emissions from Utility Natural Gas in 2007

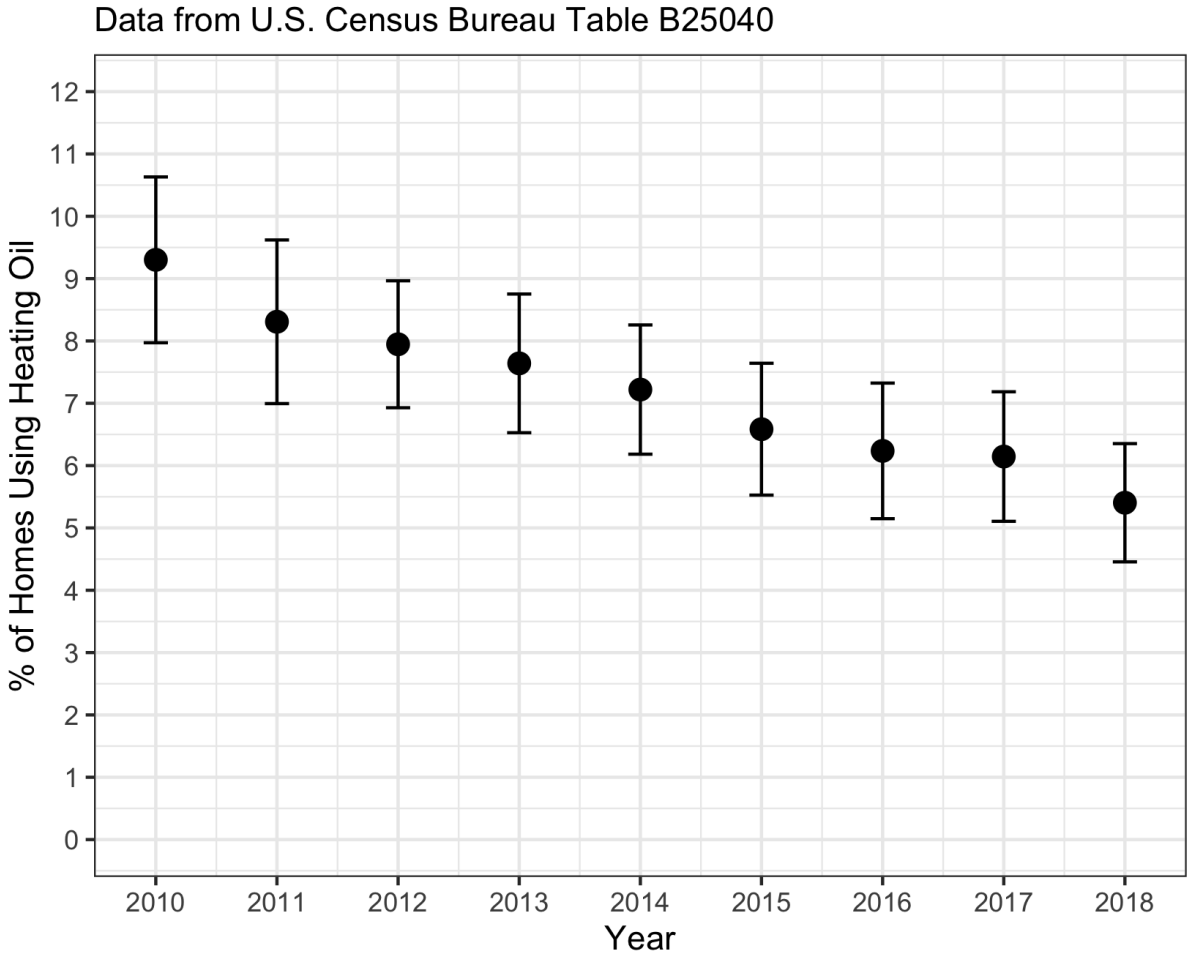
Greenhouse Gas	Sector	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	I&C	775,512	775,512	775,512
CH_4	I&C	14.6	1,226	409
N_2O	I&C	1.5	385	387
Total	I&C	–	**777,124**	**776,308**
CO_2	Residential	765,394	765,394	765,394
CH_4	Residential	14.4	1,210	403
N_2O	Residential	1.4	380	382
Total	Residential	–	**766,984**	**766,179**
Total	**Total**	–	**1,544,108**	**1,542,487**

