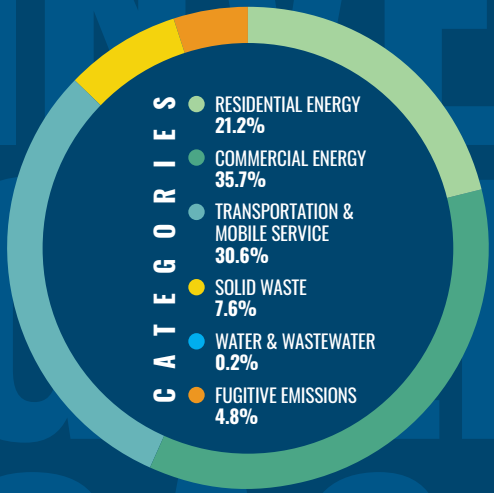
The City *of*
WORCESTER

2020–2023
(with a 2009 baseline)

COMMUNITY EMISSIONS IN 2023



GREENHOUSE GAS EMISSIONS INVENTORY

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The City *of* WORCESTER

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EXECUTIVE SUMMARY

This report is the City of Worcester's Greenhouse Gas (GHG) emissions inventory from 2020 to 2023, providing a comprehensive analysis of the City's progress towards its carbon neutrality goals. Utilizing methodologies from the US Community Protocol and data from various sectors, the inventory presents a detailed overview of Worcester's efforts to mitigate GHG emissions across residential, commercial, transportation, and municipal operations.

EXECUTIVE SUMMARY

Summary Tables[1]:

TABLE 1 – COMMUNITY GHG EMISSIONS BY SECTOR FROM 2009 TO 2023.

RESIDENTIAL ENERGY		2009	2019	2020	2021	2022	2023	% CHANGE 2009-2023
Grid Electricity	MT CO2e	161,448	120,288	97,852	102,853	80,822	75,286	-53.4
Natural gas use	MT CO2e	192,760	209,346	201,066	201,066	196,724	177,296	-8.0
Propane	MT CO2e	5,789	8,532	8,027	9,074	9,402	9,408	62.5
Fuel Oil No.2	MT CO2e	106,237	101,704	90,836	101,445	101,523	101,586	-4.4
COMMERCIAL ENERGY		**2009**	**2019**	**2020**	**2021**	**2022**	**2023**	**% CHANGE 2009-2023**
Grid Electricity	MT CO2e	383,587	238,758	194,180	206,558	180,770	188,176	-50.9
Natural gas combustion	MT CO2e	297,536	349,617	346,500	412,975	403,122	403,374	+35.5
Fuel Oil No. 2	MT CO2e	24,338	13,149	9,752	19,234	19,244	19,256	-20.9
TRANSPORTATION AND MOBILE SERVICE		**2009**	**2019**	**2020**	**2021**	**2022**	**2023**	**% CHANGE 2009-2023**
Community on-road transportation (VMT[2] for Worcester)	MT CO2e	409,105	480,205	375,895	482,837	506,015	506,064	+23.7
Bus Transit	MT CO2e	5,341	5,068	4,346	4,593	5,055	5,058	-5.3
Air travel	MT CO2e	2,211	3,098	5,411	5,716	9,602	8,742	+295.4
Rail transportation	MT CO2e	1,580	2,150	382	942	2,259	3,228	+104.3
SOLID WASTE		**2009**	**2019**	**2020**	**2021**	**2022**	**2023**	**% CHANGE 2009-2023**
Residential Waste	MT CO2e	25,627	25,526	23,347	24,111	23,245	23,307	-9.1
Commercial Waste	MT CO2e	75,196	82,935	79,205	82,466	94,023	83,659	+11.3
Compost	MT CO2e	3,954	3,954	1,353	1,091	1,304	1,305	-67.0
In jurisdiction landfill	MT CO2e	46,777	26,454	24,988	23,604	22,296	21,060	-55.0
WATER AND WASTEWATER		**2009**	**2019**	**2020**	**2021**	**2022**	**2023**	**% CHANGE 2009-2023**
Potable Water	MT CO2e	2,180	1,501	1,205	1,324	1,116	939	-56.9
Wastewater	MT CO2e	1,529	1,566	1,744	1,739	1,734	1,731	+13.2
FUGITIVE EMISSIONS		**2009**	**2019**	**2020**	**2021**	**2022**	**2023**	**% CHANGE 2009-2023**
Natural Gas Leakage	MT CO2e	146,057	166,513	77,424	86,824	84,817	82,105	-43.7
SUMMARY		**2009**	**2019**	**2020**	**2021**	**2022**	**2023**	
TOTAL EMISSIONS	MT CO2e	1,891,253	1,840,361	1,543,512	1,768,451	1,743,074	1,711,580	
TOTAL % CHANGE FROM 2009 BASELINE			-2.7	-18.4	-6.5	-7.8	-9.5	

[1] Note: all numbers may not add exactly to total due to rounding to the nearest whole number.

[2] Vehicle Miles Traveled

EXECUTIVE SUMMARY

TABLE 2 – COMMUNITY USAGE BY SECTOR FROM 2009 TO 2023.

RESIDENTIAL ENERGY		2009	2019	2020	2021	2022	2023	% CHANGE 2009-2023
Grid Electricity	MWh	426,880	415,778	416,635	420,862	429,319	441,255	+3.4
Natural gas use	therms	36,291,405	39,414,006	37,855,107	37,855,107	37,037,786	33,379,888	-8.0
Stationary Fuel Consumption: Propane	MMBtu	91,770	135,239	127,238	143,838	149,040	149,133	+62.5
Stationary Fuel Consumption: Fuel Oil No.2	MMBtu	1,435,500	1,374,254	1,227,400	1,370,747	1,371,804	1,372,659	-4.3%
COMMERCIAL ENERGY		**2009**	**2019**	**2020**	**2021**	**2022**	**2023**	**% CHANGE 2009-2023**
Grid Electricity	MWh	1,014,230	825,276	767,762	806,486	837,314	921,880	-9.1
Natural gas combustion	therms	56,017,923	65,823,323	65,236,419	77,751,849	75,896,855	75,944,171	35.6
Stationary Fuel Consumption: Fuel Oil No.2	MMBtu	328,860	177,674	131,765	259,896	260,032	260,194	-20.9
TRANSPORTATION AND MOBILE SERVICE		**2009**	**2019**	**2020**	**2021**	**2022**	**2023**	**% CHANGE 2009-2023**
Community on-road transportation (VMT for Worcester)	Miles	847,621,170	1,015,501,175	757,430,180	973,214,843	1,020,378,698	1,021,014,823	+20.5
Bus Transit	Gallons of gasoline	129,533	137,231	113,996	113,900	123,143	123,220	-4.9
Bus Transit	Gallons of Diesel	411,094	371,131	323,330	349,109	388,637	388,879	-5.4
Bus Transit	kWh	-	232,480	163,200	92,960	-	-	-
Air travel	LTO	-	-	2,019	2,133	3,583	3,262	-
Rail transportation	Passenger miles	10,963,368	14,916,616	2,652,845	6,534,472	15,675,522	22,399,935	+104.3
SOLID WASTE		**2009**	**2019**	**2020**	**2021**	**2022**	**2023**	**% CHANGE 2009-2023**
Waste generation	tonnage	27,794	27,684	25,321	26,150	25,211	25,278	-9.1
Commercial generation	workers	81,442	91,116	83,753	87,202	88,765	88,463	+8.6
Compost	tonnage	15,556	15,556	5,323	4,293	5,130	5,133	-67.0
In jurisdiction landfill	MT CH4	1,671	945	892	843	796	752	-55.0
WATER AND WASTEWATER		**2009**	**2019**	**2020**	**2021**	**2022**	**2023**	**% CHANGE 2009-2023**
Potable Water Distributed	gallons	8,071,341,253	7,262,194,385	7,181,279,698	7,586,491,163	8,302,352,614	7,702,563,074	-4.6
Wastewater Nitrification/ Denitrification	Population served	181,045	185,428	206,518	205,918	205,319	205,000	+13.2
Wastewater Effluent Discharge	Population served	181,045	185,428	206,518	205,918	205,319	205,000	+13.2
FUGITIVE EMISSIONS			**2019**	**2020**	**2021**	**2022**	**2023**	**% CHANGE 2009-2023**
Natural gas loss rate	therms	2,561,513	2,920,255	1,357,842	1,522,685	1,487,488	1,439,932	-43.8

EXECUTIVE SUMMARY

Key Findings

- **Compared to 2009 levels, 2023 community emissions are 9.5% less.** Worcester's GHG emissions have shown a downward trajectory, with a notable reduction in 2020. See figure 1 for more information.

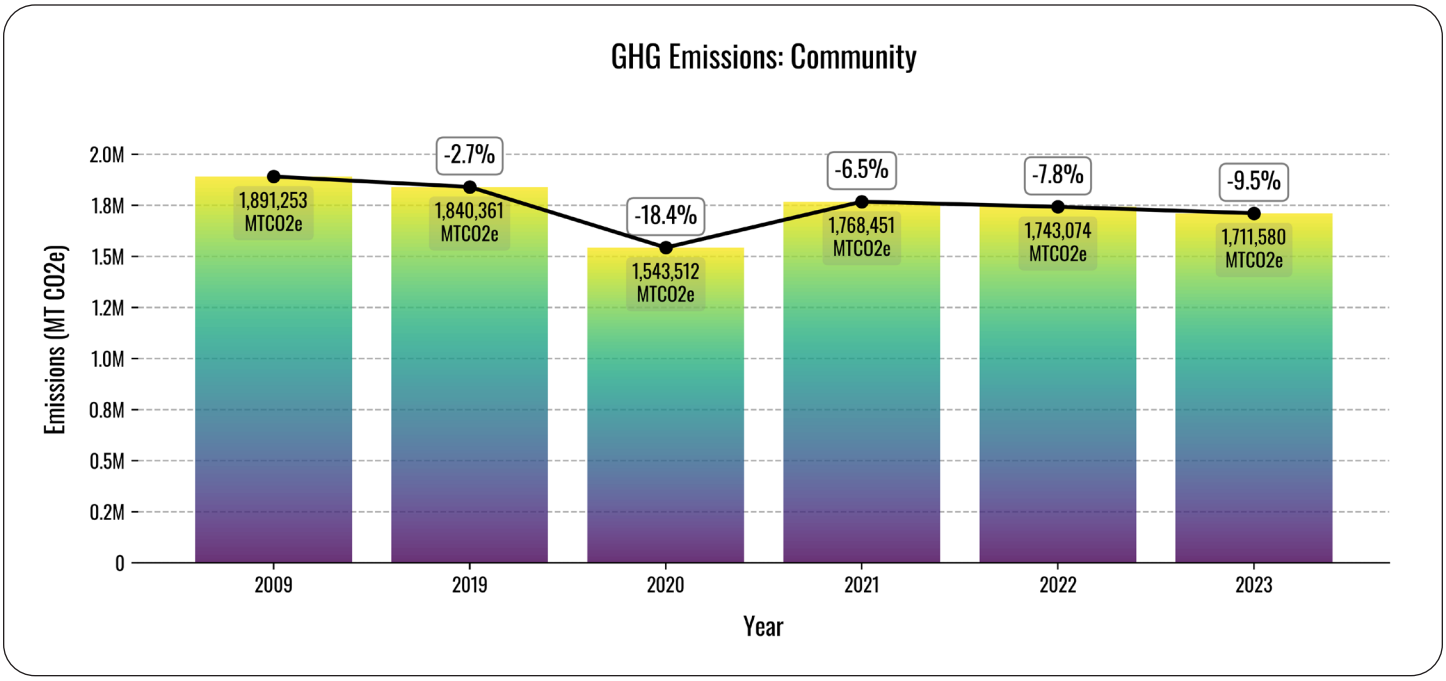

FIGURE 1: BAR CHART ILLUSTRATING THE COMMUNITY GHG EMISSIONS AND THE PERCENTAGE CHANGE IN EMISSIONS RELATIVE TO THE 2009 BASELINE.

EXECUTIVE SUMMARY

- **The four sectors with the highest contributions to total emissions have remained constant since 2019.** The primary sources of emissions in 2023 are dominated by Commercial Energy, followed closely by the Transportation sector. Residential Energy is the third-largest source, and finally Solid Waste is the fourth largest source. Together, these sectors highlight the key areas for targeted emissions reduction efforts. Figure 2 describes the sources in more detail.

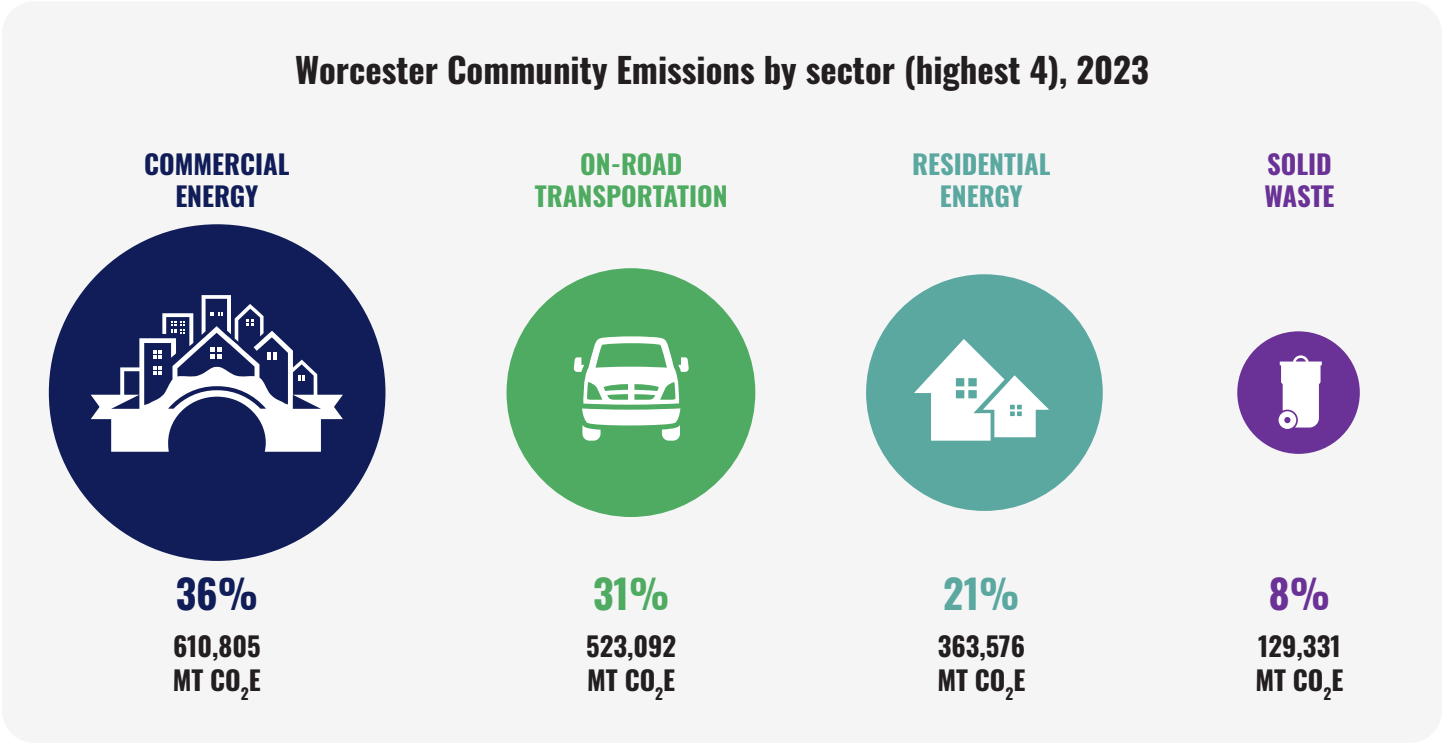

FIGURE 2: WORCESTER COMMUNITY EMISSIONS BY SECTOR (HIGHEST 4), 2023.

EXECUTIVE SUMMARY

- **Community emissions are expected to decrease by 23.5% by 2045.** If trends from 2009 to 2023 continue, we expect a downward trajectory compared to the 2009 baseline. However, this projection underscores the need for sustained and intensified efforts in renewable energy procurement, building electrification, and other strategic initiatives to achieve the city's carbon neutrality target by 2045.

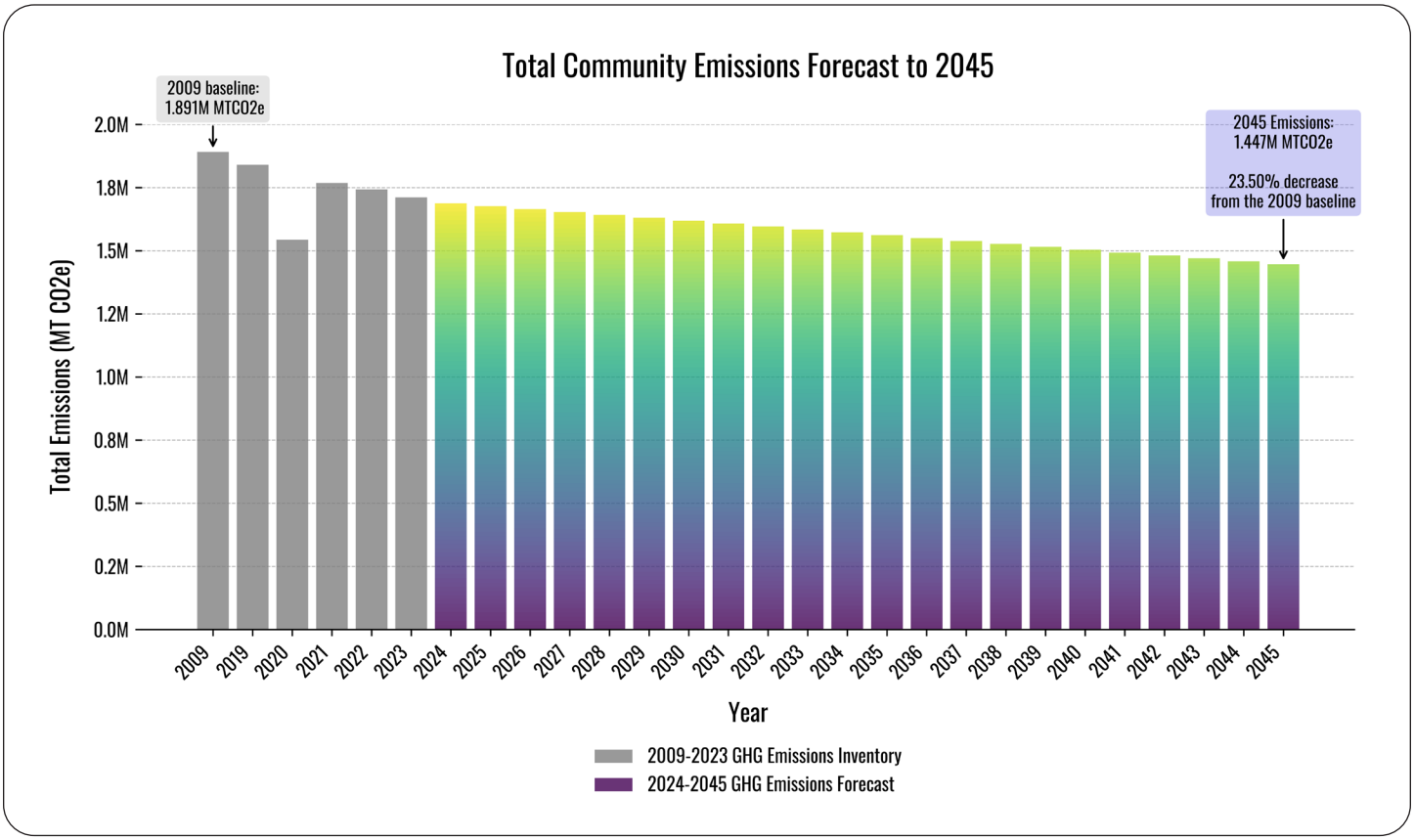

FIGURE 3: BAR CHART SHOWING COMMUNITY EMISSION PROJECTIONS THROUGH 2045.

EXECUTIVE SUMMARY

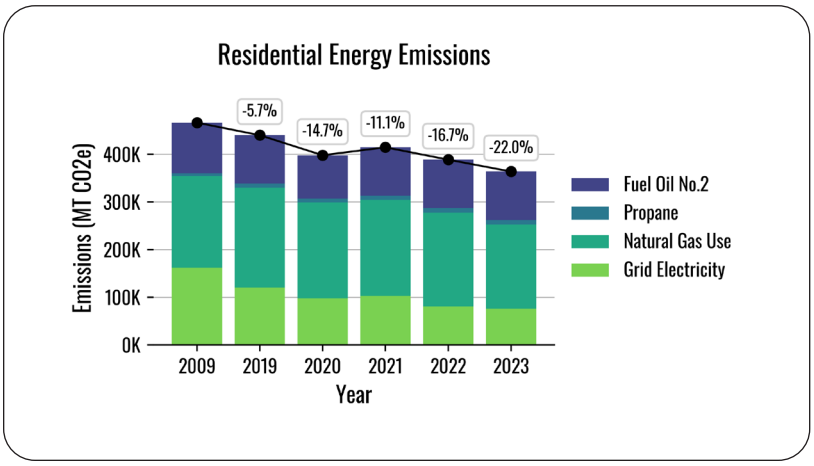

FIGURE 4: YEARLY EMISSIONS IN THE RESIDENTIAL ENERGY SECTOR AND CHANGES RELATIVE TO THE 2009 BASELINE.

- **Community residential energy emissions have decreased by 22.0% since 2009.** This reduction was driven by a decrease in grid electricity emissions, indicating a shift towards utilities using more sustainable energy sources spearheaded by the Massachusetts Renewable Portfolio Standard and Worcester's Municipal Electric Aggregation Program, Green Worcester ElectriCITY.

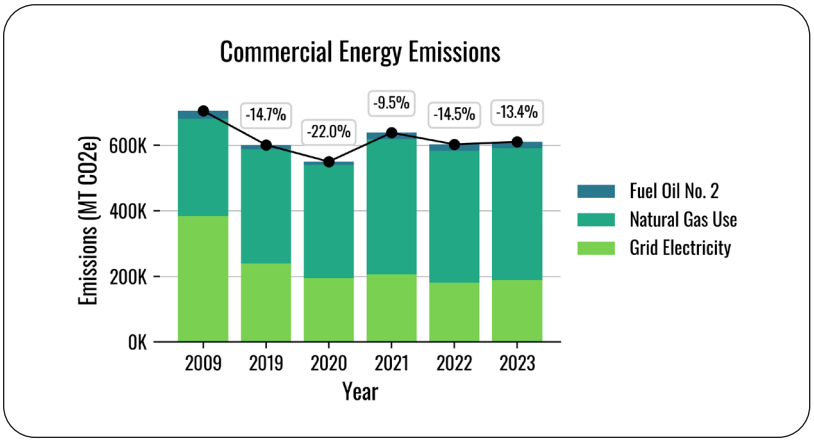

FIGURE 5: YEARLY EMISSIONS IN THE COMMERCIAL ENERGY SECTOR AND CHANGES RELATIVE TO THE 2009 BASELINE.