Table A8: Total Emissions from Fugitive Natural Gas in 2007

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	–	–	–
CH_4	10,844	910,896	303,632
N_2O	–	–	–
Total	–	**910,896**	**303,632**

did not start reporting Table B25040, which indicates the number of homes in Baltimore that utilize heating oil, until 2010. To estimate the percentage of Baltimore homes that utilized heating oil in 2007, we first note that that percentage has steadily decreased from 2010 to 2018, as shown in Figure A.5. We can then compute the mean annual change and extrapolate back three years to yield the estimate that about 10.3% of Baltimore homes utilized heating oil in 2007. This estimate follows the assumption that the fraction of homes using heating oil has been linearly decreasing by about 0.443%/year since 2007. If this decreasing trend continues linearly, homes in Baltimore City will no longer use home heating oil by the year 2031. Using the same approach, we also estimate that 64.9% of Baltimore homes used natural gas as the primary fuel for space and water heating in 2007.

Figure A.5: Home Heating Oil Usage by Year in Baltimore City



$$\left(\frac{0.103}{0.649}\right) \cdot (0.931) \cdot (144, ,223{,}487 \text{ therms}) \cdot \left(7.520 \times 10^{-3} \ \frac{\text{tons } CO_2}{\text{therm}}\right) = 160{,}153 \text{ tons } CO_2$$

Similarly, we can compute the emissions of CH_4 and N_2O from home heating oil combustion using emission factors reported by the U.S. EPA [14]:

$$\left(\frac{0.103}{0.649}\right) \cdot (0.931) \cdot (144, ,223{,}487 \text{ therms}) \cdot \left(3.0 \times 10^{-7} \ \frac{\text{tons } CH_4}{\text{therm}}\right) = 6.4 \text{ tons } CH_4$$

$$\left(\frac{0.103}{0.649}\right) \cdot (0.931) \cdot (144, ,223{,}487 \text{ therms}) \cdot \left(6.0 \times 10^{-8} \ \frac{\text{tons } N_2O}{\text{therm}}\right) = 1.3 \text{ tons } N_2O$$

Total emissions from the combustion of home heating oil are summarized in Table 1.1.8. Emissions of CO_2 dominate the greenhouse gas effect caused by home heating oil combustion.

Note that the 100-year GWP CO_2eq emissions from home heating oil has decreased from approximately 160,676 tons CO_2eq in 2007 to 74,650 tons CO_2eq in 2017 – a 53.5% decrease over 10 years. This downward trend in emissions is driven in part by the diminishing percentage of homes that utilize heating oil as their primary means of space and water heating, but also by a 23.8% decrease in residential natural gas usage between 2007 and 2017.

Table A9: Total Emissions from Home Heating Oil in 2007

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	160,153	160,153	160,153
CH_4	6.4	538	179
N_2O	1.3	343	345
Total	–	**161,033**	**160,676**

A.1.5 Point Sources

Calculating point source emissions for the City of Baltimore in 2007 poses some challenges because unlike in 2017, there is no EPA National Emissions Inventory, or any analogous inventory, for the 2007 calendar year. While the EPA did compile a National Emissions Inventory for 2008, they did not include greenhouse gases like CO_2, CH_4, or N_2O in that inventory [35]. However, they do include data for carbon monoxide (CO) and nitrogen oxides (NO_x) emissions, which are also included in the 2017 inventory. We can thus use the 2017 NEI data for Baltimore City to compute the ratio of CO to CO_2, CO to CH_4, and NO_x to N_2O, and then use those ratios to approximate the emissions of CO_2, CH_4, and N_2O that correspond to the tabulated emissions of CO and NO_x in 2008. With these ratios, we are then able create an estimate for the total facility-level GHG emissions in 2008 for the City of Baltimore. We justify the choice of using CO and NO_x as proxy gases for CO_2, CH_4, and N_2O because most processes that emit CO will also emit CO_2 and CH_4, and most processes that release NO_x also release N_2O. We are making the assumption here that the ratio of those simultaneously emitted gases remained constant between 2008 and 2017, and that the estimated emissions for 2008 are also a reasonable estimate for 2007 emissions.

In the 2008 EPA NEI data, we filtered out any emissions arising from the use of natural gas, as was done in Sections 1.2.3, 1.3.1, and 1.4.1, in order to avoid double counting emissions from natural gas consumption in Section A.1.2. The approach of using proxy gas ratios carries a relatively high uncertainty for the estimates derived from those ratios, and isn't likely to be accurate for any particular point source on its own. However, if we use proxy gas ratios computed from the sum of all point sources in Baltimore City in 2017, we can reasonably compare the sum of corresponding 2008 emissions to the sum of 2017 emissions. In other words, the mean proxy gas ratio in 2008 is similar to the mean proxy gas ratio in 2017, but there is high variability in the proxy gas ratios of individual emission sources that is somewhat averaged out by taking the mean. Individual point sources may have a different CO:CO_2, CO:CH_4, or NO_x:NO_2 ratio than the summed ratio, but the sum of all estimated point sources can be reasonably computed from the summed ratio. Most of the point sources in the 2008 inventory also appear in 2017, and the largest emitters remain the same, lending confidence to the method of using proxy gas ratios computed from the sum of all point sources.

By summing the total CO_2, CH_4, N_2O, CO, and NO_x emissions from Baltimore City in the 2017 EPA NEI, we can then compute CO:CO_2, CO:CH_4, and NO_x:NO_2 ratios. We can then use these ratios to compute estimates of CO_2, CH_4, and N_2O emissions in 2008 from the EPA NEI reported totals of CO and NO_x. This computation is summarized in Table A10, and the total estimates are summarized by global warming potential in Table A11.

Summary of Stationary Energy Emissions

Table A10: Proxy Gas Emission Ratios and Corresponding 2008 GHG Emissions

2017 Proxy Gas Ratio	2008 Proxy Gas Emissions	2008 Estimated GHG
$\frac{62{,}673.2 \text{ Tons } CO_2}{526.7 \text{ Tons CO}} = 118.99$	487.6 Tons CO	58,018 tons CO_2
$\frac{126.2 \text{ Tons } CH_4}{526.7 \text{ Tons CO}} = 0.2396$	487.6 Tons CO	116.9 tons CH_4
$\frac{1.1 \text{ Tons } N_2O}{665.6 \text{ Tons } NO_x} = 0.00165$	1918.9 Tons NO_x	3.2 tons N_2O

Table A11: Emissions from Point Sources in 2007

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	58,018	58,018	58,018
CH_4	116.9	9,820	3,273
N_2O	3.2	845	848
Total	–	**68,683**	**62,140**

Table A12: Total Emissions from Stationary Energy in 2007

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	5,507,595	5,507,595	5,507,595
CH_4	11,383	956,172	318,724
N_2O	63.7	16,817	16,881
Total	–	**6,480,584**	**5,843,200**

A.2 Transportation

A.2.1 On-road

Emissions from on-road transportation in 2007 can be estimated using the 2008 U.S. EPA National Emissions Inventory [35]. Since neither the EPA nor the MDE has released an emissions inventory for the 2007 calendar year, we approximate 2007 transportation emissions using the 2008 EPA NEI, assuming that there were minimal changes to traffic patterns, public transportation, and vehicle fleets between 2007 and 2008. MDE does not provide a county-level analysis of on-road transportation emissions in their 2006 inventory, as they did in 2017. As noted in section 2.1, the EPA NEI estimate of on-road transportation emissions is about 26% higher than the MDE estimate in 2017, and thus the EPA NEI estimate for 2008 is also likely to be higher than what the MDE estimate would be for the same year. However, one can directly compare the 2017 NEI estimate to the 2008 NEI estimate when analyzing on-road transportation emissions trends. The U.S. EPA uses the MOVES model to compute on-road transportation emissions for Baltimore City. Table A13 summarizes these emissions by vehicle type, vehicle duty, and fuel type, and Table A14 summarizes these emissions by global warming potential.