- **Commercial energy emissions have decreased by 13.4% since 2009.** This reduction can mainly be attributed to a significant reduction in grid electricity emissions. Figure 5 shows emissions changes relative to a 2009 baseline.

EXECUTIVE SUMMARY

- **Transportation-related emissions have increased by 25.1% since 2009.** The sector's emissions are slowly trending upwards, showing an increasing dependence on car travel. However, there was a significant drop in 2020 due to the COVID-19 pandemic.

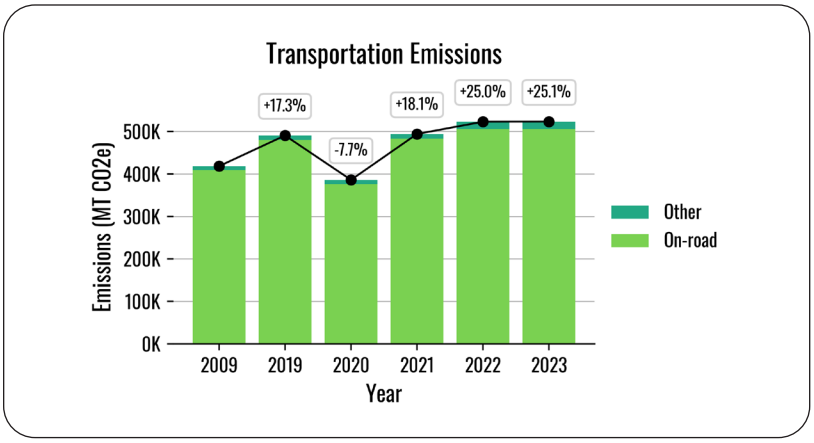

FIGURE 6: ANNUAL EMISSIONS BY TRANSPORTATION AND MOBILE SERVICE SECTOR FROM 2009 TO 2023 AND RELATIVE CHANGES COMPARED TO THE 2009 BASELINE.

EXECUTIVE SUMMARY

- **Other[3] Emissions have decreased by 28.9% since 2009.** The decrease was driven by a change in fugitive gas emission reporting. Fugitive emissions from natural gas usage decreased due to recalculation. In this inventory, the leakage rate of natural gas was reevaluated and found to be much lower than reported in the 2009 and 2019 inventory. Through evaluation of Environmental Protection Agency (EPA) reporting and regional averages leakage rate was found to be approximately 1.3%[4] for our region, much lower compared to the 2.7% national average used in the 2019 inventory. This updated leakage percentage is more accurate and confirmed by analysis of EPA reporting from the local natural gas company. More information can be found in Appendix B.

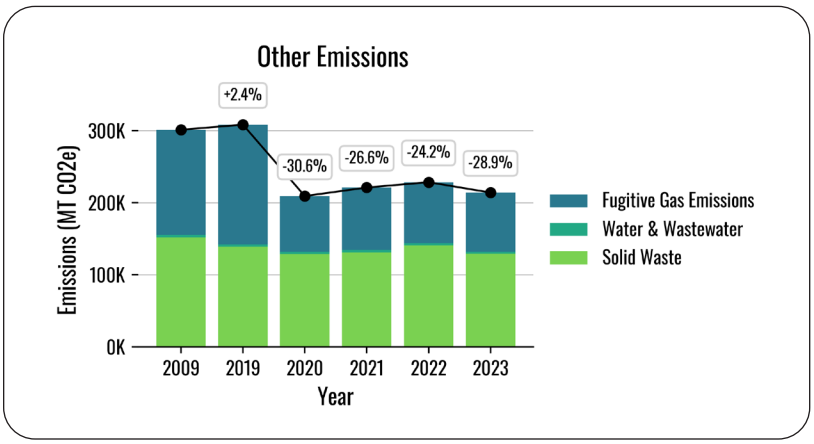

FIGURE 7: ANNUAL EMISSIONS BY OTHER EMISSION SOURCES FROM 2009 TO 2023 WITH CHANGES RELATIVE TO THE 2009 BASELINE.

[3] Other emissions are sectors that contribute less than 10% of total emissions. In this case Fugitive emissions from natural gas, water and wastewater emissions, and solid waste emissions are included.

[4] Sources: https://doi.org/10.1088/1748-9326/abef33 and Microsoft Word - U S Natural Gas Leakage Model User Guide _4_.docx (www.edf.org). More information on fugitive emission methodology can be found in Appendix B.

EXECUTIVE SUMMARY

- **Composting emissions experienced a marked decline,** dropping approximately 67% from the 2009 baseline to 2023[5]. These usage figures were reported from the Massachusetts Department of Environmental Protection CY 2019–2023 Solid Waste and Recycling Survey.

- **Municipal emissions account for 2.7% of total community emissions in 2023.** Figure 8 shows the relationship between the community inventory and the municipal inventory broken down by sector for the year 2023.

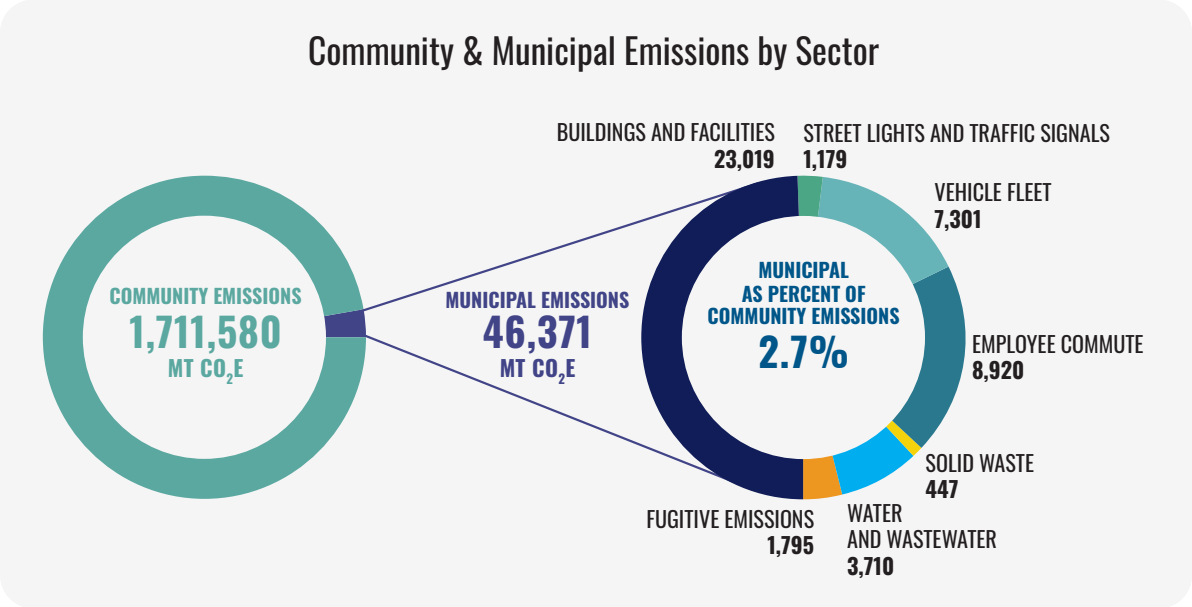

FIGURE 8: COMPARISON BETWEEN TOTAL COMMUNITY EMISSIONS AND MUNICIPAL EMISSIONS BY SECTOR (2023)

[5] This is potentially due to a miscalculation in the 2019 inventory. In future inventories the 2009 and 2019 figures will be reevaluated.

EXECUTIVE SUMMARY

- **By 2023 Municipal Operations decreased by 18.6% since 2009.**
  Municipal operations saw a decline in emissions as shown in figure 9.

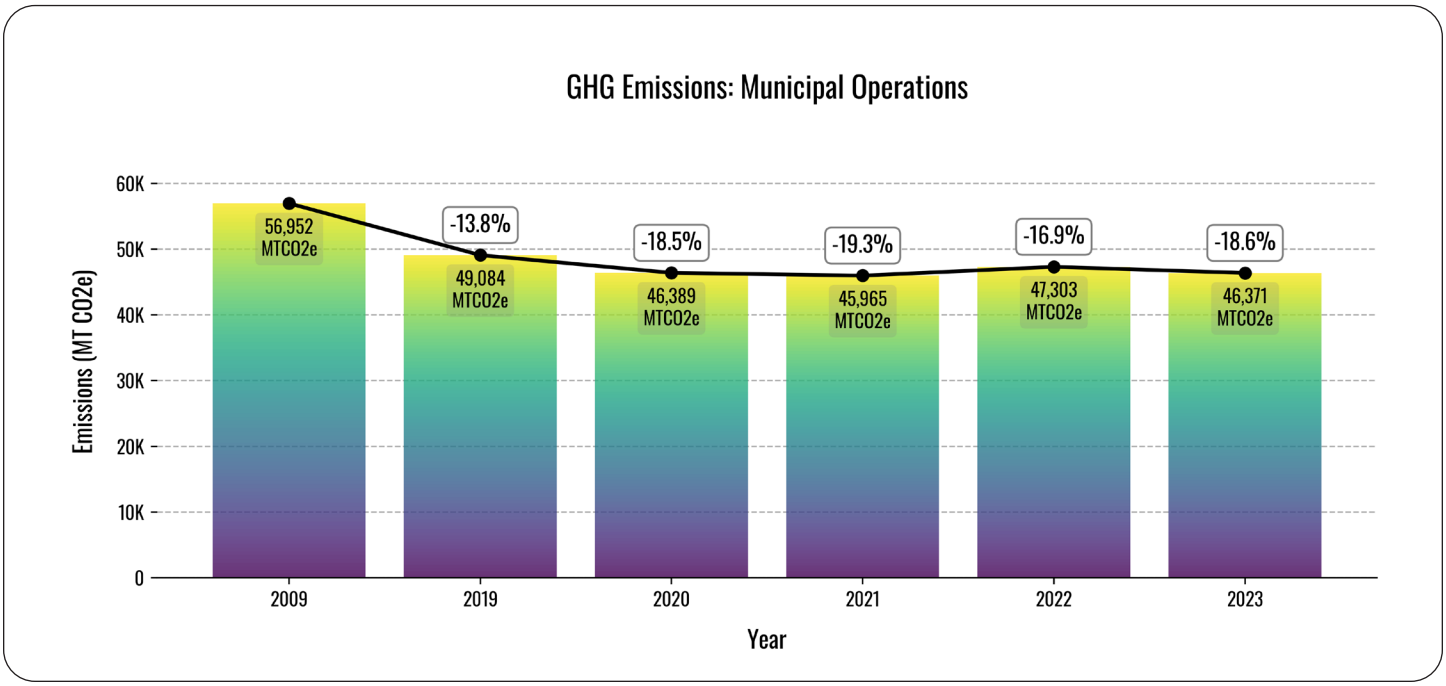

FIGURE 9: BAR CHART ILLUSTRATING THE YEAR-TO-YEAR EMISSIONS IN MUNICIPAL OPERATIONS GHG EMISSIONS WITH CHANGES RELATIVE TO THE 2009 BASELINE.

EXECUTIVE SUMMARY

- **We project a 26.5% and 46.5% reduction in Municipal Operations Emissions for 2030 and 2045, respectively, compared to the 2009 baseline.** If the trends observed from 2009 to 2023 persist, municipal operations will have a downward trajectory in emissions through 2045, although not meeting the City's goal of carbon neutrality by 2030.

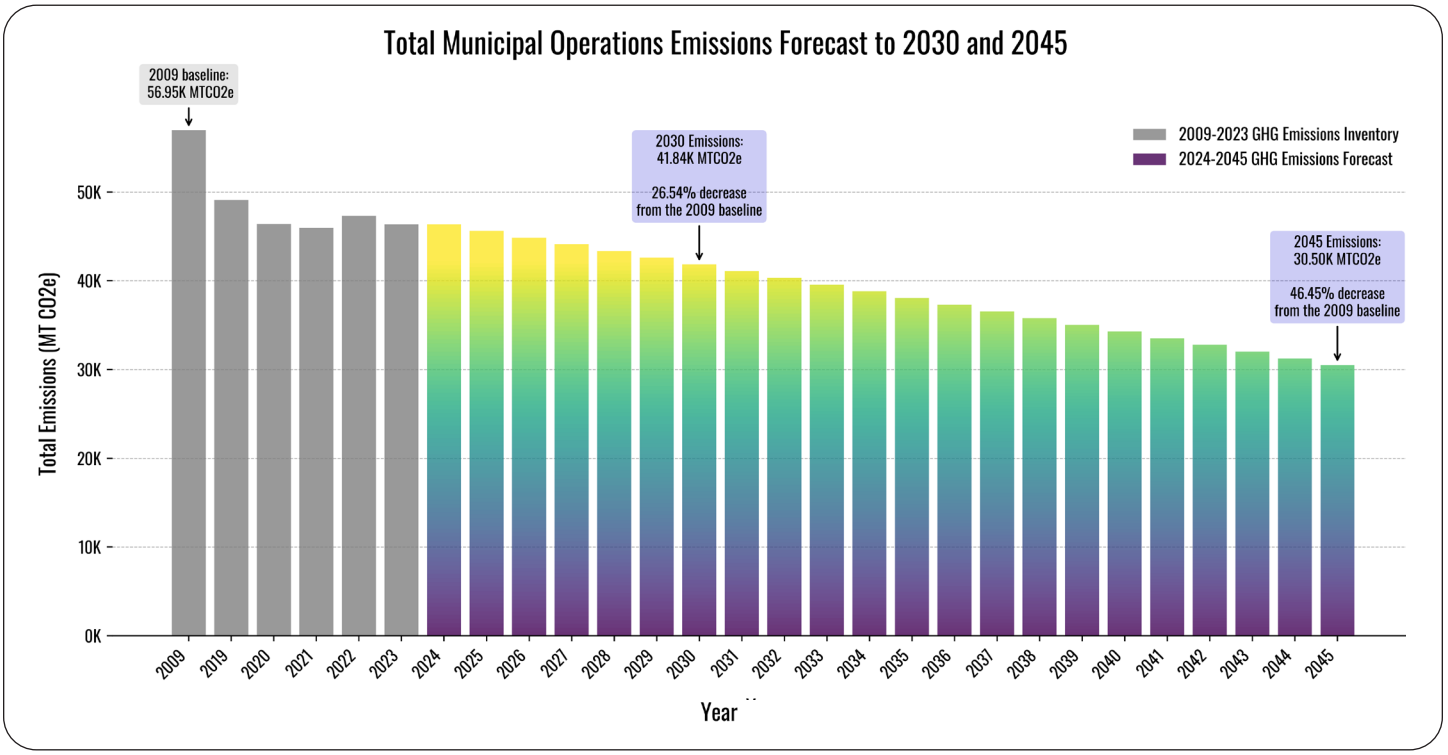

FIGURE 10: LINEAR FORECAST OF MUNICIPAL OPERATIONS EMISSION REDUCTIONS THROUGH 2030 AND 2045.

The City of Worcester has made commendable strides in reducing GHG emissions. This detailed analysis presented in this report serves as a critical tool for identifying both achievements and areas requiring further action. To meet their ambitious goal of carbon neutrality by 2045 established in the Green Worcester Plan, the City must continue to innovate, implement targeted interventions, and engage all stakeholders in a collective effort towards a sustainable future.

INTRODUCTION

The City *of*
WORCESTER

INTRODUCTION

The purpose of this report is to summarize the inventory of Greenhouse Gas (GHG) emissions attributable to human activities in Worcester, MA. It serves as a foundational document for understanding emissions trends from 2020 to 2023. The GHG inventory identifies primary emission sources within Worcester, including those from residential, commercial, and governmental operations, among others. Emissions can be direct, such as from natural gas combustion in buildings, or indirect, originating from purchased electricity generated elsewhere. The report utilizes the best available data, resorting to estimates where necessary, and compiles emission factors from reputable sources like the EPA and the US Community Protocol.

This inventory follows the US Community Protocols for GHG Accounting studies as outlined by ICLEI for our calculations. In the methodology appendix, we account for raw usage data collected from utilities and other sources, details the emission factors, and describe the methods used for emission calculations. This GHG inventory provides a reliable overview of emissions in Worcester from 2020 to 2023 while including a key baseline of 2009 that serves as a crucial tool for understanding emission trends and informing future decision-making.

CALCULATING EMISSIONS

CALCULATING EMISSIONS

Greenhouse Gasses

Local governments are expected to evaluate emissions of the six internationally recognized greenhouse gasses under the Kyoto Protocol[6], namely Carbon dioxide (CO2), Methane (CH4), Nitrous oxide (N2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), and Sulfur hexafluoride (SF6). The emissions of each of these GHGs are documented and converted into a common unit of measurement, metric tons (MT). This conversion considers each gas's Global Warming Potential (GWP), a factor that indicates how much heat a given mass of the gas will trap in the atmosphere over a specific period, relative to the same mass of CO2. For instance, the GWP of CO2 is set as the baseline at 1, meaning all other gasses' GWPs are compared to that of CO2. Methane (CH4), for example, has a GWP of 28, indicating it is twenty-eight times more effective at trapping heat in the atmosphere than CO2, and is primarily emitted from sources such as landfills, wastewater, and natural gas leaks.

Nitrous Oxide, with a higher GWP of 265, is primarily associated with energy production and wastewater treatment. Hydrofluorocarbons, having a wide GWP range of 12-11,700, are tied to refrigerant usage. Perfluorocarbons, with a GWP between 6,500-9,200, typically result from manufacturing and production processes. Sulfur Hexafluoride, possessing the highest GWP of 23,900, is principally connected with power transmission and distribution. To calculate the CO2e for all sectors analyzed, this inventory primarily focuses on the emissions of Carbon, Methane, and Nitrous Oxide.[7] These three gasses are chosen due to their significant impact on global warming and the availability of robust data. By converting the emissions of Methane and Nitrous Oxide into their CO2e based on their respective GWPs, the inventory provides a standardized measure of emissions. All emissions with statistical significance are reported and calculated within this inventory.

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6 Kyoto Protocol To The United Nations Framework Convention On Climate Change

7 As referenced in the US Community Protocol the high GWP GHG's perfluorocarbons and sulfur hexafluoride are not required to complete an accurate inventory. The City reported no refrigerant loss, and therefore no hydrofluorocarbons do not appear in the inventory. All other GHGs are measured and reported.

CALCULATING EMISSIONS

Inventory Boundary

In the City of Worcester, Massachusetts, emissions are divided into two primary tracks: the community and the government inventory. The community inventory focuses on emissions from individuals residing within Worcester's jurisdiction, encompassing those mainly within the City limits, as well as those resulting from residents' activities. Key sectors included in the community inventory are building energy usage, transportation, solid waste, wastewater, and water management.

Building energy usage sources comprise residential and commercial electricity, natural gas, propane, fuel oil or heating oil consumption, and fugitive emissions. Transportation emissions cover both on-road and off-road transportation activities. This inventory also accounts for emissions occurring from the transportation, distribution, and processing of water and wastewater. Finally, we calculate emissions from solid waste management.

The government inventory, on the other hand, focuses on emissions stemming from government activities and facilities. This section of the report provides insights into emissions generated by the local government, offering a detailed breakdown of municipal emissions. While government emissions constitute a small percentage of the overall community emissions inventory, it includes reports on emissions from municipal buildings' energy usage, public lighting (including streetlights and traffic signals), municipal vehicle fleets, employee commuting, solid waste, and water and wastewater facilities. These emission records serve as valuable tools for guiding efforts towards achieving the City of Worcester's goal of carbon neutrality in municipal operations by 2030.

Comprehensive Data Collection Approach

This inventory collected data through primary and secondary sources, while leveraging estimations when necessary. The community inventory analyzed residential and commercial energy consumption through utility bills and energy audits; transportation metrics like vehicle miles from travel, flight records, and public transit and rail usage; waste generation and recycling statistics; water usage data from utility records; and population-based emissions for wastewater treatment plants.

Similarly, the municipal inventory assesses environmental impacts across various sectors including buildings and facilities, streetlights and traffic signals, government-owned vehicle fleet, employee commuting, waste management, water and wastewater treatment, and fugitive emissions. This exhaustive evaluation aids in identifying specific areas for improvement within government operations.

More information on data collection can be found in Appendix B.

CALCULATING EMISSIONS

Scope Emissions

Both the Municipal and Community inventories categorize GHG emissions into three scopes:

SCOPE 1
DIRECT EMISSIONS

- In the Community inventory, this is represented by emissions from residential heating systems using fuels like natural gas or oil, and from personal vehicles driven within the city limits.
- For the Municipal inventory, it includes emissions from heating and powering public buildings and facilities, as well as emissions from government-owned vehicles, including city buses and maintenance fleets.

SCOPE 2 EMISSIONS
INDIRECT EMISSIONS FROM PURCHASED ENERGY

Addresses GHG emissions from the generation of purchased electricity, heating, cooling, and steam.

- For the Community inventory, Scope 2 emissions are primarily emissions associated with the electricity consumed by households and businesses, sourced from power plants outside the city.
- In the Municipal inventory, this scope covers emissions from electricity and other energy forms used in government buildings, streetlights, and traffic signals.

SCOPE 3 EMISSIONS
OTHER INDIRECT EMISSIONS

- Encompasses emissions that occur because of the city's activities but are not directly controlled by it.
- In the Community inventory, examples include emissions from waste generated by the community but processed outside the city, and fugitive emissions from natural gas pipelines outside of the city gate.
- For the Municipal inventory, Scope 3 includes emissions from waste disposal related to government operations, but not controlled by the City, and the commuting patterns of government employees.

Green Worcester Plan

The Green Worcester Plan outlines the city's comprehensive approach to sustainability and climate action, with a strong emphasis on updating its GHG inventory. Initially, the City completed a Climate Action Plan (CAP) in 2006, which set ambitious emissions reduction targets. A significant update of the CAP: The Green Worcester Plan, in 2020 provided a refreshed GHG inventory to guide efforts across seven key areas: building energy, municipal operations, waste, transportation, consumption, green infrastructure, and community engagement.

The plan aims for Worcester to achieve 100% clean and affordable energy by 2045, with intermediate goals such as powering all municipal facilities with renewable energy by 2030 and providing 100% renewable residential electricity by 2035. To achieve these goals, the City will continue to update and publish its citywide GHG emissions inventory, ensuring transparency and accountability in its sustainability efforts. This ongoing assessment is crucial for tracking progress, identifying areas for improvement, and implementing necessary actions to meet the ambitious emissions reduction targets set forth in the Green Worcester Plan.

CALCULATING EMISSIONS

Municipal Electricity Aggregation

Worcester's Municipal Electric Aggregation program, known as the Green Worcester ElectriCITY Municipal Aggregation Program, is designed to provide residents and businesses with more stable and potentially lower electricity rates by pooling demand to negotiate better terms with electricity suppliers. This initiative aims to increase the use of renewable energy sources, thereby reducing the city's carbon footprint and supporting its climate goals outlined in the Green Worcester Plan. The program allows participants to opt into different tiers of renewable energy, further enhancing the city's commitment to sustainability. This program has been included in the inventory by using the ISO New England Emission reports in conjunction with a custom emission factor calculation tool that analyzes the specific amount of renewable energy purchased for those that are in the program. This enables a sophisticated and detailed emission factor calculation that closely approximates the actual emission factor for the City of Worcester.

For more details, visit the Worcester Energy page.

Impacts of COVID-19

The COVID-19 pandemic significantly impacted Worcester's GHG emissions. During the pandemic, city-wide emissions experienced a temporary decline due to reduced transportation and industrial activities because of lockdown measures and decreased economic activity. This period saw lower traffic volumes, less industrial output, and diminished energy consumption in commercial buildings, contributing to a short-term reduction in GHG emissions. However, the long-term implications remain uncertain as the city's activities gradually return to normal levels. The pandemic highlighted the potential for emissions reductions through behavior changes and increased remote work, which could inform future sustainability initiatives. The impact of COVID-19 can be seen in many sectors by a significant decline in emissions for the years 2020 and 2021.

RESULTS

The City *of*
WORCESTER

Summary Of Inventory Results by Year

From 2009 to 2023, Worcester's annual community-wide emissions decreased by 9.5%, reflecting a notable downward trend despite some fluctuations. Emissions began at approximately 1.89 million tons in 2009 and decreased to about 1.71 million tons by 2023. This period saw a significant low in 2020, with emissions dropping to around 1.54 million tons, likely influenced by the COVID-19 pandemic, which temporarily reduced economic activities and emissions. However, emissions increased slightly in the subsequent years, as shown in figure 11.

The last four years (2020-2023) demonstrate the importance of analyzing long-term trends rather than focusing solely on year-to-year changes. While the emissions reduction in 2020 seemed pronounced, the following years indicate a return to pre-pandemic levels, underscoring the ongoing challenge in managing emissions sustainably. Figure 11 below illustrates the change in emissions per year, highlighting the overall progress and the complexities in achieving consistent reductions.

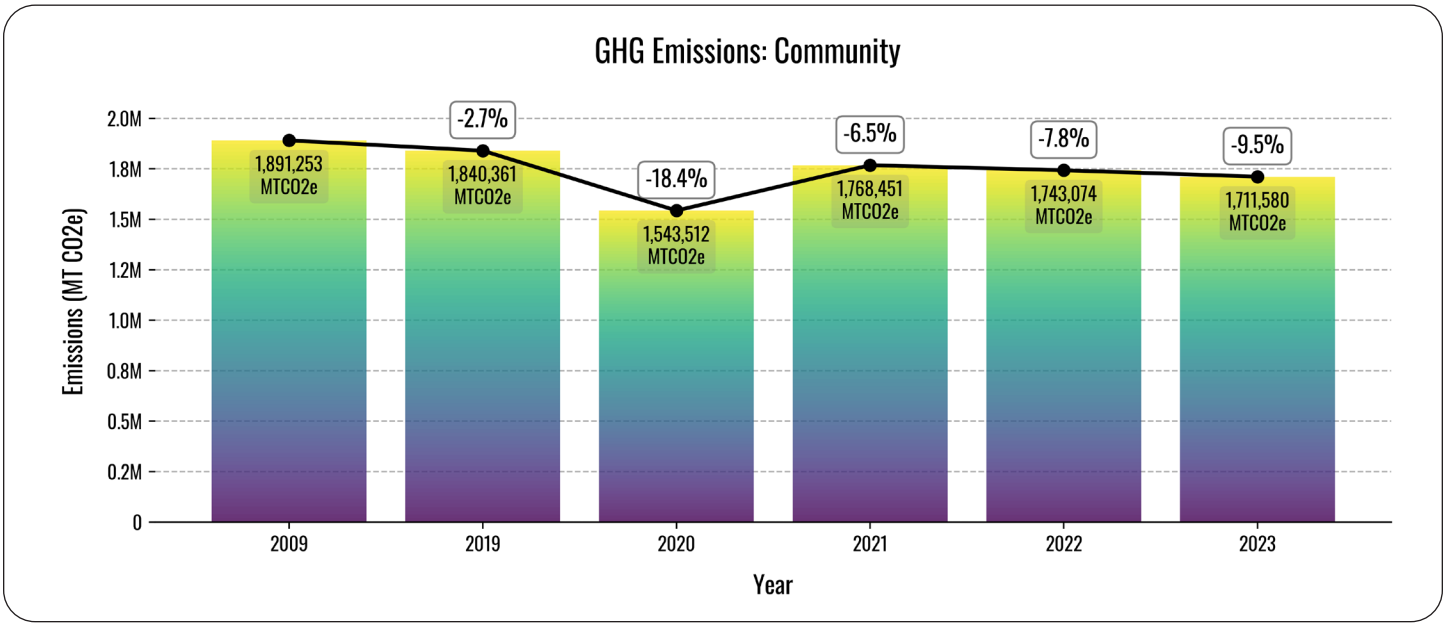

FIGURE 11: BAR CHART ILLUSTRATING THE YEAR-TO-YEAR EMISSIONS IN COMMUNITY GHG EMISSIONS WITH CHANGES RELATIVE TO THE 2009 BASELINE.

Summary Of Inventory Results by Sector

Over the past 15 years, emissions across various sectors in the City of Worcester have experienced significant changes. The Residential and Commercial Energy sectors saw a general decline, with notable reductions in grid electricity due to the municipal aggregation program implemented in 2020. Conversely, the Transportation and Mobile Services sector experienced an increase in emissions for the same period, primarily driven by on-road transportation. The Solid Waste, Water and Wastewater sector exhibited mixed trends. Additionally, Fugitive Emissions from natural gas dropped following a recalculation.[8] Figure 12 shows the long-term trends by sector over time.

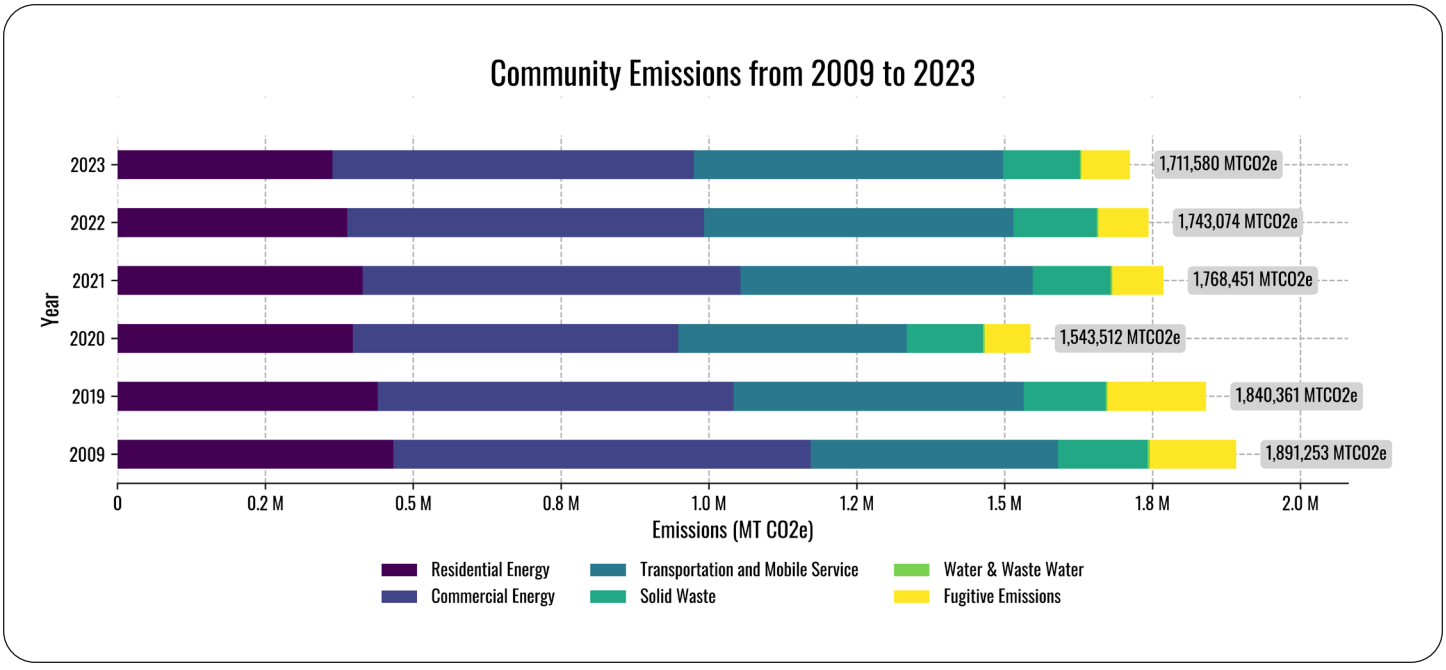

FIGURE 12: BAR CHART ILLUSTRATING COMMUNITY GHG EMISSIONS ACROSS VARIOUS SECTORS FROM 2009 TO 2023.

[8] For this inventory Fugitive emissions were calculated at 1.3% leakage compared to the 2019 inventory, which used a much larger leakage rate of 2.7%. More information can be found in Appendix B.

The four sectors with the highest contributions to total emissions have remained constant since 2019. The primary sources of emissions in 2023 are dominated by Commercial Energy, followed closely by the Transportation sector. Residential Energy is the third-largest source, and finally Solid Waste is the fourth largest source. Together, these sectors highlight the key areas for targeted emissions reduction efforts. Figure 13 describes the sources in more detail.

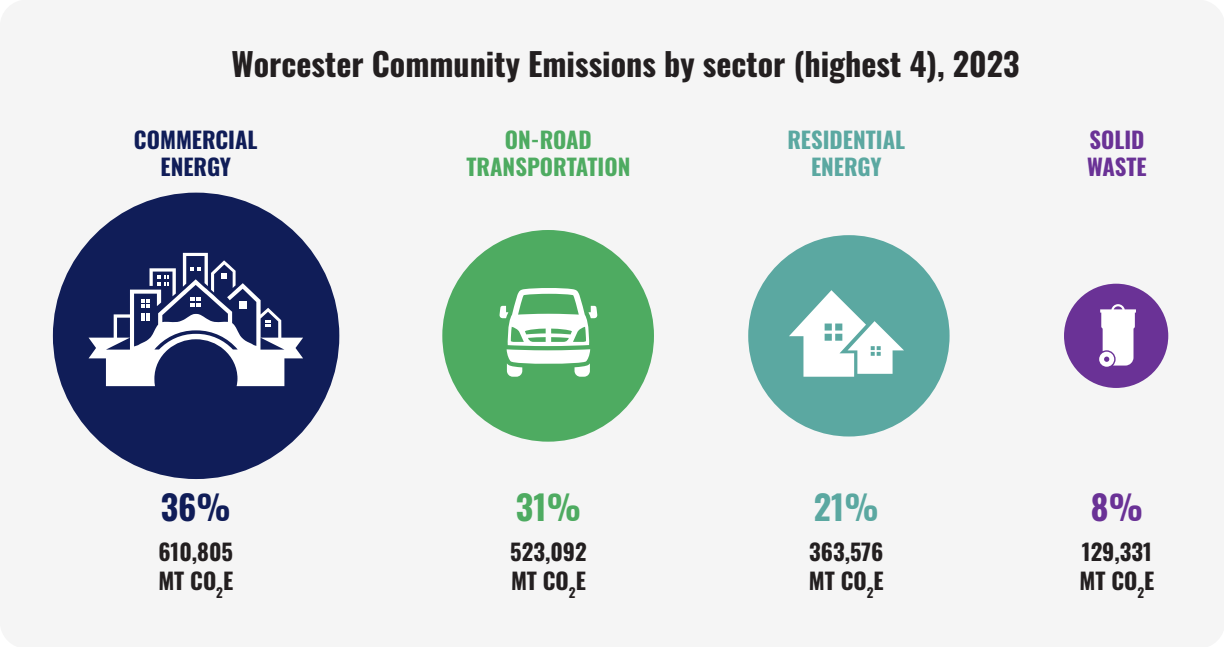

FIGURE 13: WORCESTER COMMUNITY EMISSIONS BY SECTOR (HIGHEST 4), 2023.

The **Residential Energy** sector encompasses grid electricity, natural gas, propane, and fuel oil No. 2 used by Worcester residents in their homes. From 2009 to 2023, total emissions in this sector decreased by 22% reflecting the impact of the Green Worcester ElectriCITY Municipal Aggregation Program. This program shifted the residential grid electricity usage towards more sustainable energy sources. Figure 14 identifies the change in emissions compared to the 2009 baseline.

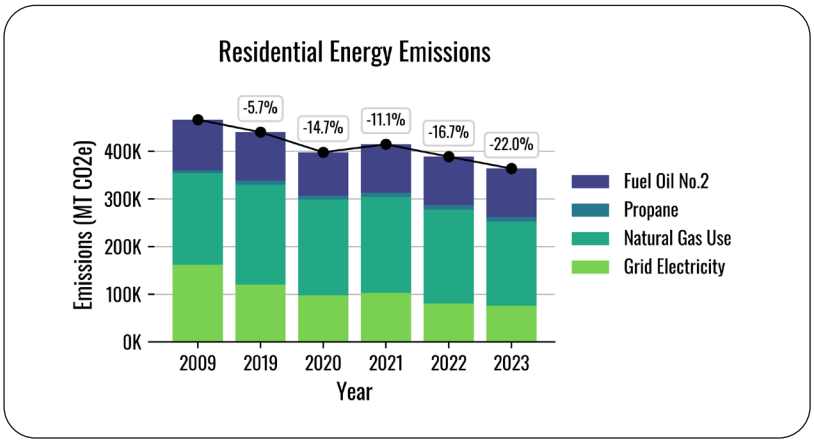

FIGURE 14: YEARLY EMISSIONS IN THE RESIDENTIAL ENERGY SECTOR AND CHANGES RELATIVE TO THE 2009 BASELINE.

The **Commercial Energy** sector encompasses grid electricity, natural gas, propane, and fuel oil No. 2 used by businesses, offices, and other commercial establishments in Worcester. The Commercial Energy sector experienced a notable decrease of 13.4% in emissions from 2009 to 2023. Figure 15 shows the percent change in emissions compared to a 2009 baseline for this sector.

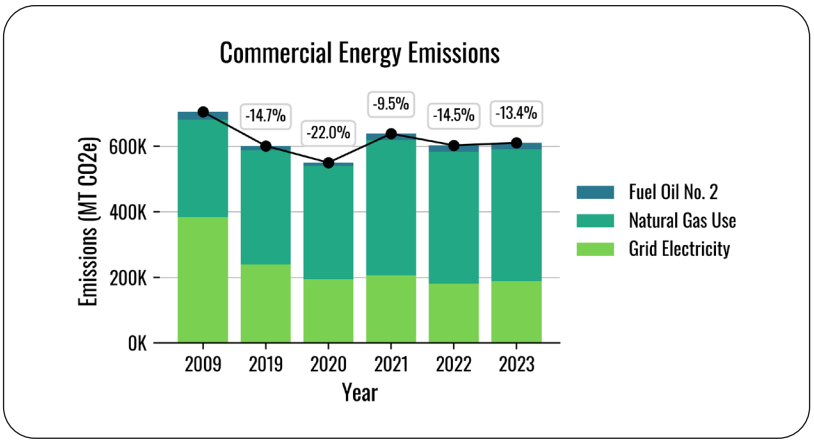

FIGURE 15: YEARLY EMISSIONS CHANGE IN THE COMMERCIAL ENERGY SECTOR RELATIVE TO THE 2009 BASELINE.

The **Transportation and Mobile Service** sector represents the community on-road transportation, bus transit, air travel and rail transportation. Emissions in the Transportation and Mobile Service sector increased by 25.1% from 2009 to 2023, underscoring the growing demand for transportation. The pandemic in 2020 led to a significant decrease in relation to the 2009 baseline, reflecting reduced travel and commuting. Figure 16 shows the year-by-year emission change for this sector compared to the 2009 baseline.

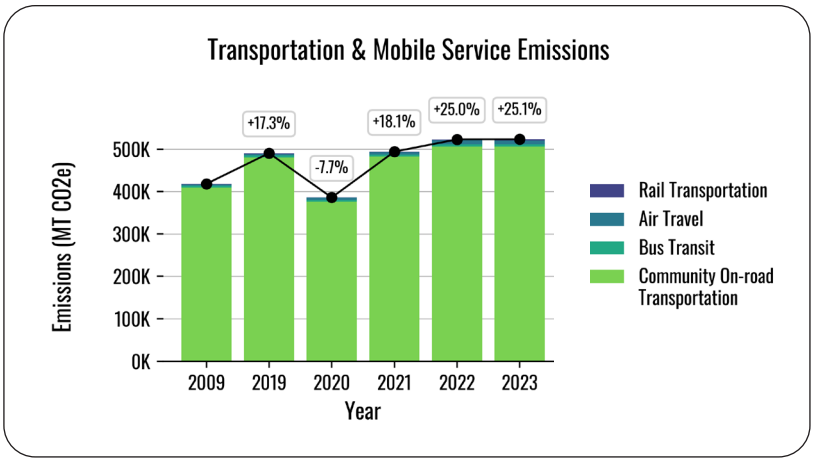

FIGURE 16: YEARLY EMISSIONS IN THE TRANSPORTATION & MOBILE SERVICE SECTOR AND CHANGES RELATIVE TO THE 2009 BASELINE.

The **Solid Waste** sector represents residential waste, commercial waste, compost, and in-jurisdiction landfill. The Solid Waste sector saw a decrease of 14.7% in emissions from 2009 to 2023. Figure 17 shows the yearly emissions change compared to the 2009 baseline for the solid waste sector.

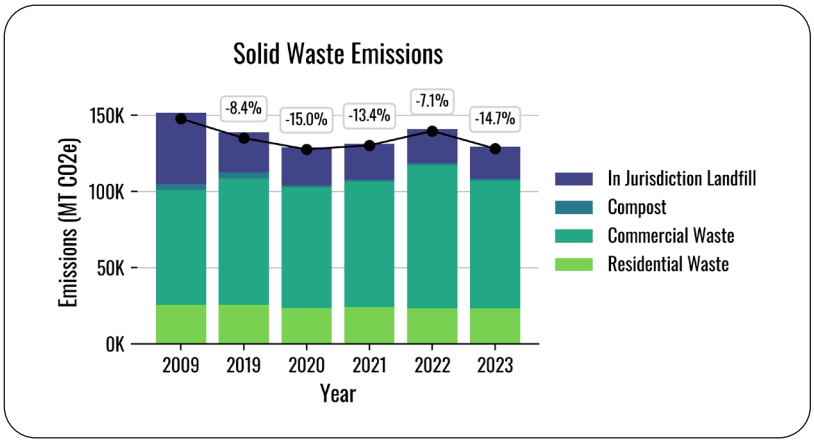

FIGURE 17: YEARLY EMISSIONS IN THE SOLID WASTE SECTOR AND CHANGES RELATIVE TO THE 2009 BASELINE.

Emissions associated with **Potable Water and Wastewater** treatment decreased by 28.0% from 2009 to 2023. Figure 18 shows the emission comparison between years relative to a 2009 baseline.

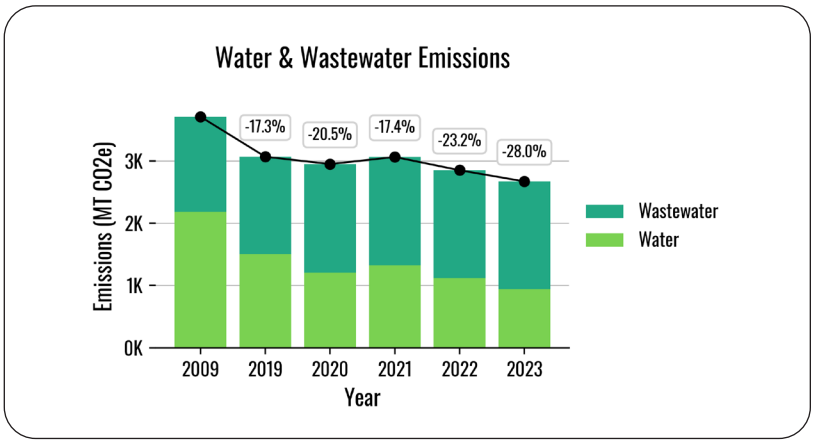

FIGURE 18: YEARLY EMISSIONS IN THE WATER & WASTEWATER SECTOR AND CHANGES RELATIVE TO THE 2009 BASELINE.

Overall, this detailed dataset provides valuable insights into Worcester's environmental performance over the specified period, highlighting both progress and areas of concern. By understanding these trends and patterns, stakeholders can work towards implementing targeted interventions to enhance sustainability, reduce emissions, and foster a healthier environment for current and future generations.

Summary Table

TABLE 3: COMMUNITY GHG EMISSIONS BY SECTOR FROM 2009 TO 2023.

RESIDENTIAL ENERGY		2009	2019	2020	2021	2022	2023	% CHANGE 2009-2023
Grid Electricity	MT CO2e	161,448	120,288	97,852	102,853	80,822	75,286	-53.4
Natural gas use	MT CO2e	192,760	209,346	201,066	201,066	196,724	177,296	-8.0
Propane	MT CO2e	5,789	8,532	8,027	9,074	9,402	9,408	62.5
Fuel Oil No.2	MT CO2e	106,237	101,704	90,836	101,445	101,523	101,586	-4.4
COMMERCIAL ENERGY		**2009**	**2019**	**2020**	**2021**	**2022**	**2023**	**% CHANGE 2009-2023**
Grid Electricity	MT CO2e	383,587	238,758	194,180	206,558	180,770	188,176	-50.9
Natural gas combustion	MT CO2e	297,536	349,617	346,500	412,975	403,122	403,374	+35.5
Fuel Oil No. 2	MT CO2e	24,338	13,149	9,752	19,234	19,244	19,256	-20.9
TRANSPORTATION AND MOBILE SERVICE		**2009**	**2019**	**2020**	**2021**	**2022**	**2023**	**% CHANGE 2009-2023**
Community on-road transportation (VMT[9] for Worcester)	MT CO2e	409,105	480,205	375,895	482,837	506,015	506,064	+23.7
Bus Transit	MT CO2e	5,341	5,068	4,346	4,593	5,055	5,058	-5.3
Air travel	MT CO2e	2,211	3,098	5,411	5,716	9,602	8,742	+295.4
Rail transportation	MT CO2e	1,580	2,150	382	942	2,259	3,228	+104.3
SOLID WASTE		**2009**	**2019**	**2020**	**2021**	**2022**	**2023**	**% CHANGE 2009-2023**
Residential Waste	MT CO2e	25,627	25,526	23,347	24,111	23,245	23,307	-9.1
Commercial Waste	MT CO2e	75,196	82,935	79,205	82,466	94,023	83,659	+11.3
Compost	MT CO2e	3,954	3,954	1,353	1,091	1,304	1,305	-67.0
In jurisdiction landfill	MT CO2e	46,777	26,454	24,988	23,604	22,296	21,060	-55.0
WATER AND WASTEWATER		**2009**	**2019**	**2020**	**2021**	**2022**	**2023**	**% CHANGE 2009-2023**
Potable Water	MT CO2e	2,180	1,501	1,205	1,324	1,116	939	-56.9
Wastewater	MT CO2e	1,529	1,566	1,744	1,739	1,734	1,731	+13.2
FUGITIVE EMISSIONS		**2009**	**2019**	**2020**	**2021**	**2022**	**2023**	**% CHANGE 2009-2023**
Natural Gas Leakage	MT CO2e	146,057	166,513	77,424	86,824	84,817	82,105	-43.7
SUMMARY		**2009**	**2019**	**2020**	**2021**	**2022**	**2023**	
TOTAL EMISSIONS	MT CO2e	1,891,253	1,840,361	1,543,512	1,768,451	1,743,074	1,711,580	
TOTAL % CHANGE FROM 2009 BASELINE			-2.7	-18.4	-6.5	-7.8	-9.5	

[9] Vehicle Miles Traveled

Detailed Results

RESIDENTIAL ENERGY

The **Residential Energy** sector encompasses grid electricity, natural gas, propane, and fuel oil No. 2 used by Worcester residents in their homes. The main difference between 2019, Worcester's last GHG inventory, and 2023 is the decrease in grid energy, likely because of the municipal aggregation program, Green Worcester ElectriCITY Municipal Aggregation Program, implemented in 2020. Figure 19 shows the composition of emissions between 2019 and 2023.