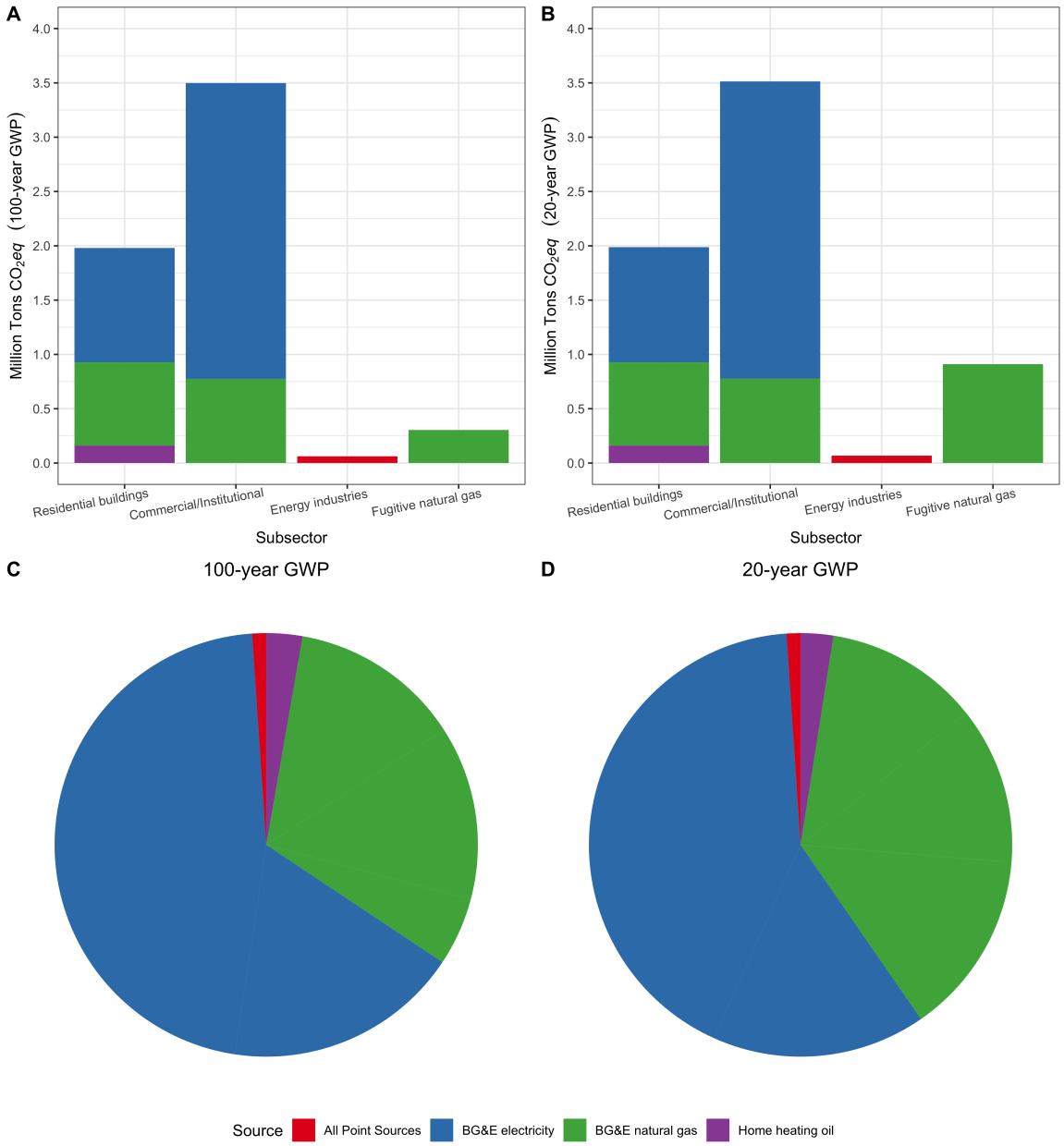


Figure A.6: Summary of Stationary Energy Emissions by Subsector. Note that while the Wheelabrator Trash Incinerator is included here for illustrative purposes, its emissions are counted toward the totals in the waste sector (A.3), not the stationary energy sector.

Table A13: 2008 On-Road Emissions by Vehicle Type (EPA NEI Estimate)

Fuel Type	Vehicle Duty	Vehicle Type	Tons CO_2	Tons CH_4	Tons N_2O
Gasoline	Light	Vehicles (General)	786,363	41.2	30.8
Gasoline	Light	Trucks	791,730	58.9	53.2
Gasoline	Heavy	Vehicles and Buses	79,879	7.2	5.2
Gasoline	Light	Motorcycles	8,410	2.0	0.1
Diesel	Light	Vehicles (General)	2,038	0.04	0.003
Diesel	Light	Trucks	13,830	0.2	0.05
Diesel	Heavy	Vehicles (General)	361,056	8.4	0.5
Diesel	Heavy	Buses	12,304	0.1	0.03
Total	**Total**	**Total**	**2,055,611**	**118**	**89.9**

Table A14: 2008 Total On-Road Emissions (EPA NEI Estimate)

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	2,055,611	2,055,611	2,055,611
CH_4	118	9,929	3,310
N_2O	89.9	23,740	23,830
Total	–	**2,089,280**	**2,082,751**

A.2.2 Off-Road

We use the same method for estimating off-road transportation emissions as was done for on-road emissions in 2007, using the 2008 EPA NEI [35]. The EPA uses the MOVES-NONROAD model to estimate these emissions for a variety of vehicle types. These emissions are summarized by equipment type and fuel type in Table A15. Note that the version of MOVES-NONROAD used by the EPA only estimates emissions of CO_2, and does not include construction equipment, unlike the version used in the 2017 EPA NEI.

Table A15: 2008 Off-road Emissions by Equipment and Fuel Type (EPA Estimate)

Emission Source	Fuel Type	Tons CO_2
Industrial Equipment	Gasoline	1,213
Industrial Equipment	Diesel	23,130
Industrial Equipment	Other	21,765
Lawn and Garden Equipment	Gasoline	27,420
Lawn and Garden Equipment	Diesel	1,371
Lawn and Garden Equipment	Other	54
Commercial Equipment	Gasoline	13,837
Commercial Equipment	Diesel	10,970
Commercial Equipment	Other	2,177
Railroad Equipment	Gasoline	6.2
Railroad Equipment	Diesel	131
Railroad Equipment	Other	0.2
Golf Carts	Gasoline	413
Total	**Total**	**102,489**

A.2.3 Waterborne Navigation

The 2008 U.S. EPA National Emissions Inventory reports emissions of CO_2 from recreational marine vessels occurring within Baltimore City. As was done for on-road and off-road transportation emissions, we assume that the 2008 NEI can be used to approximate waterborne navigation emissions in 2007. Note that emissions from the Port of Baltimore are not included in this section because they are outside of the jurisdiction of the City of Baltimore. Table A16 summarizes these emissions by gasoline type and engine type.

Table A16: 2008 Emissions from Recreational Marine Vessels

Fuel Type	Tons CO_2
Gasoline - 2 Stroke	2,554
Gasoline - 4 Stroke	858
Diesel	678
Total	**4,090**

Summary of Transportation Emissions

Table A17: Total Emissions from Transportation in 2007

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	2,162,190	2,162,190	2,162,190
CH_4	118.2	9,929	3,310
N_2O	89.9	23,740	23,830
Total	–	**2,195,859**	**2,189,330**

A.3 Waste

A.3.1 Solid Waste

The Maryland Department of the Environment reports landfill greenhouse gas emissions by landfill site in their 2006 State Inventory, including the Quarantine Road Landfill [36]. In lieu of a landfill emissions estimate from MDE or the EPA for 2007, we assume MDE's estimate of emissions from the Quarantine Road Landfill in 2006 is representative of what landfill emissions from that landfill would be in 2007. MDE estimates emissions of CO_2 and CH_4 from landfills in Maryland using the EPA LandGEM 3.0 model, as was done in the 2017 analysis. The results of the LandGEM analysis for the Quarantine Road Landfill are summarized in Table A18. Note that the Quarantine Road Landfill is by far the largest point source of CH_4 emissions in Baltimore City.

Table A18: 2006 Emissions from the Quarantine Road Landfill

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	41,676	41,676	41,676
CH_4	15,066	1,265,544	421,848
N_2O	–	–	–
Total	–	**1,307,220**	**463,524**

A.3.2 Incineration and Open Burning

Wheelabrator Trash Incinerator

As was done in the 2017 analysis, we do not explicitly count emissions from municipal solid waste incineration towards the total greenhouse gas emissions in 2007 since they are already included in the emissions from stationary electricity generation by PJM Interconnection. However, we report emissions from the Wheelabrator Baltimore trash incinerator here for reference.

According to data from the Maryland Department of the Environment, Wheelabrator Baltimore was responsible for the emission of 605,820 metric tons of CO_2 in 2006 [36]. In lieu of an estimate of municipal solid waste combustion emissions from the MDE or the EPA, we assume that the reported 2006 emissions from Wheelabrator Baltimore are representative of what that site would have emitted in 2007, assuming there were no major technological innovations installed and that there were minimal changes to operating procedures and the waste supply stream. MDE reports that the Wheelabrator facility processed and incinerated 671,484 tons of municipal solid waste in 2006, which yielded 605,820 tons of emitted CO_2. Notably, MDE does not estimate emissions of CH_4 or N_2O in 2006. However, we can use the ratio of CO_2:CH_4 emissions and CO_2:N_2O emissions from 2017 to estimate the emissions of CH_4 and N_2O that correspond to the measured emissions of CO_2. The total estimated emissions of these greenhouse gases are summarized by global warming potential in Table A19.