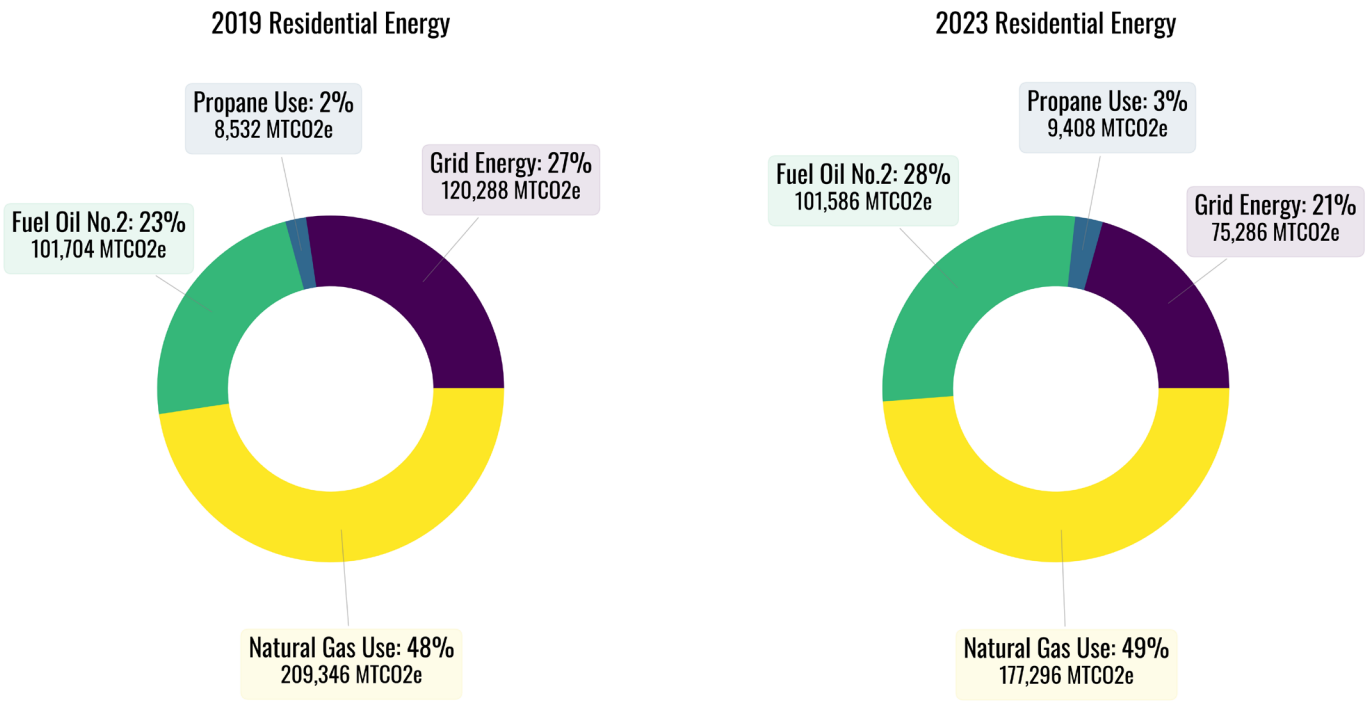

FIGURE 19: RESIDENTIAL ENERGY SECTOR EMISSIONS BREAKDOWN BY SOURCE IN WORCESTER IN 2023 COMPARED TO 2019.

Grid Electricity

From 2009 to 2023, Worcester's Residential Grid Electricity emissions decreased by approximately 53.4% over the 14-year period as shown in figure 20. This is due to the widespread adoption of renewable energy sources from the municipal aggregation efforts provided by the Green Worcester ElectriCITY Municipal Aggregation Program and the Massachusetts Renewable Energy Portfolio Standard (RPS). Figure 21 shows that electricity usage has grown by 3.4% by 2023 compared to a 2009 baseline.

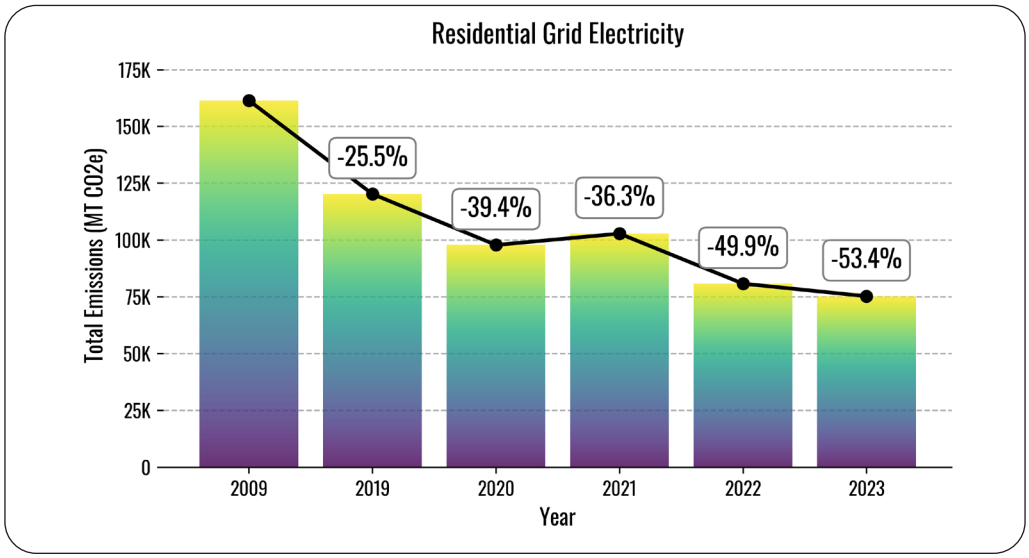

FIGURE 20: RESIDENTIAL GRID ELECTRICITY EMISSIONS WITH CHANGES RELATIVE TO THE 2009 BASELINE.

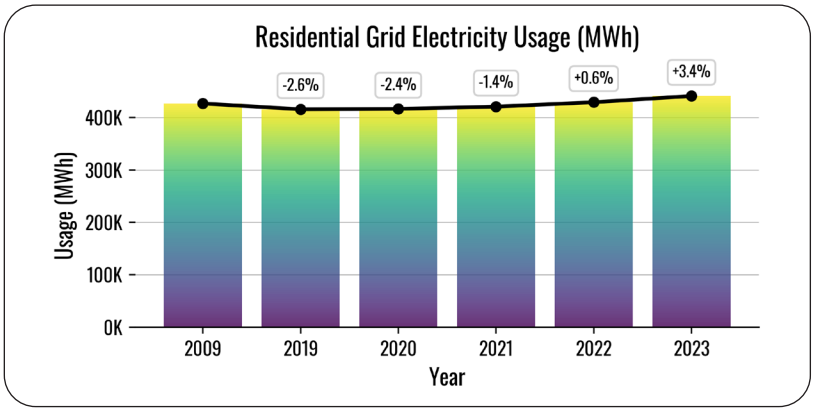

FIGURE 21: RESIDENTIAL GRID ELECTRICITY USAGE (MWH) WITH CHANGES RELATIVE TO THE 2009 BASELINE.

Natural Gas Usage

From 2009 to 2023, Worcester's Residential Natural Gas use had a net reduction of 8.0% as shown in figure 22. Figure 23 identifies the amount of natural gas consumed by the community over the period as compared to a 2009 baseline.

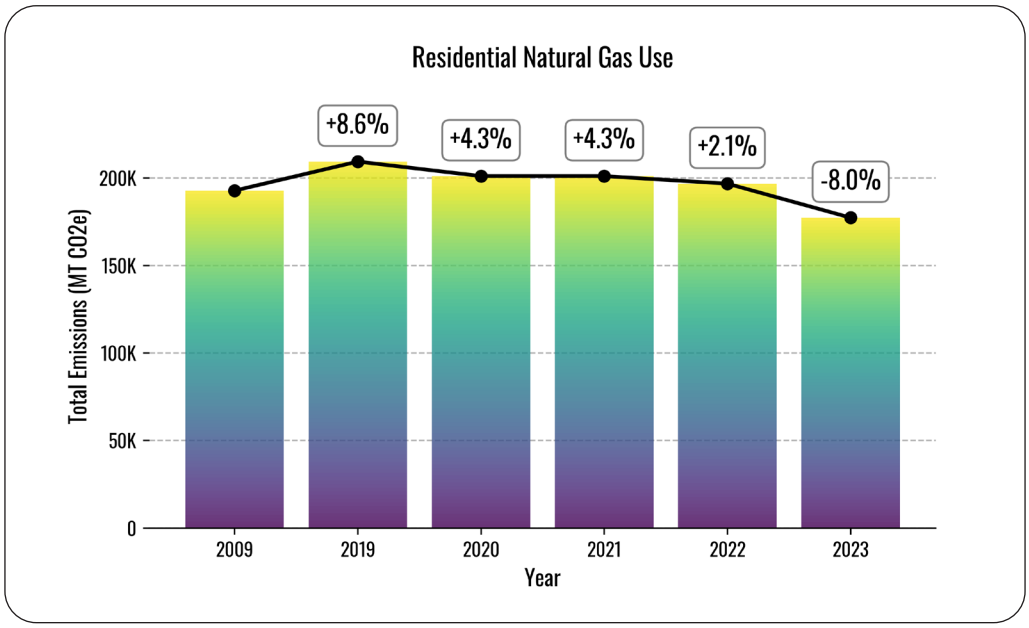

FIGURE 22: RESIDENTIAL NATURAL GAS EMISSIONS WITH CHANGES RELATIVE TO THE 2009 BASELINE.

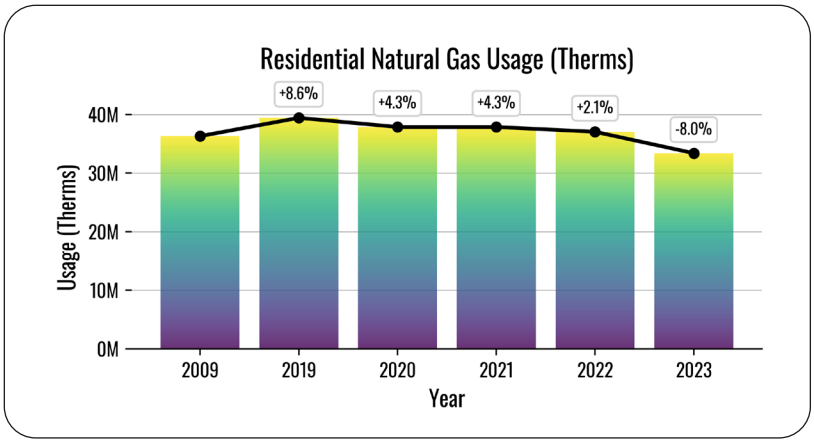

FIGURE 23: RESIDENTIAL NATURAL GAS USAGE (THERMS) WITH CHANGES RELATIVE TO THE 2009 BASELINE.

Propane Usage

Residential propane emissions between 2009 to 2023 rose 62.5%. Although this rise is large, propane represents a minor portion of Worcester energy consumption, representing 0.55% of total emissions in the City. Figure 24 identifies the pattern of emissions associated with propane consumption over the period.

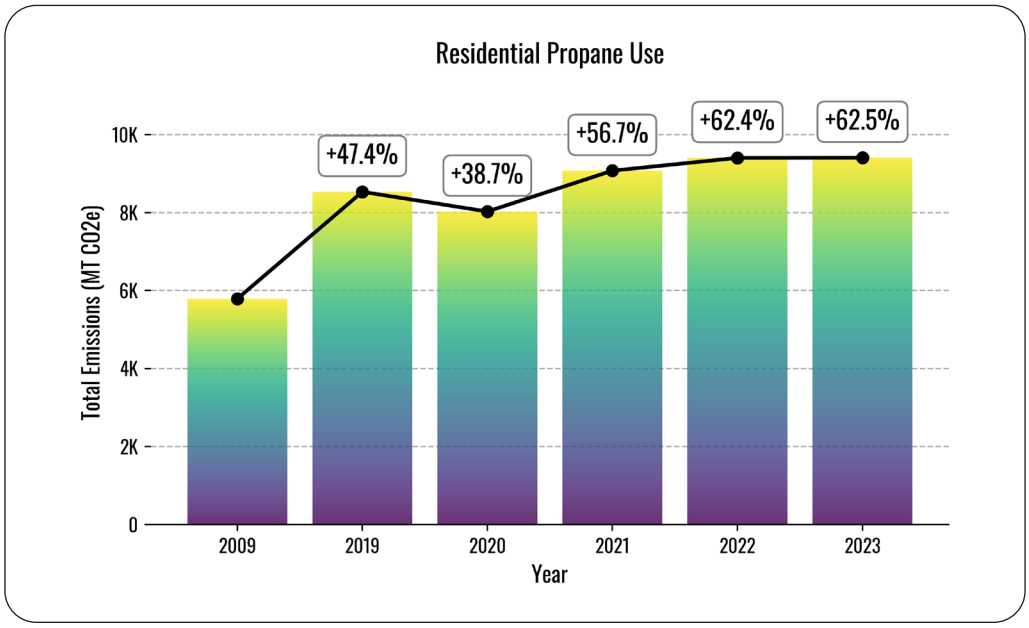

FIGURE 24: RESIDENTIAL PROPANE EMISSIONS WITH CHANGES RELATIVE TO THE 2009 BASELINE.

Fuel Oil No 2

Fuel Oil No. 2 emissions decreased by 4.4% between 2009 and 2023. The 2009 and 2019 values in this category were reevaluated in this inventory to match with U.S. Community Protocol methodology.[10] Figure 25 shows the change in emissions compared to a 2009 baseline.

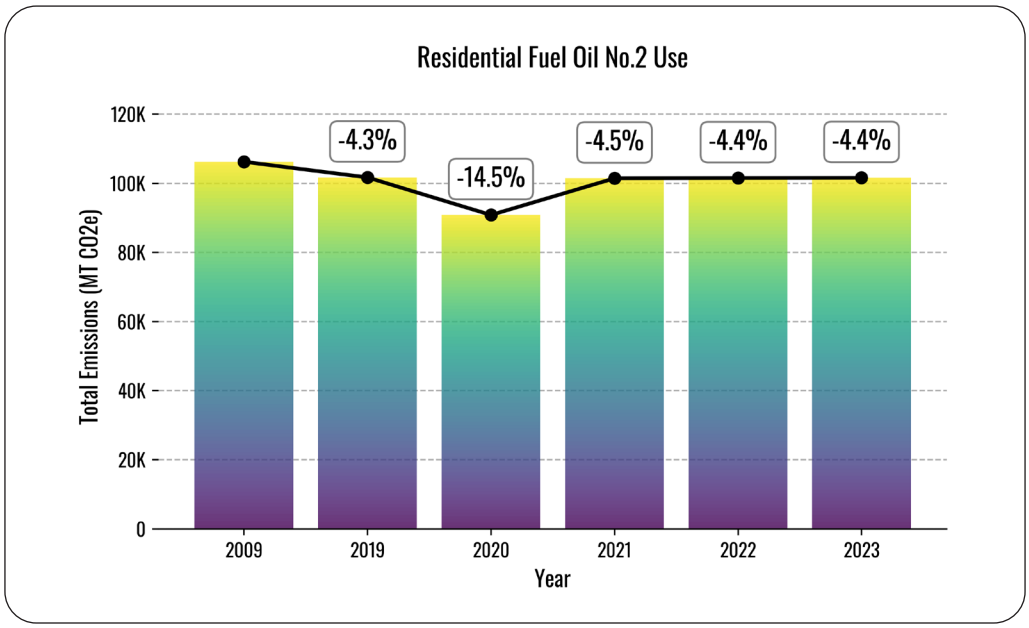

FIGURE 25: RESIDENTIAL FUEL OIL NO.2 USE EMISSIONS WITH CHANGES RELATIVE TO THE 2009 BASELINE.

[10] Please refer to Appendix B for more information on the methodology change compared to the 2019 inventory.

COMMERCIAL ENERGY

The **Commercial Energy** sector in Worcester includes grid electricity, natural gas, and fuel oil No. 2 used by businesses. Figure 26 shows the comparison in emission composition between 2019 and 2023.

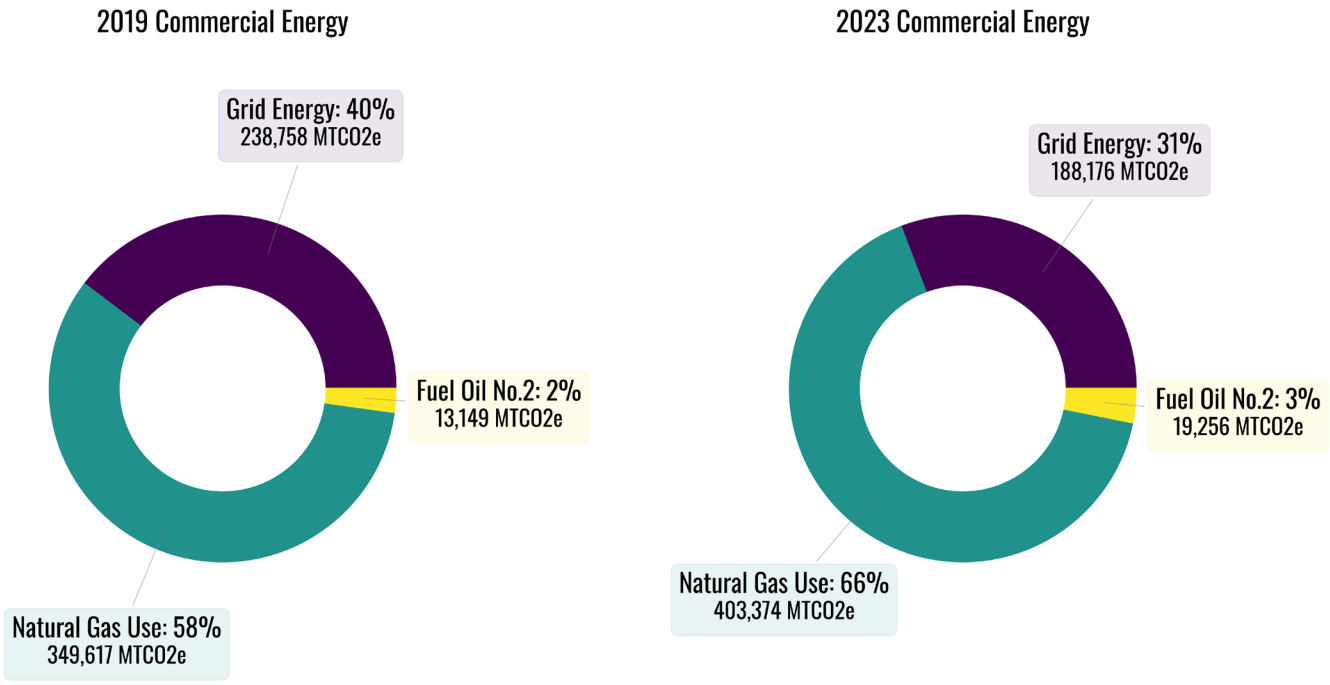

FIGURE 26: COMMERCIAL ENERGY SECTOR EMISSIONS IN WORCESTER IN 2023.

Grid Electricity

Between 2009 and 2023, commercial grid electricity emissions were reduced by nearly half compared to the 2009 baseline, while energy usage has fallen by 9.1% in 2023 compared to 2009. Emissions trends can be seen in figure 27 as compared to a 2009 baseline. Usage in MWh can be seen in Figure 28.

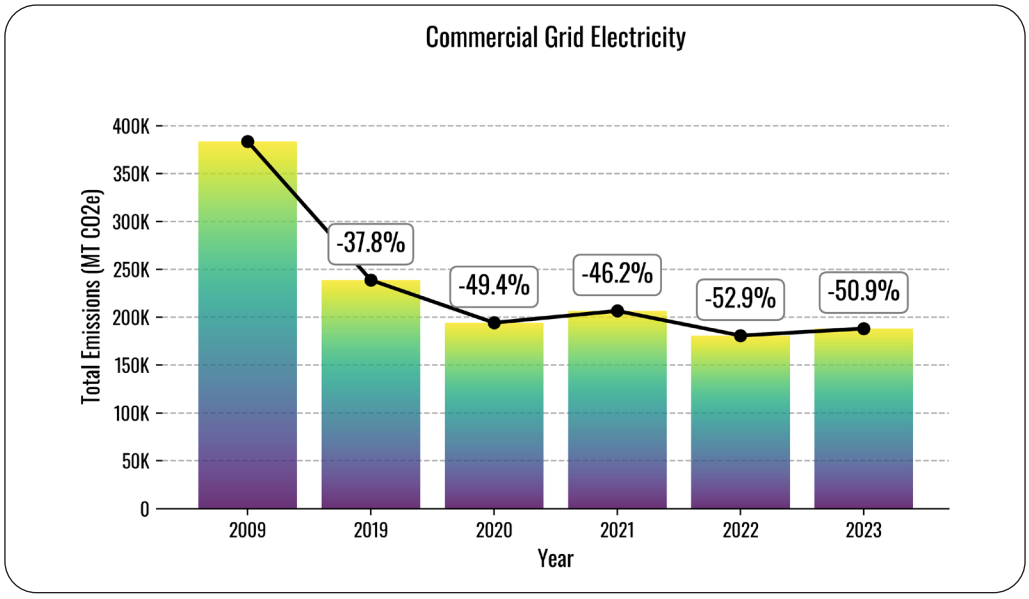

FIGURE 27: COMMERCIAL GRID ELECTRICITY EMISSIONS WITH CHANGES RELATIVE TO THE 2009 BASELINE.