When directly comparing the 2006 MDE estimate of Wheelabrator Baltimore's CO_2 emissions to the 2017 estimate in Table 3.3.2, we see a 5.8% increase in CO_2 emissions from 2006 to 2017. This emission increase from waste incineration may partially explain the decrease in landfill emissions over the same time interval, although there are likely other factors influencing that decrease as well.

Table A19: Emissions from the Wheelabrator Trash Incinerator in 2006

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	605,820	605,820	605,820
CH_4	213.7	17,951	5,984
N_2O	28.0	7,392	7,420
Total	–	**631,163**	**619,224**

Curtis Bay Medical Waste Incinerator

As was done for the Wheelabrator Baltimore facility, we do not include emissions from the Curtis Bay Medical Waste facility in the emissions totals in the 2007 inventory to avoid double counting emissions from stationary energy generation. However, we summarize emissions from the Curtis Bay facility below for reference.

We estimate emissions from the Curtis Bay Medical Waste Incinerator in 2007 by using the 2008 and 2017 EPA NEI emissions of CO and NO_x from the facility, similar to what was done in Section A.1.5. We can use the proxy gas ratios that are specific to the Curtis Bay incinerator to estimate the corresponding emissions of CO_2, CH_4, and N_2O to the NEI reported emissions of CO and NO_x. From the 2017 NEI data, we use the CO_2:CO ratio of 18621.62, the CH_4:CO ratio of 0.7839, and the N_2O:NO_x ratio of 0.01076 to estimate the CO_2, CH_4, and N_2O emissions that are summarized in Table A20.

Table A20: Emissions from the Curtis Bay Medical Waste Incinerator in 2008

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	32,285	32,285	32,285
CH_4	1.36	114	38.1
N_2O	0.65	172	172
Total	–	**32,571**	**32,495**

A.3.3 Wastewater Treatment

According to the City of Baltimore Wastewater Facilities Division, the Patapsco facility treated 18,355 million gallons of wastewater and the Back River facility treated 52,141 million gallons of wastewater from the City of Baltimore in 2007 [30], as summarized in Table A22. Overall, there was a 9.2% decrease in the total gallons of wastewater treated from 2007 to 2017 (Tables 3.4.5 and A22). This downward trend may be explained by the decrease in the population of Baltimore City over that time period.

Table A21: Gallons of Wastewater Treated in 2007

Treatment Facility	Gallons Wastewater
Patapsco	$18{,}355 \times 10^6$
Back River	$52{,}141 \times 10^6$
Total	$\mathbf{70{,}496 \times 10^6}$

Following the U.S. EPA methodology used by MDE in their state inventory, and in this inventory in Section 3.4, we can estimate the total emissions from wastewater treatment using the population of Baltimore City in 2007. According to data from the U.S. Census Bureau, the population of Baltimore City in 2007 was 640,150 (4.6% higher than in 2017) [31]. Using the emission factors from MDE's 2006 state inventory (which were the same as in the 2017 state inventory), and assuming that 100% of Baltimore City residents utilize the municipal wastewater system, we compute that Baltimore City emitted 2,074 tons CH_4 and 61.6 tons N_2O in 2007. These emissions are summarized by global warming potential in Table A22. As was discussed in Section 3.4, this estimate has a relatively high uncertainty due to a lack of consensus surrounding wastewater treatment emission factors. We opt to follow the U.S. EPA methodology to align with MDE's estimate in the 2006 state inventory.

Table A22: Emissions from Wastewater Treatment in 2007

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	–	–	–
CH_4	2,074	174,233	58,078
N_2O	61.6	16,249	16,311
Total	–	**190,482**	**74,388**

Summary of Waste Emissions

Table A23: Emissions from Waste in 2007

Greenhouse Gas	Tons GHG	Tons CO_2eq (20-yr GWP)	Tons CO_2eq (100-yr GWP)
CO_2	41,676	41,676	41,676
CH_4	17,140	1,439,777	479,926
N_2O	61.6	16,249	16,311
Total	–	**1,497,702**	**537,912**

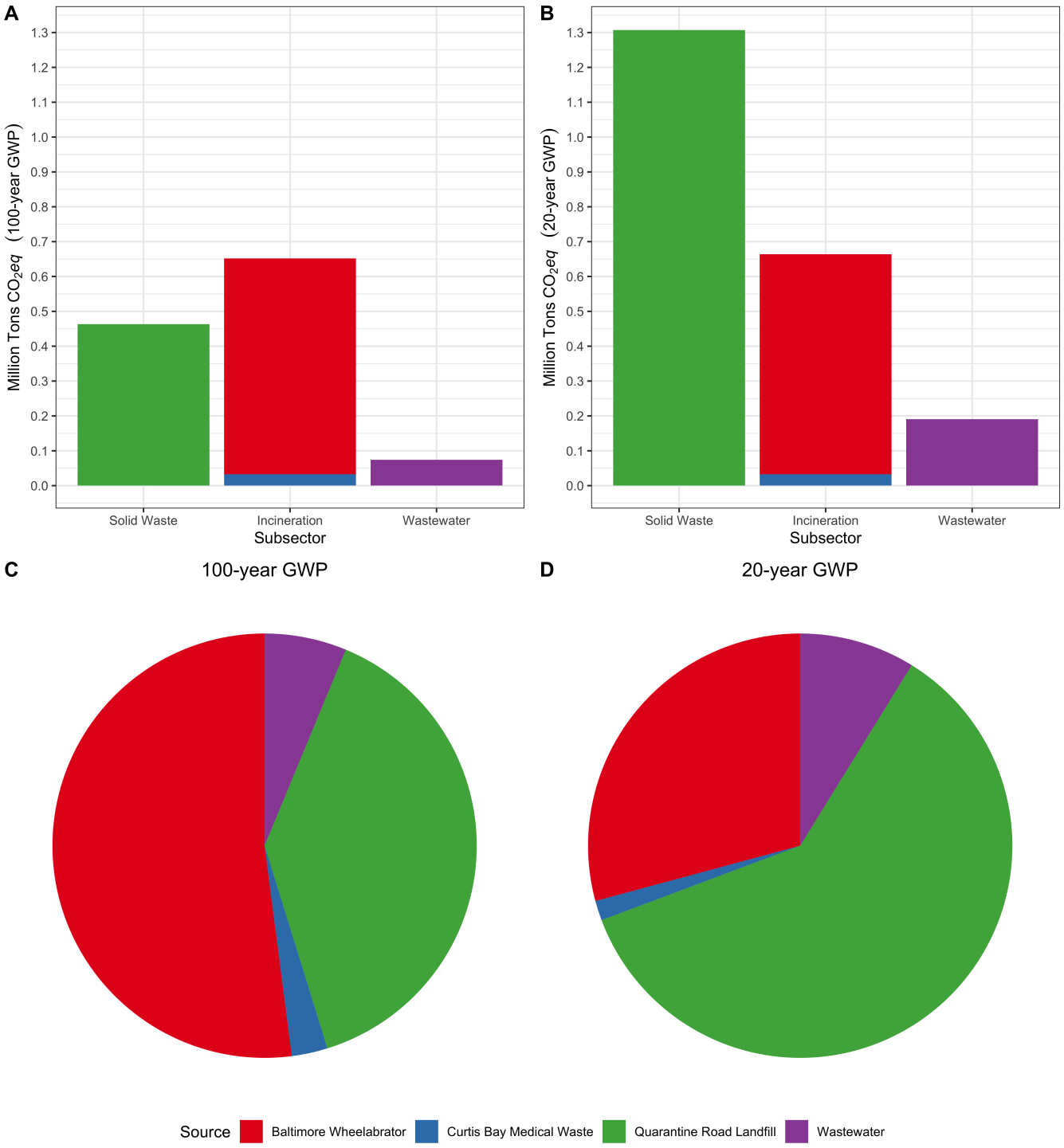


Figure A.7: Summary of Waste Emissions by Subsector. Note that emissions from the Baltimore Wheelabrator and Curtis Bay Medical Waste facilities are included in this figure for illustrative purposes, but are excluded from the overall emissions totals in Section A.3 Waste and in the overall report totals.

End of 2007 Inventory

Click to jump back to tables and figures summarizing overall emissions totals in 2007.

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