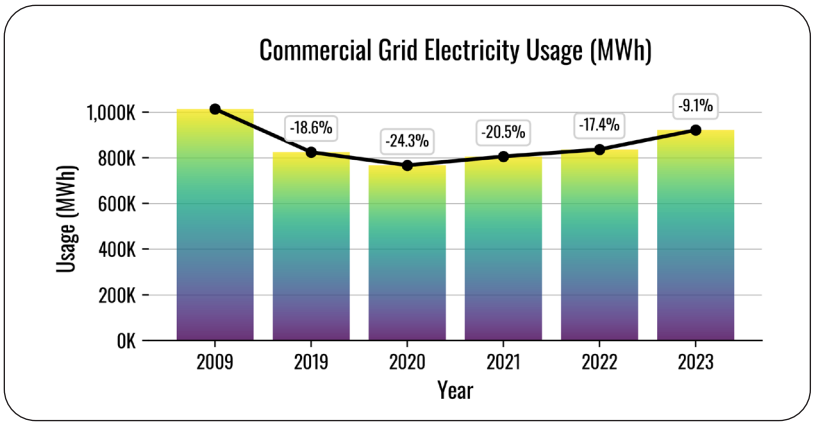

FIGURE 28: COMMERCIAL GRID ELECTRICITY USE (MWH) WITH CHANGES RELATIVE TO THE 2009 BASELINE.

Natural Gas Use

From 2009 to 2023, natural gas usage and emissions have risen by 35.6%. Emissions trends from natural gas can be seen in figure 29 while usage data can be seen in figure 30 as compared to the 2009 baseline. This overall increase reflects a growing reliance on natural gas as a source of commercial energy over the observed period.

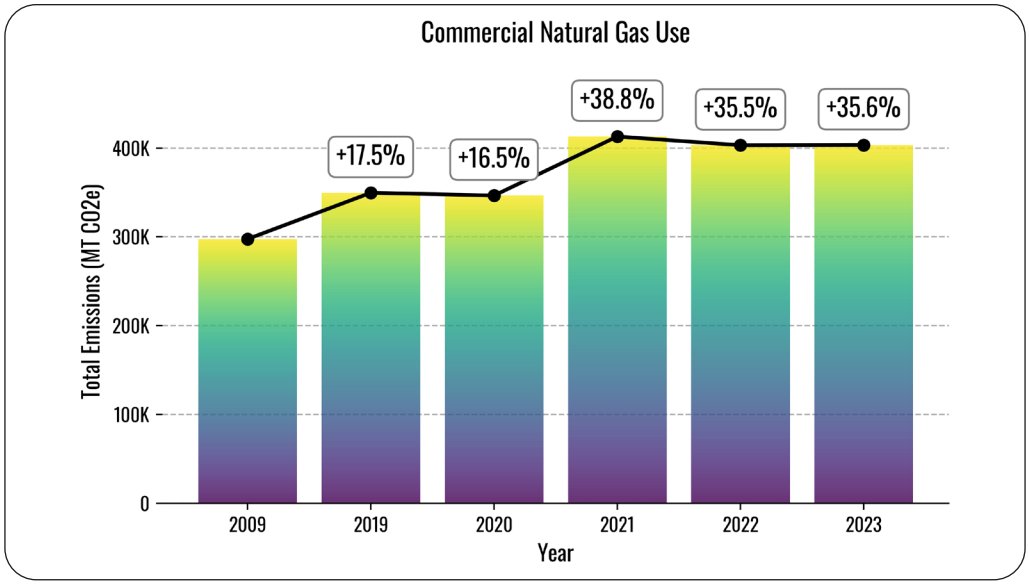

FIGURE 29: COMMERCIAL NATURAL GAS USE EMISSIONS WITH CHANGES RELATIVE TO THE 2009 BASELINE.

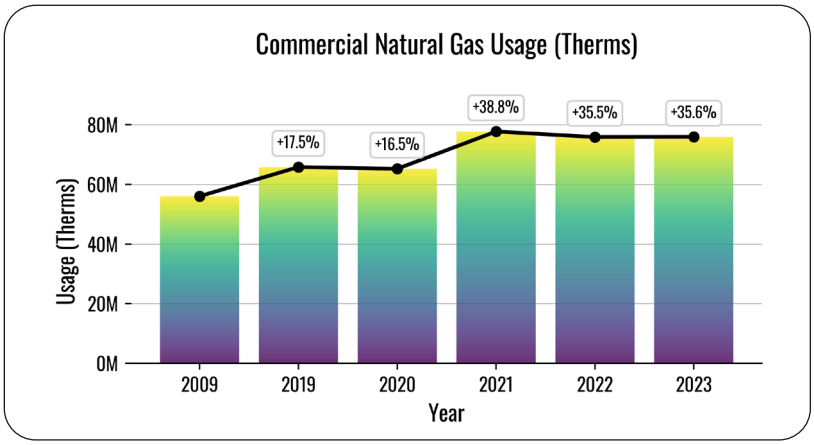

FIGURE 30: COMMERCIAL NATURAL GAS USE (THERMS) WITH CHANGES RELATIVE TO THE 2009 BASELINE.

Fuel Oil No 2

Commercial fuel oil usage has fallen by almost 21% by 2023 as compared to a 2009 baseline. Figure 31 shows the pattern of emissions related to fuel oil emissions as compared to a 2009 baseline.

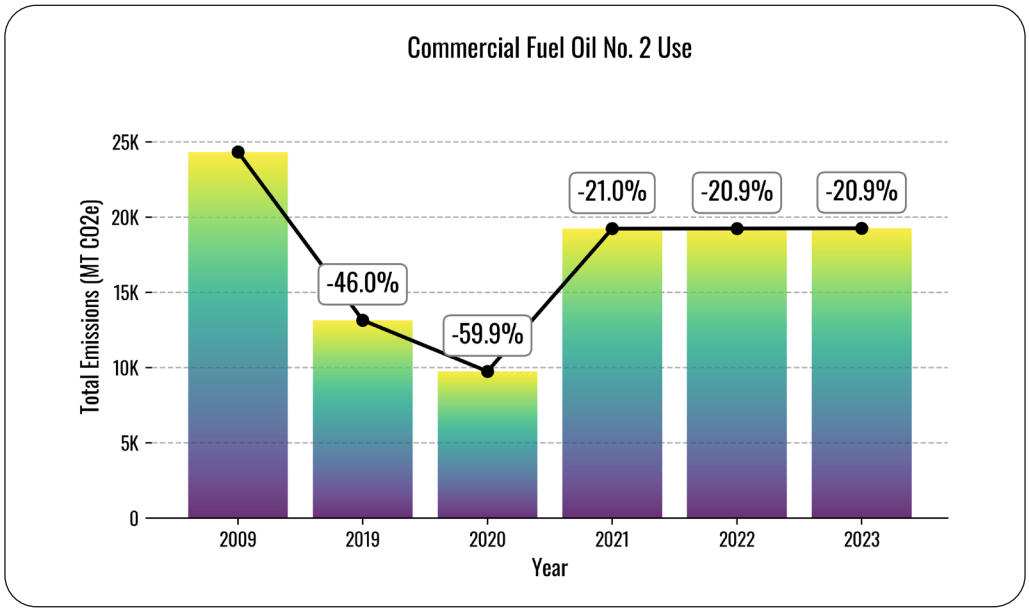

FIGURE 31: COMMERCIAL FUEL OIL NO.2 EMISSIONS WITH CHANGES RELATIVE TO THE 2009 BASELINE.

TRANSPORTATION AND MOBILE SERVICES

The **Transportation and Mobile Services** sector in Worcester includes community vehicle on-road transportation, bus transit, air travel, and rail transportation. In both 2019 and 2023 emissions from community on-road transportation remained the main source, accounting for nearly the entirety of the emissions. Figure 32 shows the full composition of emissions between 2019 and 2023.

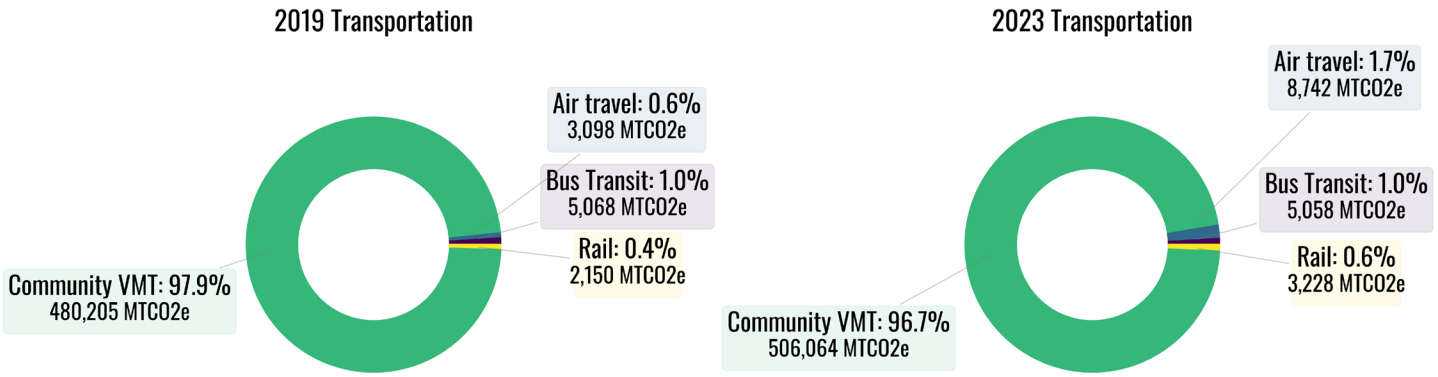

FIGURE 32: TRANSPORTATION AND MOBILE SERVICES SECTOR EMISSIONS PERCENTAGE IN 2023 COMPARED TO 2019.[11]

[11] Community VMT refers to the Community on-road transportation subsector.

Community On-Road Transportation

Emissions from community on-road transportation in Worcester experienced a notable upward trend, increasing by approximately 23.7% from 2009 to 2023. In 2020, a significant decrease to 375,893 MT CO2e was observed, attributable to the impacts of the COVID-19 pandemic, which led to reduced vehicular movement and lower transportation activity. However, as restrictions eased and economic activities resumed, emissions rebounded sharply and continued to increase in the following years. The full emission trend can be seen in Figure 33.

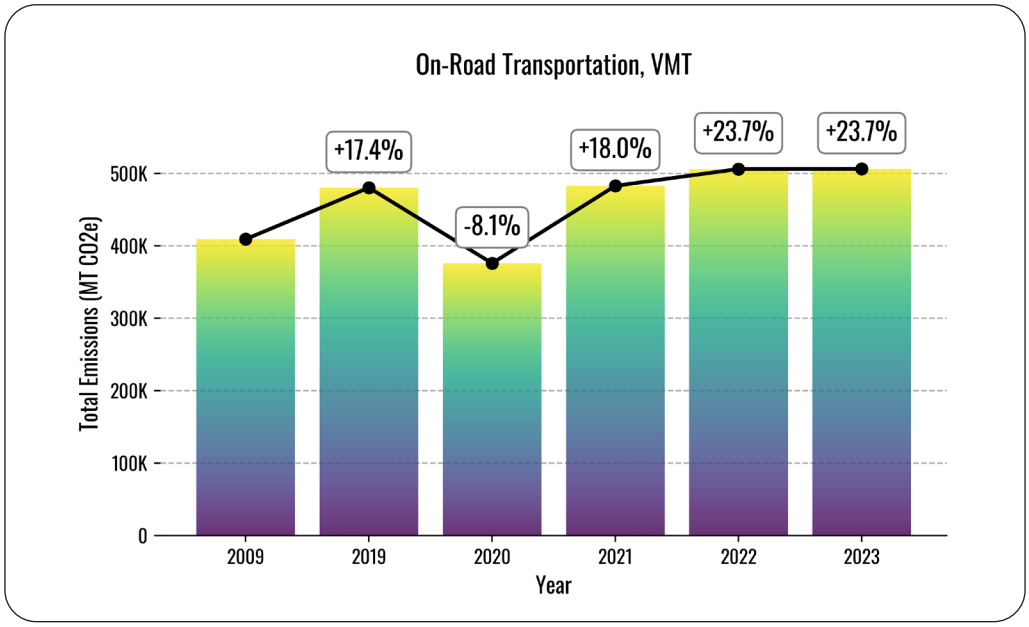

FIGURE 33: ON-ROAD TRANSPORTATION EMISSIONS WITH CHANGES RELATIVE TO THE 2009 BASELINE.

Bus Transit

Emissions from bus transit in Worcester saw a slight decline of approximately 5.3% from 2009 to 2023. The year 2020 witnessed a more noticeable drop to 18.7% from the 2009 baseline, likely due to reduced public transportation usage during the COVID-19 pandemic. Figure 34 identifies the yearly emission comparison to the 2009 baseline.

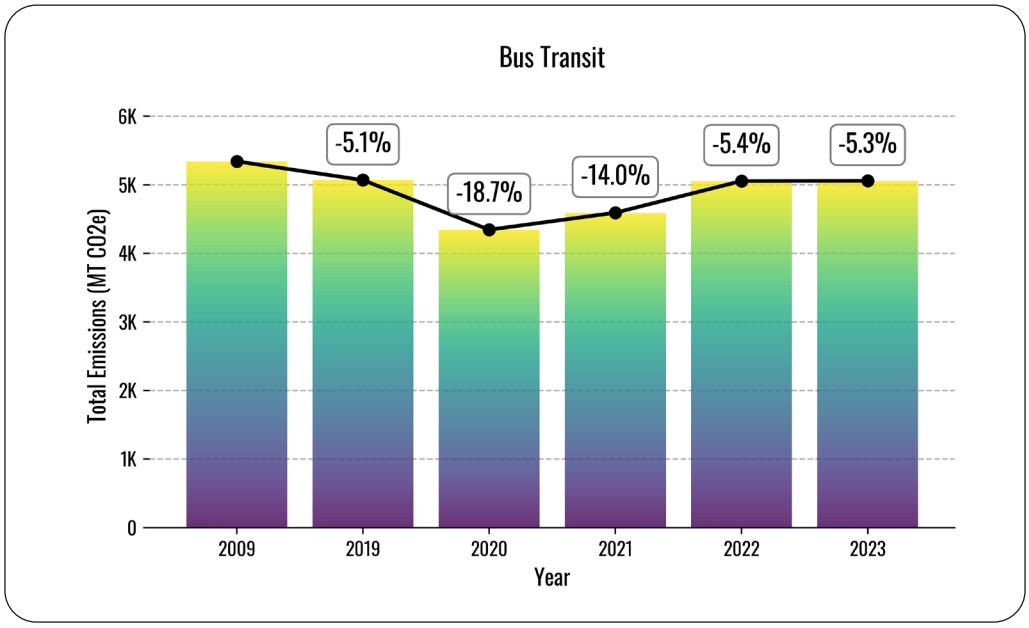

FIGURE 34: BUS TRANSIT EMISSIONS WITH CHANGES RELATIVE TO THE 2009 BASELINE.

Air Travel

Emissions from air travel experienced a dramatic increase of approximately 295.4% from the 2009 baseline to 2023, partially due to a change in the reporting methodology from Worcester's last GHG inventory in 2019 to today. Previously, emissions were calculated based on single flights and the weight of the aircraft, but the new methodology was unable to identify the types of aircraft and used an average emission factor for all planes for LTO[12] within the boundary of the inventory. More information can be found in Appendix B. Air travel remains a small number of total emissions, accounting for approximately 0.5% of total City emissions in 2023. Figure 35 identifies the change in emissions compared to the 2019 baseline between the sample years.

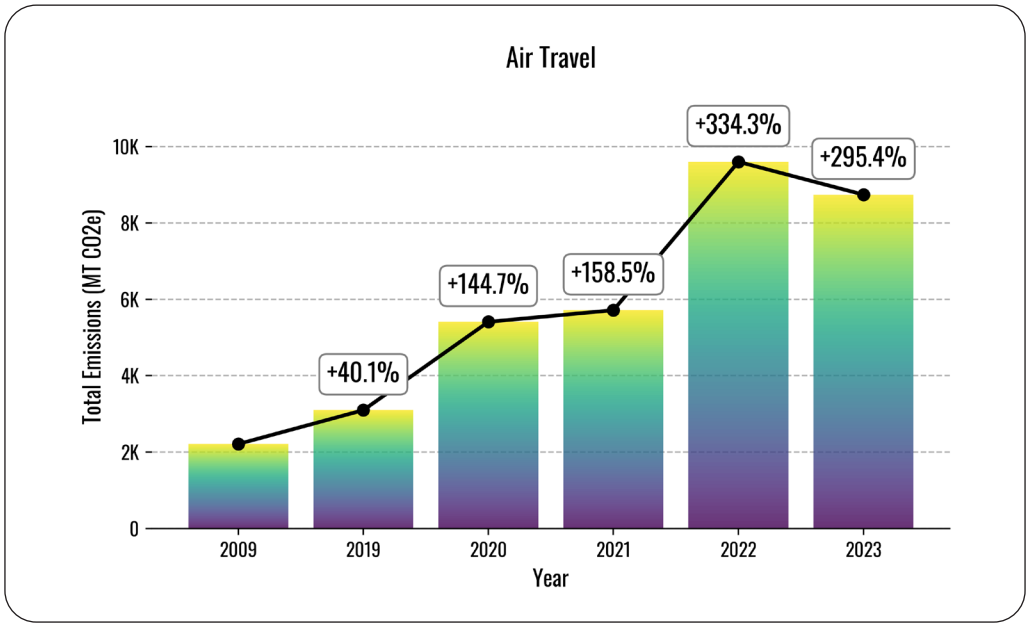

FIGURE 35: AIR TRAVEL EMISSIONS WITH CHANGES RELATIVE TO THE 2009 BASELINE.

[12] Landing and takeoffs subsector.

Rail Transportation

Emissions from rail transportation saw a substantial rise of approximately 104.3% from the 2009 baseline to 2023. In 2020, emissions were reduced by 75.8% of the 2009 baseline due to interruptions in service caused by the COVID-19 pandemic. The intermittent service resumed in 2021, reflected by the subsequent increase in emissions. Emissions rebounded in the following years and peaked in 2023. Figure 36 shows the fluctuation in emissions compared to a 2009 baseline.

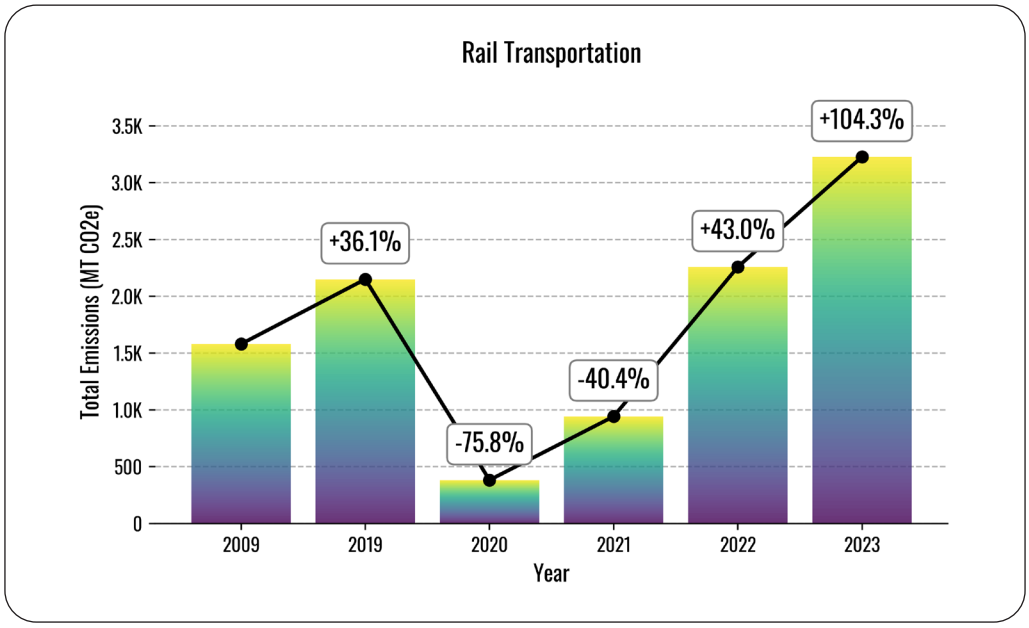

FIGURE 36: RAIL TRANSPORTATION EMISSIONS WITH CHANGES RELATIVE TO THE 2009 BASELINE.

SOLID WASTE

The **Solid Waste** sector in Worcester encompasses residential waste, commercial waste, compost, and landfill emissions. Figure 37 shows the comparison of emissions by source for the solid waste sector.

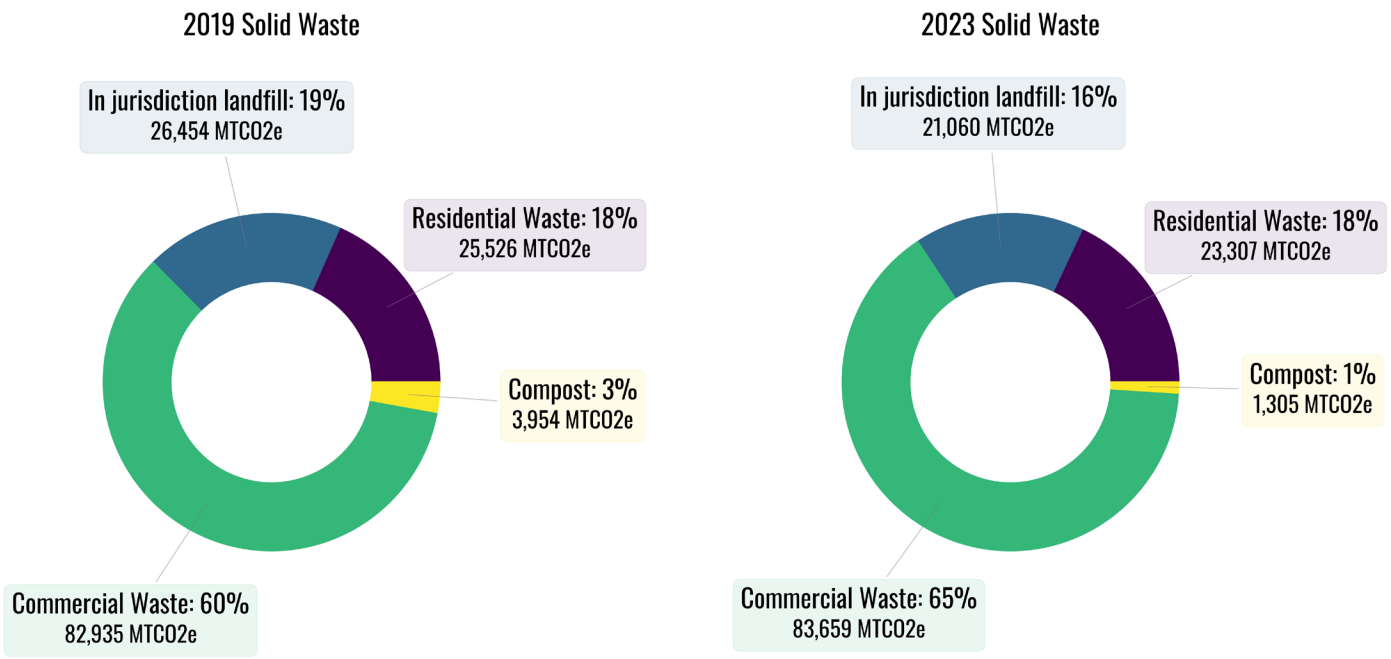

FIGURE 37: SOLID WASTE SECTOR EMISSIONS IN WORCESTER IN 2023.

Residential Waste

Residential waste emissions experienced a modest decline of approximately 9.1% from the 2009 baseline to 2023. These trends can be seen in Figure 38.

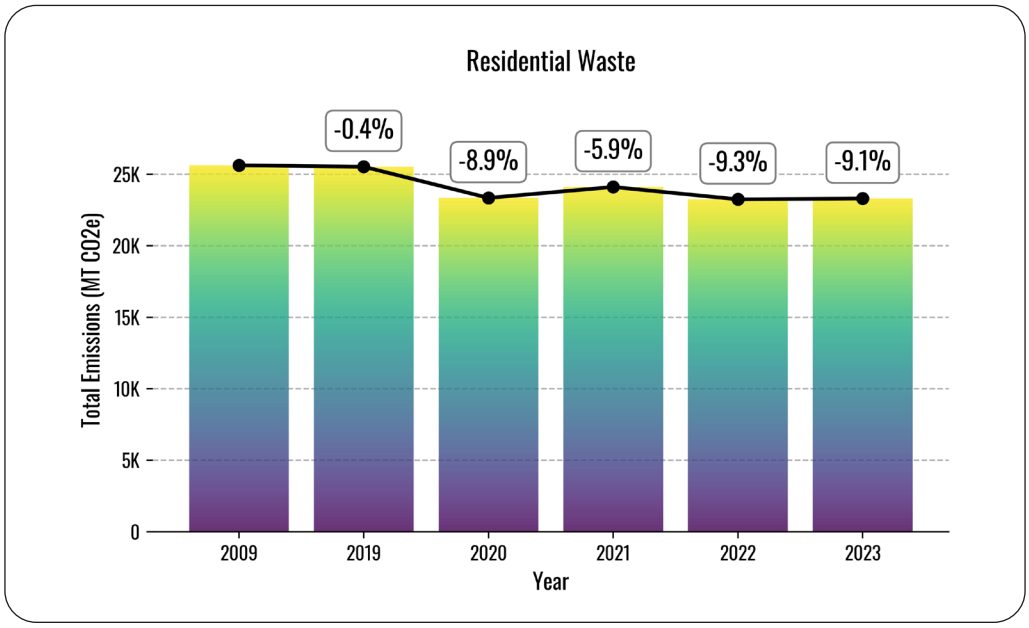

FIGURE 38: RESIDENTIAL WASTE EMISSIONS WITH CHANGES RELATIVE TO THE 2009 BASELINE.

Commercial Waste

Despite fluctuations, emissions from commercial waste rose by 11.3% from 2009 to 2023. This overall increase reflects the growing commercial activity as commercial waste estimates are based on employment data. Please refer to Appendix B for more information on the commercial waste calculations. Figure 39 shows the emissions per year for commercial waste compared to a 2009 baseline.

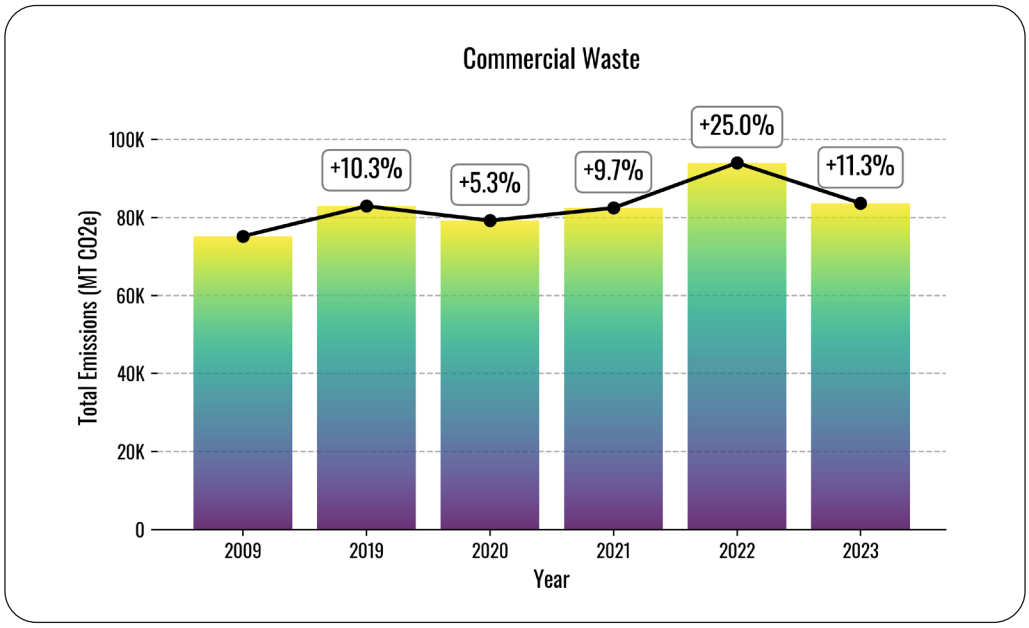

FIGURE 39: COMMERCIAL WASTE EMISSIONS WITH CHANGES RELATIVE TO THE 2009 BASELINE.

Compost

Composting emissions experienced a marked decline, dropping approximately 67% from the baseline of 2009 to 2023.[13] The usage figures from 2020–2023 were reported from the Massachusetts Department of Environmental Protection CY 2019–2023 Solid Waste and Recycling Survey. Figure 40 shows this emission reduction per year compared to the baseline.

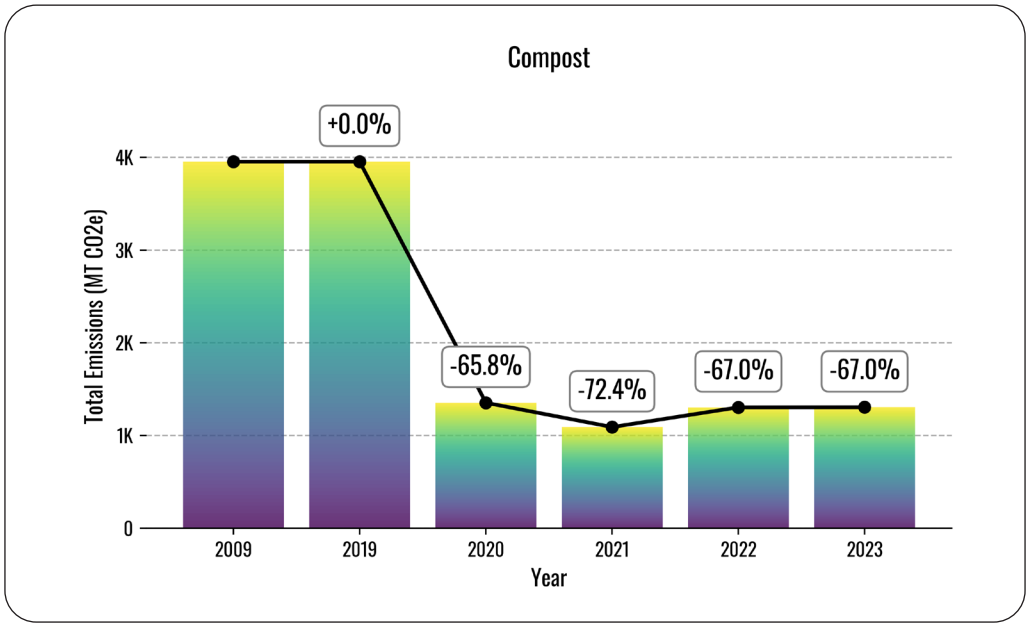

FIGURE 40: COMPOST EMISSIONS WITH CHANGES RELATIVE TO THE 2009 BASELINE.

[13] This is potentially due to a miscalculation in the 2019 inventory. In future inventories the 2009 and 2019 figures will be reevaluated.

In-Jurisdiction Landfill

Despite its closure in 1985, the Greenwood Landfill still contributes to overall emissions due to the ongoing decay of organic waste and the resulting methane production. In 2023, the emissions from in-jurisdiction landfills saw a significant decrease, dropping approximately 55% from the 2009 baseline. Figure 41 shows the emissions per year.

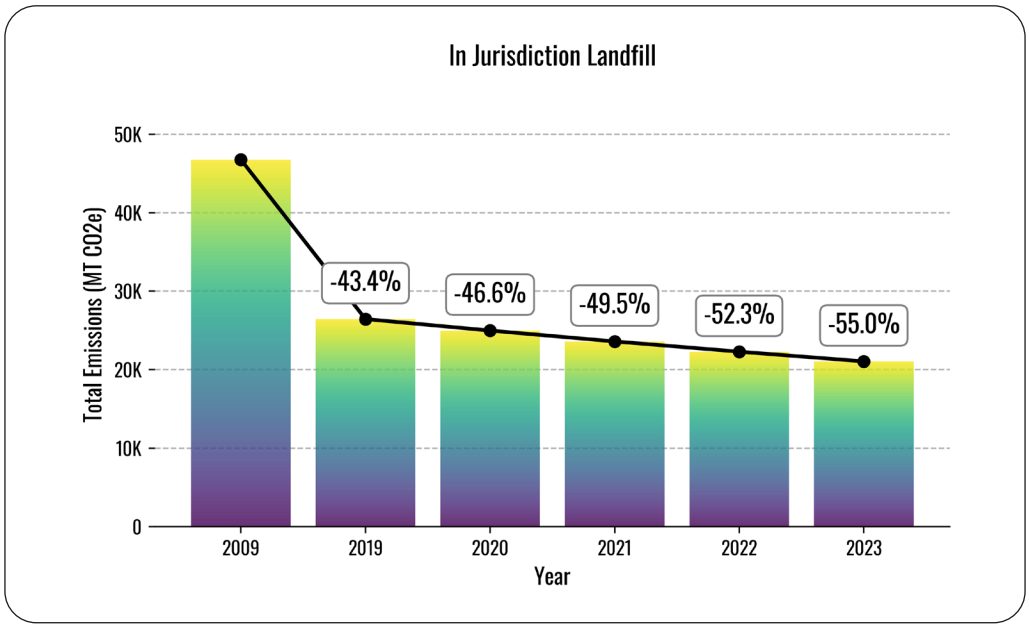

FIGURE 41: IN-JURISDICTION LANDFILL EMISSIONS WITH CHANGES RELATIVE TO THE 2009 BASELINE.

WATER AND WASTEWATER

The **Water and Wastewater** sector includes emissions from potable water and wastewater management in Worcester. Figure 42 shows the comparison between 2019 and 2023 emission composition for the Water and Wastewater sector for the City of Worcester.

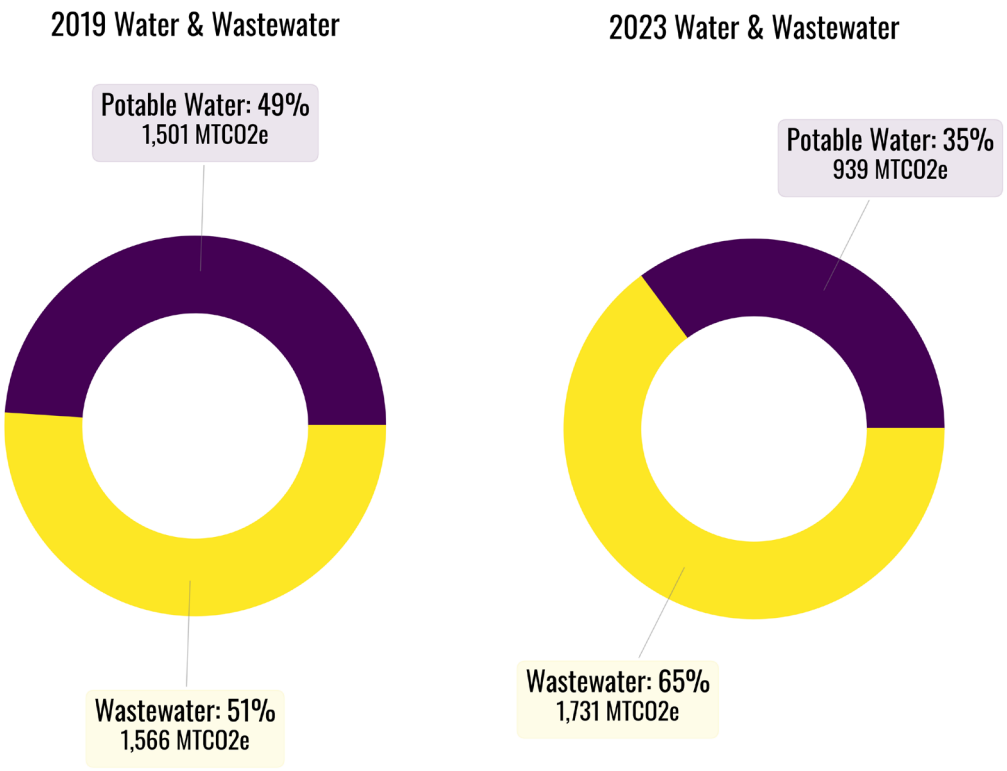

FIGURE 42: WATER AND WASTEWATER SECTOR EMISSIONS IN WORCESTER IN 2023.

Potable Water

In 2023, emissions from potable water treatment and distribution saw a significant decrease, dropping approximately 57% from the 2009 baseline. This is due to increased renewable energy used in electricity generation for potable water. Figure 43 shows the trend of potable water emissions per year compared to a 2009 baseline.

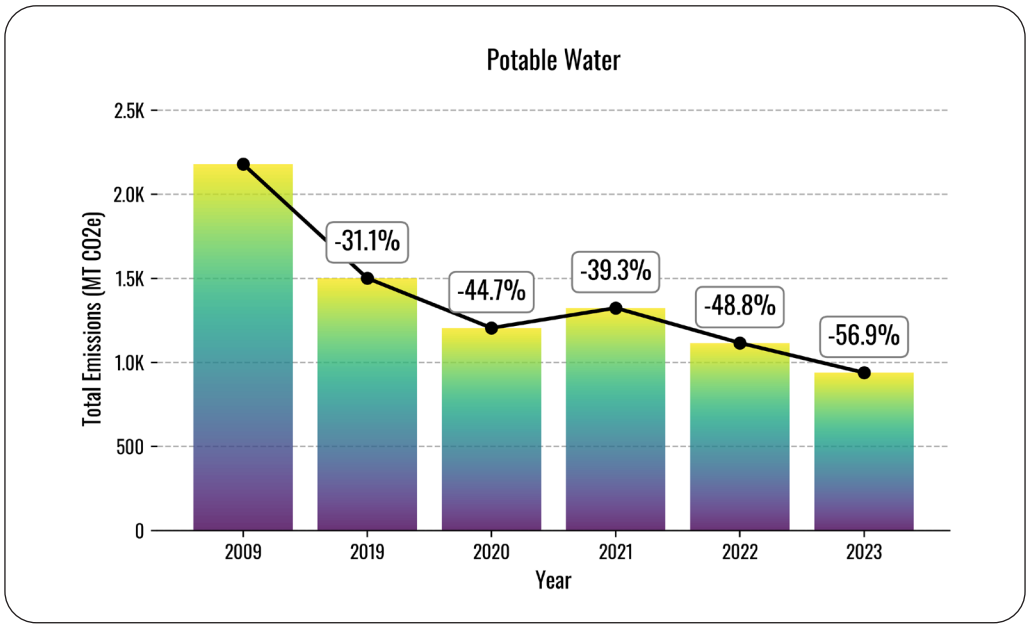

FIGURE 43: POTABLE WATER EMISSIONS WITH CHANGES RELATIVE TO THE 2009 BASELINE.

Wastewater Processes

Wastewater processes emissions saw an increase of approximately 13.2% from the 2009 baseline in 2023. This rise can be seen in Figure 44, which compares the yearly emissions of wastewater to the baseline.

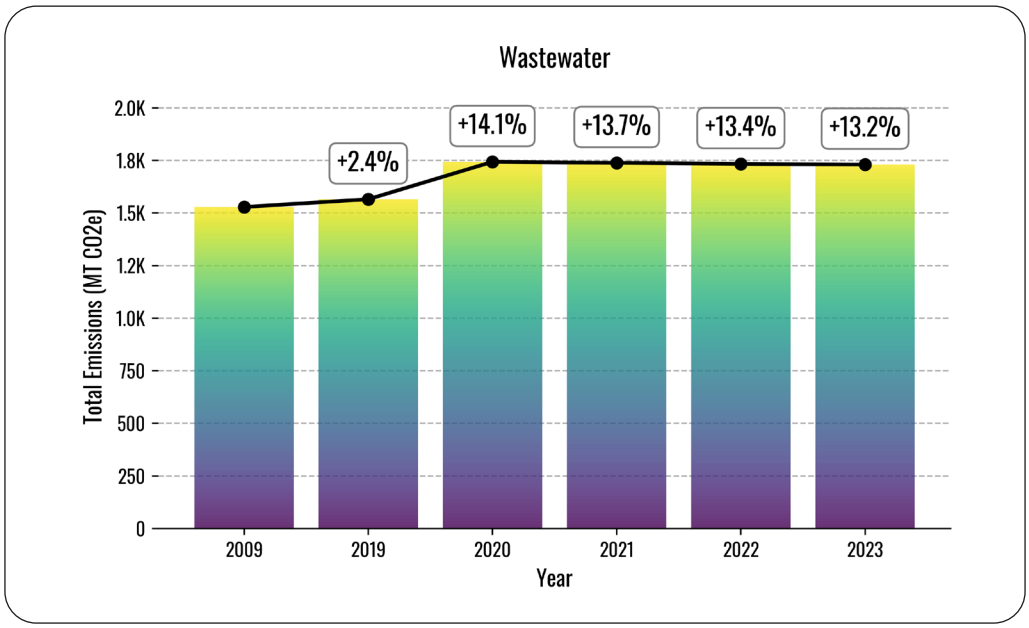

FIGURE 44: WASTEWATER EMISSIONS WITH CHANGES RELATIVE TO THE 2009 BASELINE.

Fugitive Emissions

Following a recalculation in this inventory, fugitive emissions from natural gas usage decreased by 43.8% by 2023 from 2009. Fugitive emissions are leakage of natural gas from the extraction, production, processing, storage, transportation, and distribution of natural gas. The leakage rate of natural gas for the City was reevaluated and found to be much lower than in the 2009 and 2019 inventory. In the 2019 inventory fugitive emission leakage rate was stated to be equal to the national average of 2.7%. This inventory reevaluated the leakage rate and used localized research in the Massachusetts area to find that the leakage rate is closer to 1.3%.[14] This was further proved by EPA emission reporting of the natural gas company NSTAR.[15] More information can be found in Appendix B.

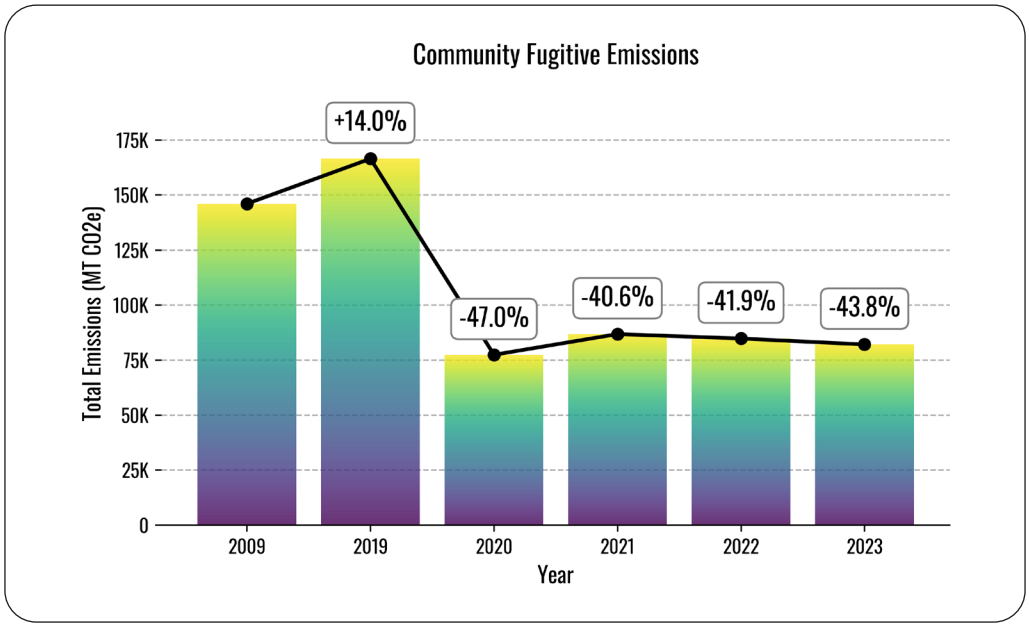

FIGURE 45: FUGITIVE EMISSIONS WITH CHANGES RELATIVE TO THE 2009 BASELINE.

[14] Diana Burns and Emily Grubert 2021 Environ. Res. Lett. 16 044059

[15] More information on NSTAR emission reporting can be found at the EPA's website

Summary Of Inventory Results by Year

This inventory also assessed all GHG emissions produced by the municipal operations from 2020 to 2023. Municipal emissions are a small subset of total community wide emissions. The City produces 2.7% of total community-wide emissions. Figure 46 visualizes this relationship between community and municipal emissions.

In the year 2023, emissions for the municipal government of Worcester have fallen by 18.6% as compared to a 2009 baseline. Emissions for the City reached an all-time low in 2021 at 19.3% reduction compared to the 2009 baseline. Table 5 outlines the specific emissions throughout the sample period, while Figure 47 illustrates Governmental Operations GHG Emissions from 2009 to 2023 with the changes relative to the 2009 baseline.

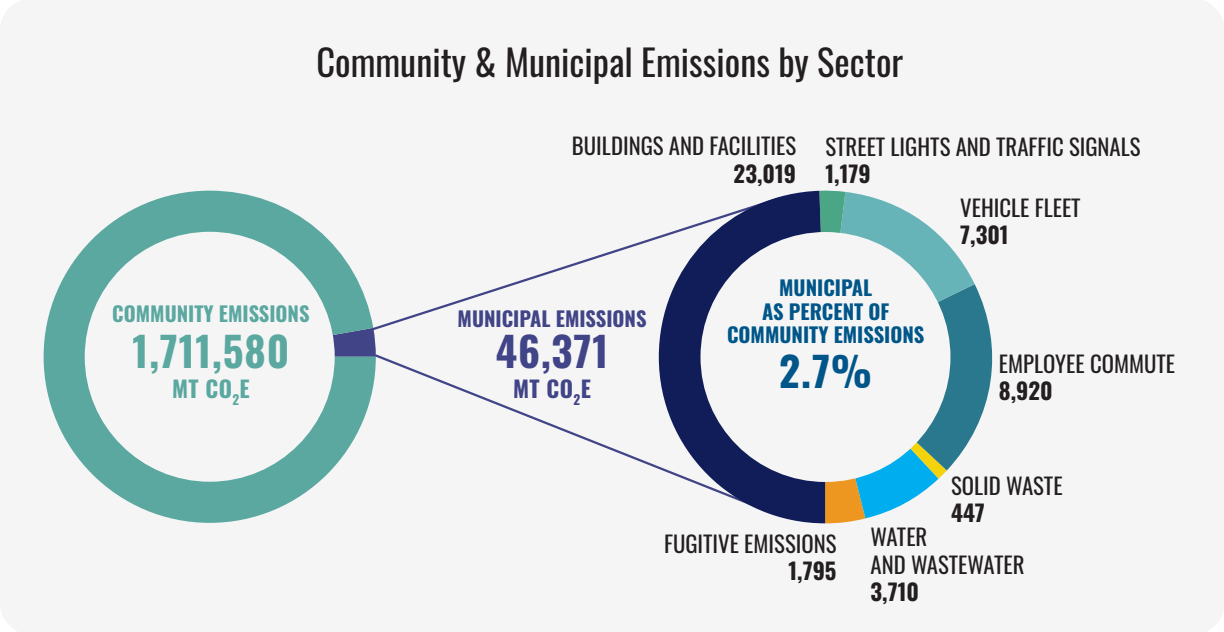

FIGURE 46: COMPARISON BETWEEN TOTAL COMMUNITY EMISSIONS AND MUNICIPAL EMISSIONS BY SECTOR (2023).

Table 4 - Table Showing Fluctuating Trends and Annual Reduction Percentages in Governmental Operations GHG Emissions from 2009 to 2023.

YEAR	2009	2019	2020	2021	2022	2023
Total Emissions	56,952[16]	49,084	46,389	45,965	47,303	46,371
Emissions Reductions in Relation to 2009	-	13.8%	18.6%	19.3%	16.9%	18.6%

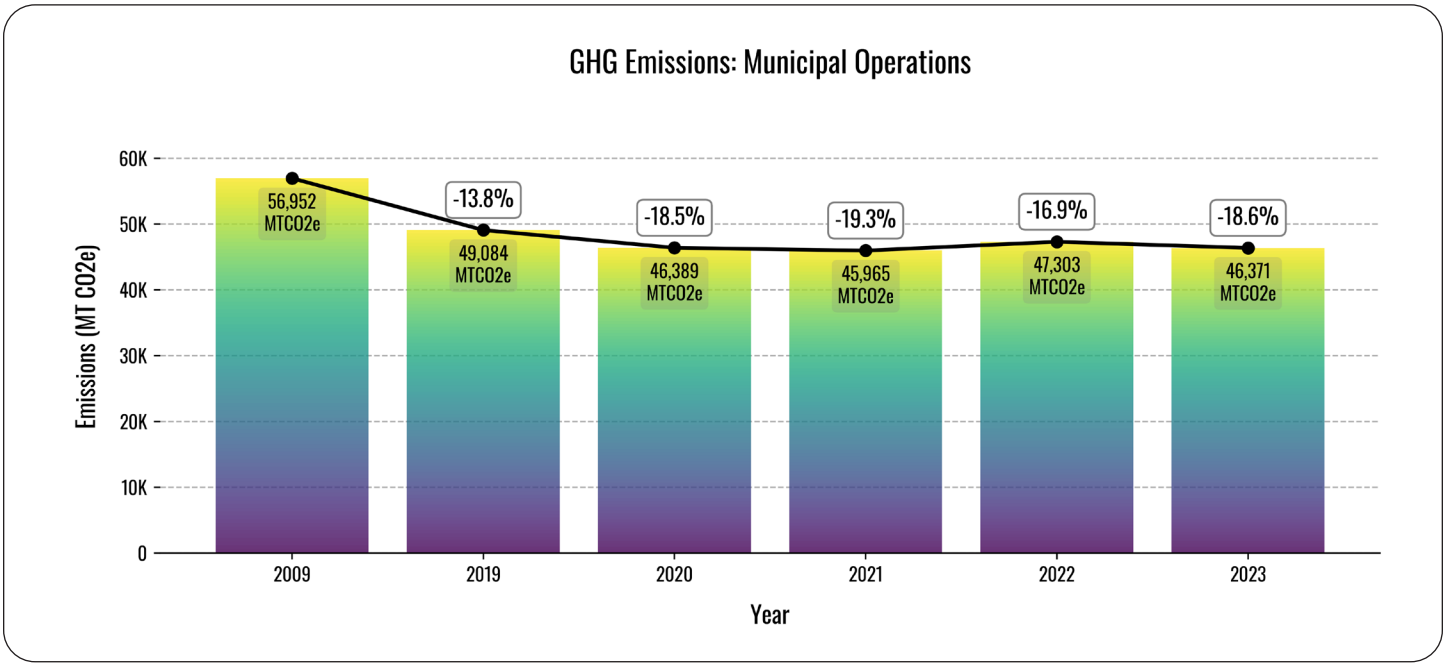

FIGURE 47: GOVERNMENTAL OPERATIONS GHG EMISSIONS FROM 2009 TO 2023 WITH CHANGES RELATIVE TO THE 2009 BASELINE.

[16] This value and the 2019 value have been updated from the 2019 inventory as there was an addition of school employees in the employee commuting emissions sector.

Summary Of Inventory Results by Sector

The governmental **Buildings and Facilities** sector includes emissions from grid electricity, natural gas combustion, and stationary fuel combustion of oil, diesel, and propane. The latter two are not compared in the figure below, as they are below 1% of the total municipal emissions. While overall emissions have decreased, the composition of the sources has slightly moved towards more electrical consumption. Figure 48 shows this comparison in source composition between 2019 and 2009.

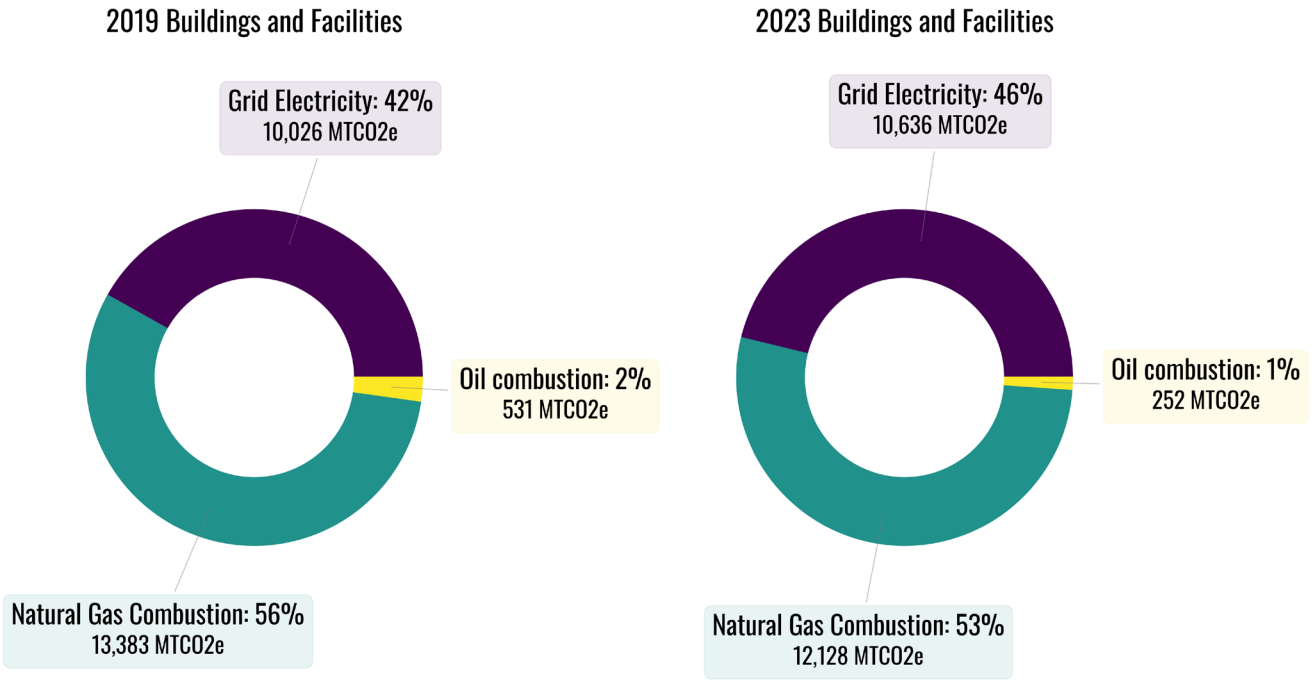

FIGURE 48: BUILDING AND FACILITIES SECTOR EMISSIONS IN WORCESTER IN 2023.

Overall, the **Buildings and Facilities** sector shows a downward trend, with a 22.0% reduction by 2023 compared to the 2009 baseline. Grid electricity consumption decreased notably, with the most significant drop observed from 2019 to 2020, influenced by the regional electricity emission factor shifts and reduced operations during COVID-19 restrictions. Natural gas use has remained fairly relatively stable since 2019. Figure 49 illustrates the buildings and facilities emissions throughout the sample period with changes relative to the 2009 baseline.

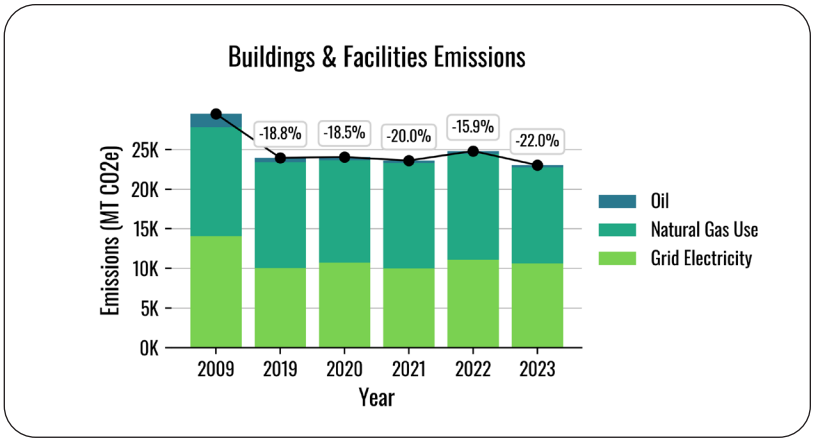

FIGURE 49: EMISSIONS IN THE BUILDINGS AND FACILITIES SECTOR WITH CHANGES RELATIVE TO THE 2009 BASELINE.

The grid electricity consumption for the **Street Lights and Traffic Signals** sector saw a 65.7% reduction in 2023 compared to the 2009 baseline. This reduction highlights the impact of the changing regional electricity grid[17] moving towards less carbon production in electricity generation, as well as city-wide streetlight lighting upgrades. This trend is highlighted in Figure 50.

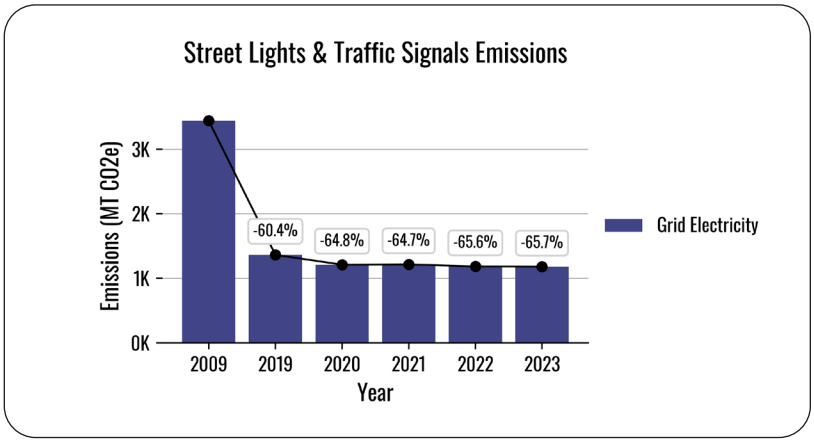

FIGURE 50: STREET LIGHTS AND TRAFFIC SIGNALS SECTOR EMISSIONS WITH CHANGES RELATIVE TO THE 2009 BASELINE.

[17] The model used the same emission factor source as the 2019 inventory ISO New England. ISO New England reports yearly electricity emission factors for the Worcester region.

The **Vehicle Fleet** sector encompasses emissions from gasoline and diesel vehicles operated by the municipal government. While overall emissions have decreased in 2023 compared to 2019, the year of Worcester's last GHG inventory, the composition of the sources has remained virtually unchanged. Figure 51 identifies the composition of emissions between 2019 and 2023.

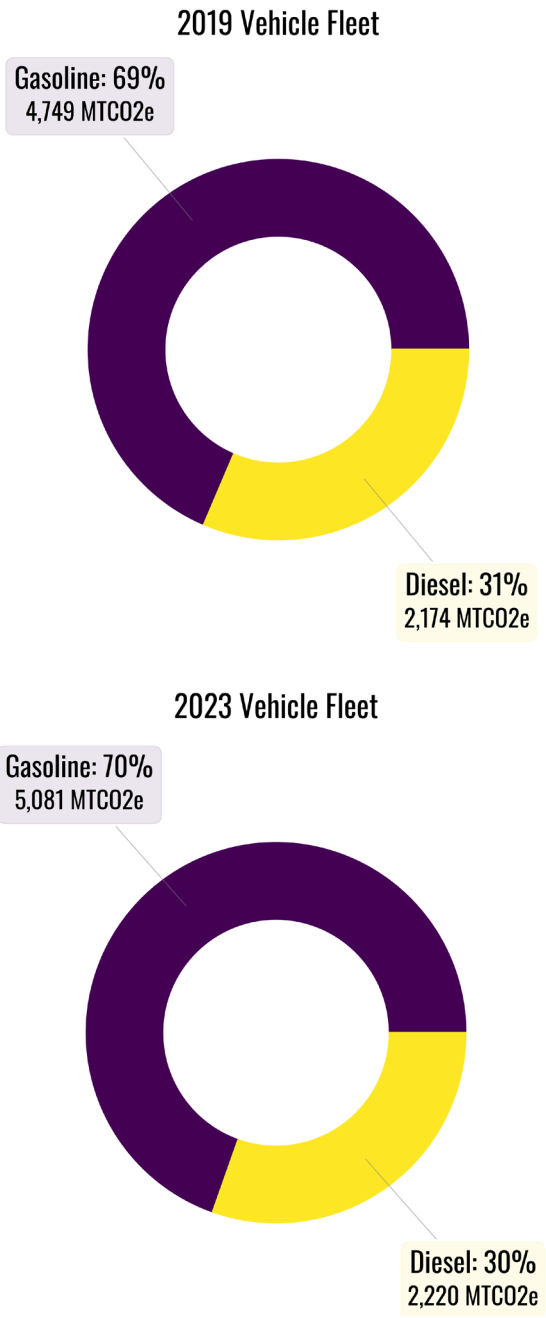

FIGURE 51:VEHICLE FLEET SECTOR EMISSIONS IN WORCESTER IN 2023 COMPARED TO 2019.

Fuel consumption in the **Vehicle Fleet** sector increased by 3.8% between 2009 and 2023. This followed an all-time low in the year 2021. Figure 52 shows the year over year trend of municipal vehicle fleet emissions with changes relative to the 2009 baseline.

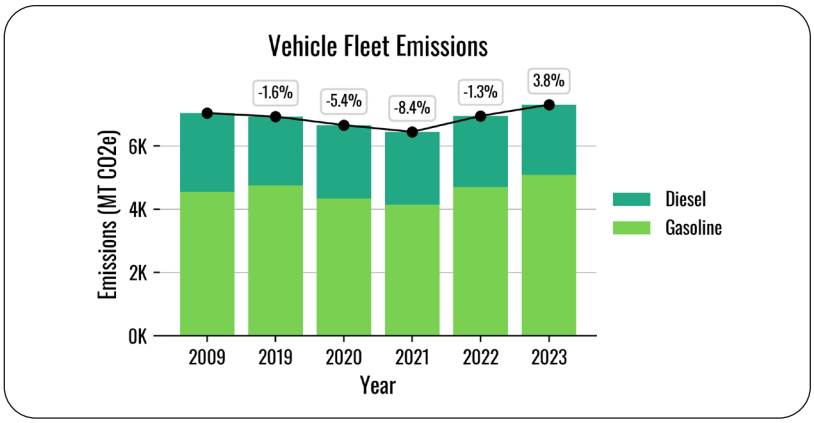

FIGURE 52: VEHICLE FLEET SECTOR EMISSIONS AND CHANGES RELATIVE TO THE 2009 BASELINE.

Employee commute emissions increased by 10.8% between 2009 and 2023. The commuting emissions data has been updated, incorporating employees within the municipal school districts, which adds approximately 12,000,000 vehicle miles traveled (VMT) in 2009 and 13,900,000 VMT in 2019. Figure 53 illustrates the annual emissions, highlighting changes relative to the 2009 baseline.

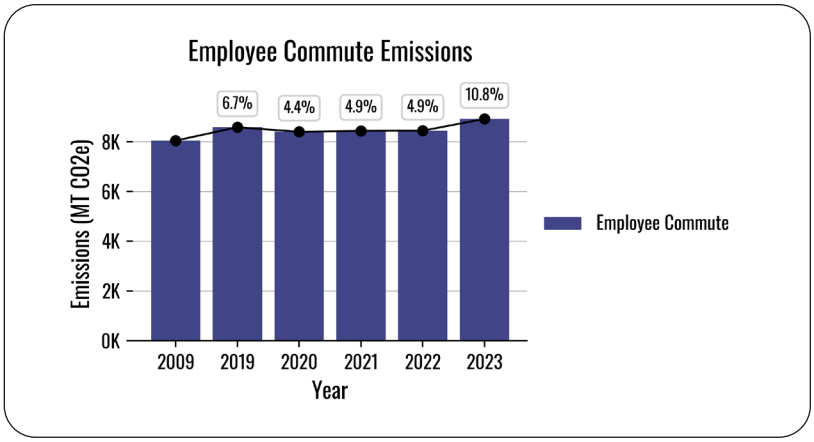

FIGURE 53: EMPLOYEE COMMUTE SECTOR EMISSIONS WITH CHANGES RELATIVE TO THE 2009 BASELINE.

Solid waste from municipal disposal increased by 30.8% between 2009 and 2023, reflecting its share of community solid waste. Despite this rise, the sector accounts for a small portion of municipal emissions, contributing approximately 0.96%. Figure 54 presents the trends in solid waste sector emissions, highlighting changes relative to the 2009 baseline.

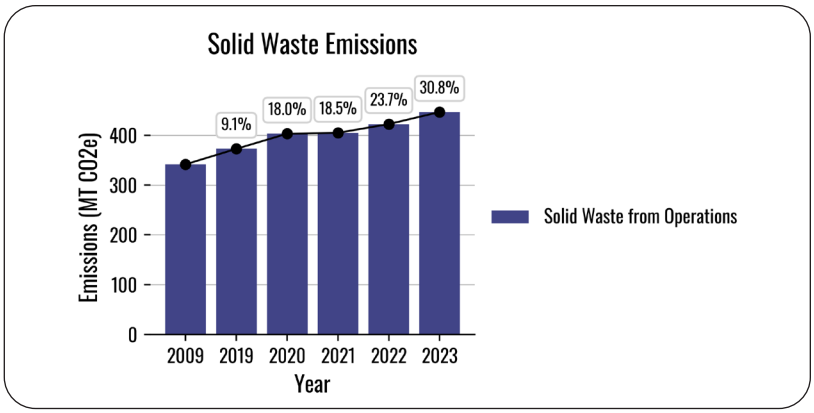

FIGURE 54: MUNICIPAL SOLID WASTE SECTOR EMISSIONS WITH CHANGES RELATIVE TO THE 2009 BASELINE.

The **Water and Wastewater** sector encompasses emissions from grid electricity, natural gas combustion, and stationary fuel combustion of fuel oil, propane, and diesel. The latter two are not compared because they constitute less than 1% of water and wastewater emissions in both 2019 and 2023. Figure 55 shows the composition of these emission sources for 2019 and 2023.

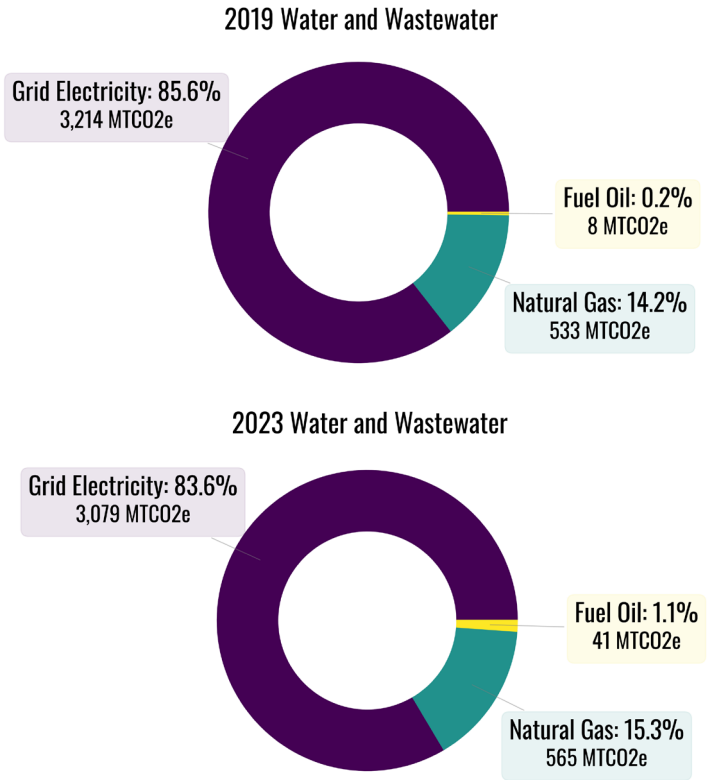

FIGURE 55: WATER AND WASTEWATER SECTOR EMISSIONS IN WORCESTER IN 2023 COMPARED TO 2019.

The **Waste and Wastewater** sector emissions have decreased by 14.7% between 2009 and 2023. Figure 56 identifies the emission trend for this sector throughout the sample period. Detailed results of specific emission trends can be found in the next sections.

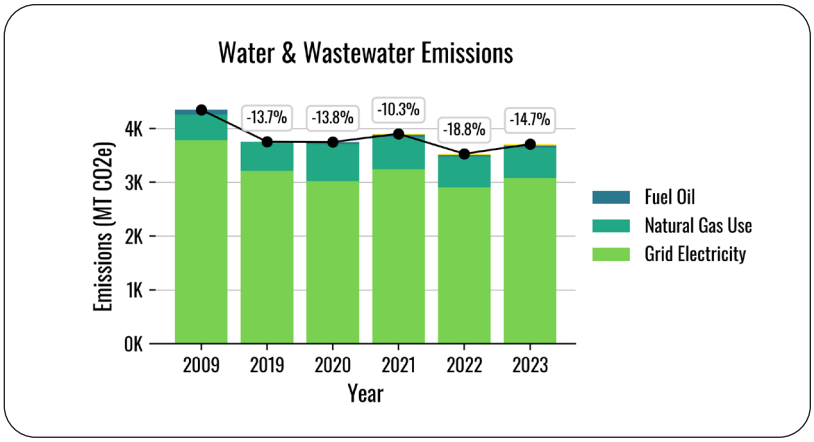

FIGURE 56: WATER AND WASTEWATER SECTOR EMISSIONS WITH CHANGES RELATIVE TO THE 2009 BASELINE.

Summary Table

TABLE 6 – TABLE ILLUSTRATING THE SECTOR-SPECIFIC GOVERNMENTAL OPERATIONS GHG EMISSIONS FROM 2009 TO 2023.

BUILDINGS AND FACILITIES		2009	2019	2020	2021	2022	2023	% CHANGE 2009-2023
Grid Electricity	MT CO2e	14,045	10,026	10,706	10,013	11,104	10,636	-24.3
Natural Gas Combustion	MT CO2e	13,769	13,383	12,921	13,267	13,345	12,128	-11.9
Stationary Fuel Combustion: Oil	MT CO2e	1,681	531	416	320	358	252	-85.0
Stationary Fuel Combustion: Diesel	MT CO2e	-	3	2		-	-	-
Stationary Fuel Combustion: Propane	MT CO2e	-	-	-	2	3	3	-
Solar Electricity	MT CO2e	-	-	-	-	-	-	-
STREETLIGHTS AND TRAFFIC SIGNALS		**2009**	**2019**	**2020**	**2021**	**2022**	**2023**	**% CHANGE 2009-2023**
Grid Electricity	MT CO2e	3,441	1,362	1,210	1,215	1,183	1,179	-65.7
FUGITIVE EMISSIONS		**2009**	**2019**	**2020**	**2021**	**2022**	**2023**	**% CHANGE 2009-2023**
Natural Gas Leakage	MT CO2e	4,244	4,146	1,924	1,960	1,968	1,795	-57.7
VEHICLE FLEET		**2009**	**2019**	**2020**	**2021**	**2022**	**2023**	**% CHANGE 2009-2023**
Gasoline	MT CO2e	4,541	4,749	4,325	4,143	4,696	5,081	11.9%
Diesel	MT CO2e	2,492	2,174	2,329	2,298	2,248	2,220	-10.9%
EMPLOYEE COMMUTE		**2009**	**2019**	**2020**	**2021**	**2022**	**2023**	**% CHANGE 2009-2023**
Gasoline	MT CO2e	8,048	8,583	8,403	8,438	8,445	8,920	+10.8
SOLID WASTE		**2009**	**2019**	**2020**	**2021**	**2022**	**2023**	**% CHANGE 2009-2023**
Waste Incinerated	MT CO2e	342	373	403	405	422	447	+30.8
WATER & WASTEWATER		**2009**	**2019**	**2020**	**2021**	**2022**	**2023**	**% CHANGE 2009-2023**
Grid Electricity	MT CO2e	3,788	3,214	3,024	3,245	2,905	3,079	-18.7
Natural Gas Combustion	MT CO2e	476	533	686	596	572	565	+18.7
Stationary Fuel Combustion: Oil	MT CO2e	78	8	37	43	30	41	-47.3
Stationary Fuel Combustion: Diesel	MT CO2e	8	-	-	-	-	-	-
Stationary Fuel Combustion: Propane	MT CO2e	-	-	2	18	23	25	-
Solar Electricity	MT CO2e	-	-	-	-	-	-	-
SUMMARY		**2009**	**2019**	**2020**	**2021**	**2022**	**2023**	
TOTAL EMISSIONS	MT CO2e	56,952	49,084	46,389	45,965	47,303	46,371	
TOTAL % CHANGE FROM 2009 BASELINE			-13.81%	-18.55%	-19.29%	-16.94%	-18.58%	

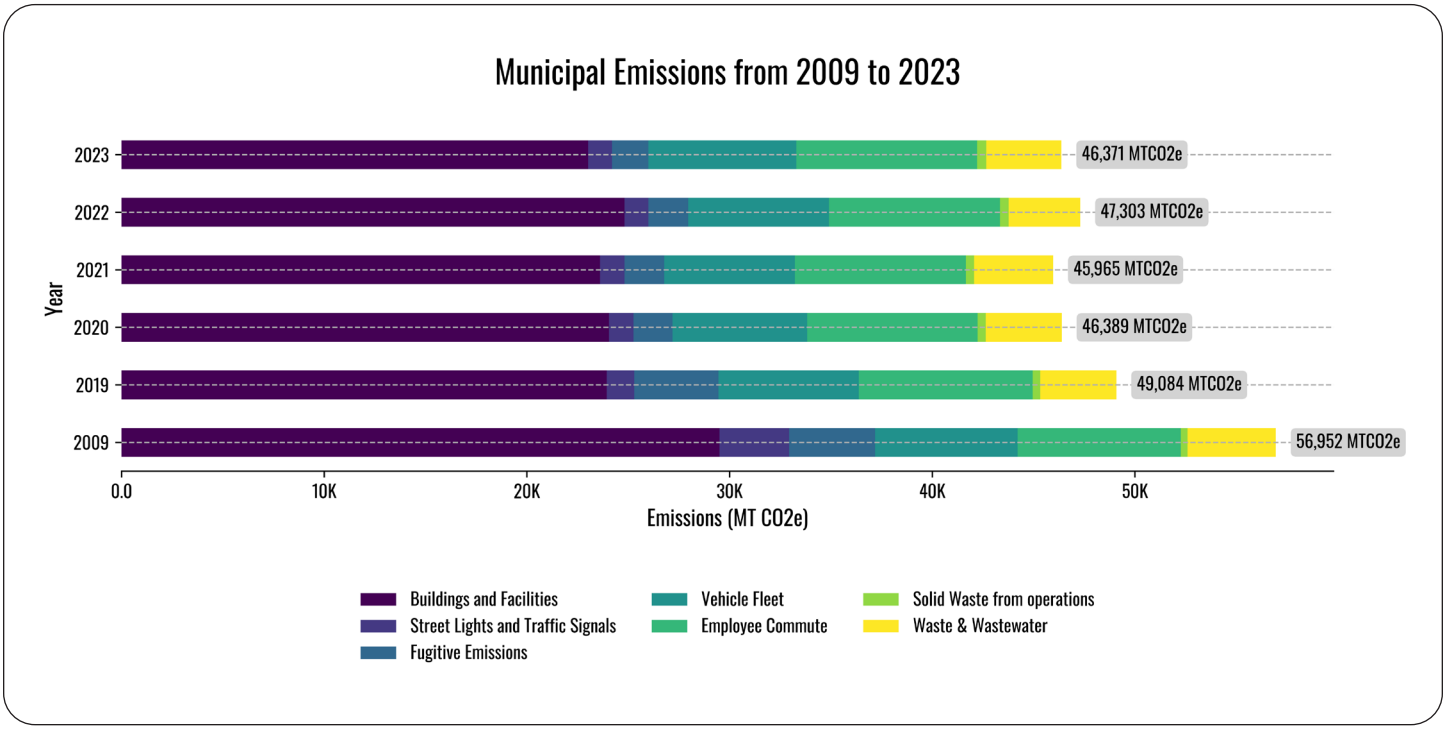

FIGURE 57: BAR CHART ILLUSTRATING MUNICIPAL OPERATION GHG EMISSIONS ACROSS VARIOUS SECTORS FROM 2009 TO 2023

Detailed Results

BUILDINGS AND FACILITIES

Purchased Grid Electricity

Electricity emissions from municipal buildings and facilities have had a 24.3% reduction in 2023 compared to the 2009 baseline. This improvement is primarily attributed to changes in the region's emission factor and the Massachusetts Renewable Portfolio Standards, as overall energy usage has remained relatively steady, decreasing by only 2.5% by 2023. Figure 58 shows the electricity emissions trends in MT CO2e throughout the sample period. Figure 59 shows the electricity consumption in MWh.

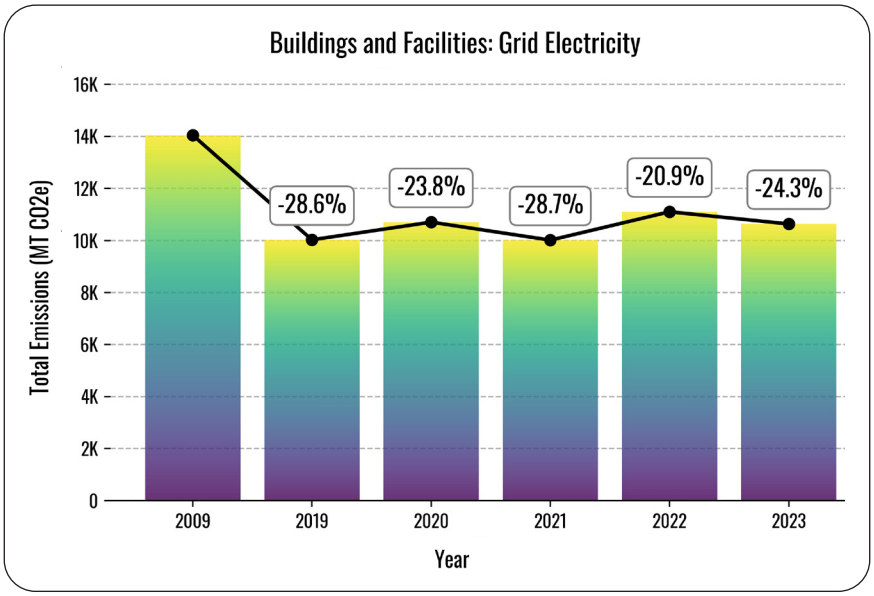

FIGURE 58: BUILDINGS & FACILITIES GRID ELECTRICITY EMISSIONS AND CHANGES RELATIVE TO THE 2009 BASELINE.

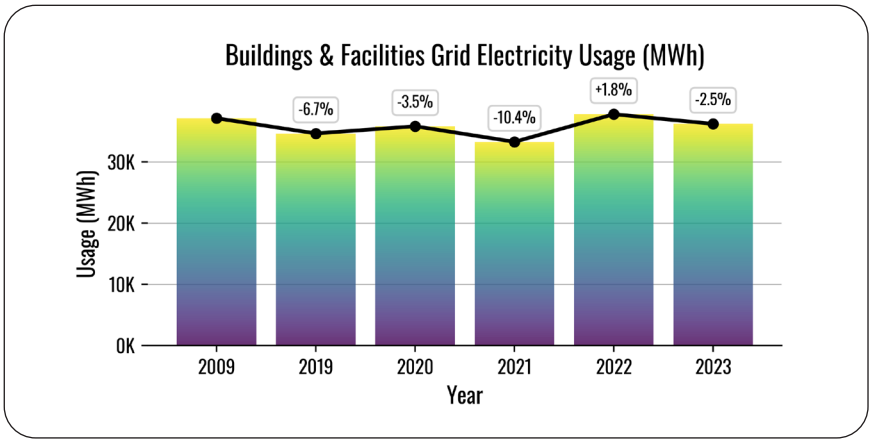

FIGURE 59: BUILDINGS & FACILITIES GRID ELECTRICITY USE (MWH) AND CHANGES RELATIVE TO THE 2009 BASELINE.

Natural Gas Combustion

Municipal natural gas usage has fallen by 11.9% since 2009. The most significant drop has been 2022–2023. Figure 60 shows the emissions trend for natural gas emissions in MT CO2e. Figure 61 shows the usage of natural gas in therms.

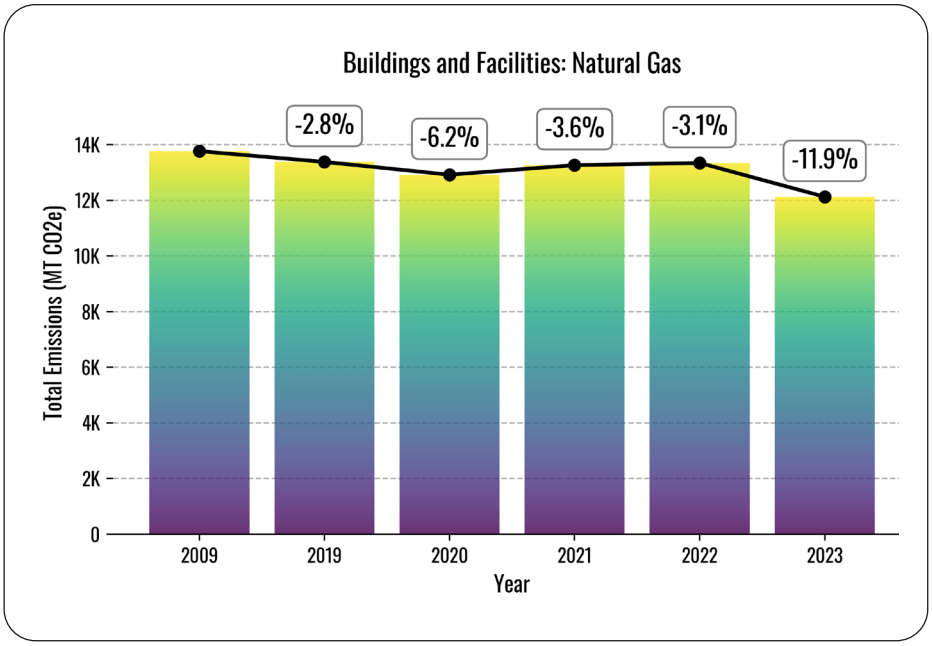

FIGURE 60: BUILDINGS & FACILITIES NATURAL GAS EMISSIONS AND CHANGES RELATIVE TO THE 2009 BASELINE.

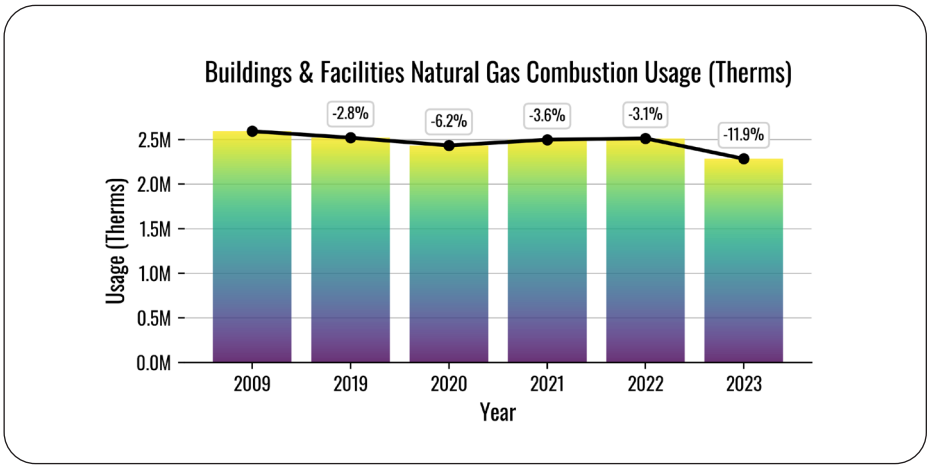

FIGURE 61: BUILDINGS & FACILITIES NATURAL GAS COMBUSTION (THERMS) AND CHANGES RELATIVE TO THE 2009 BASELINE.

Stationary fuel Combustion: Oil

Emissions from stationary fuel combustion using oil in municipal buildings have decreased by 85% by 2023 compared to 2009. Figure 62 shows the yearly emissions in municipal fuel oil with changes relative to the 2009 baseline.

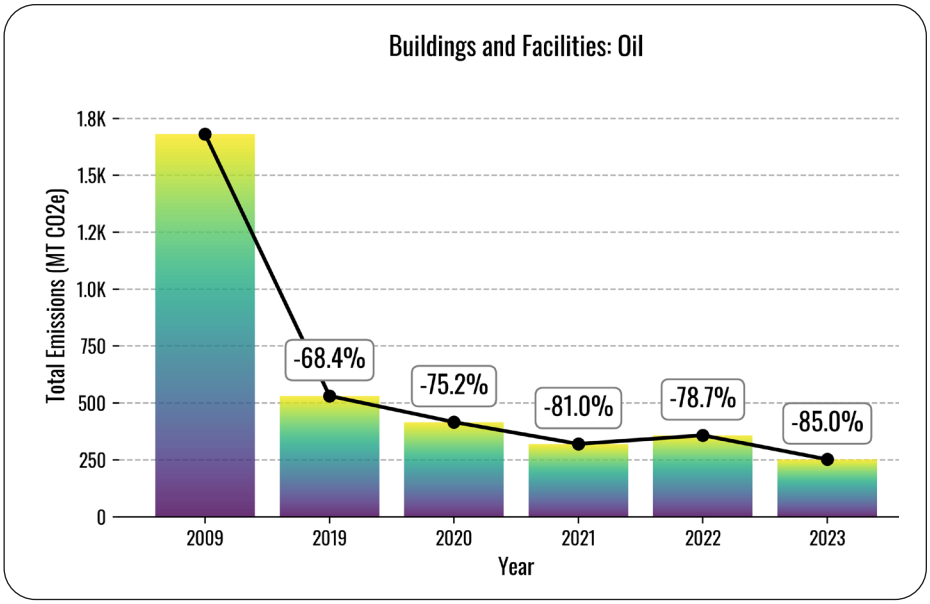

FIGURE 62: STATIONARY FUEL COMBUSTION OF OIL IN BUILDINGS AND FACILITIES AND CHANGES RELATIVE TO THE 2009 BASELINE.

Stationary Fuel Combustion: Diesel

No data on diesel use for stationary consumption in the **Buildings and Facilities** sector was reported for the years 2009, 2021, 2022, and 2023. In 2019 and 2020, emissions amounted to 3 and 2 MT CO2e, respectively. This source accounts for less than 0.01% of municipal emissions. Figure 63 shows the emissions for municipal diesel use in the years it was used.

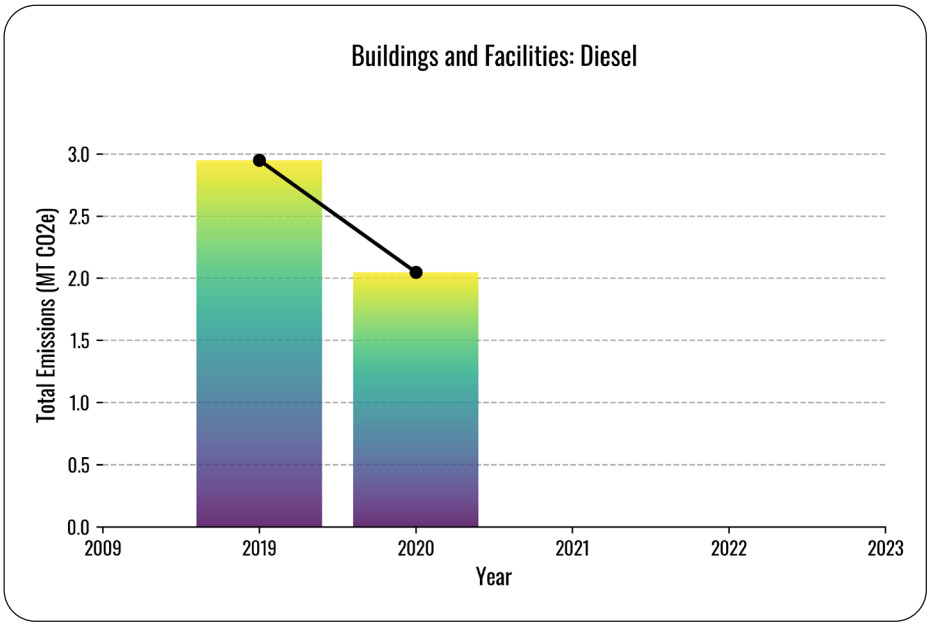

FIGURE 63: ANNUAL EMISSIONS FROM BUILDINGS & FACILITIES DIESEL USE (NO 2009 BASELINE FOR COMPARISON)

Stationary Fuel Combustion: Propane

Although no emissions were reported for 2009, 2019 and 2020 from municipal propane use, this sector shows a slight increase from 2021 to 2023. Emissions increased from 2.5 MT CO2e in 2021 to 3.5 MT CO2e in 2023. This sector accounts for less than 0.01% of municipal emissions. Figure 64 shows the trend of municipal propane emissions.

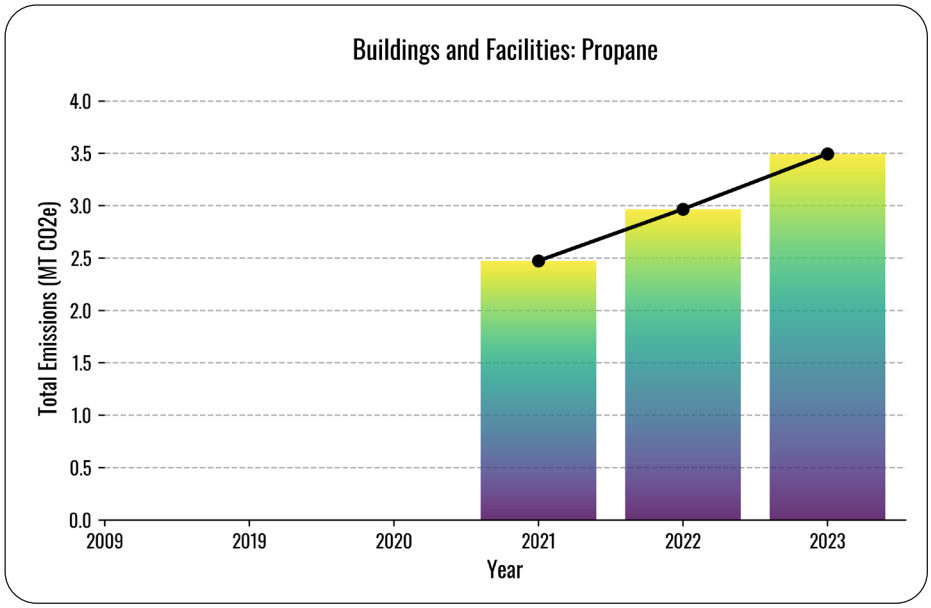

FIGURE 64: ANNUAL EMISSIONS FROM BUILDINGS & FACILITIES PROPANE USE (NO 2009 BASELINE FOR COMPARISON).

STREETLIGHTS AND TRAFFIC SIGNALS

Emissions from grid electricity consumption for streetlights and traffic signals have shown a significant downward trend from 2009 to 2023, with a reduction of 65.7% compared to the 2009 baseline. Like other electricity sources, this sector has been influenced by shifts in the regional electricity emission factor. Additionally, the decrease is in part due to a massive lighting energy efficiency upgrade the City underwent in 2017. Figure 65 illustrates the change in electricity emissions from streetlights and traffic signals.

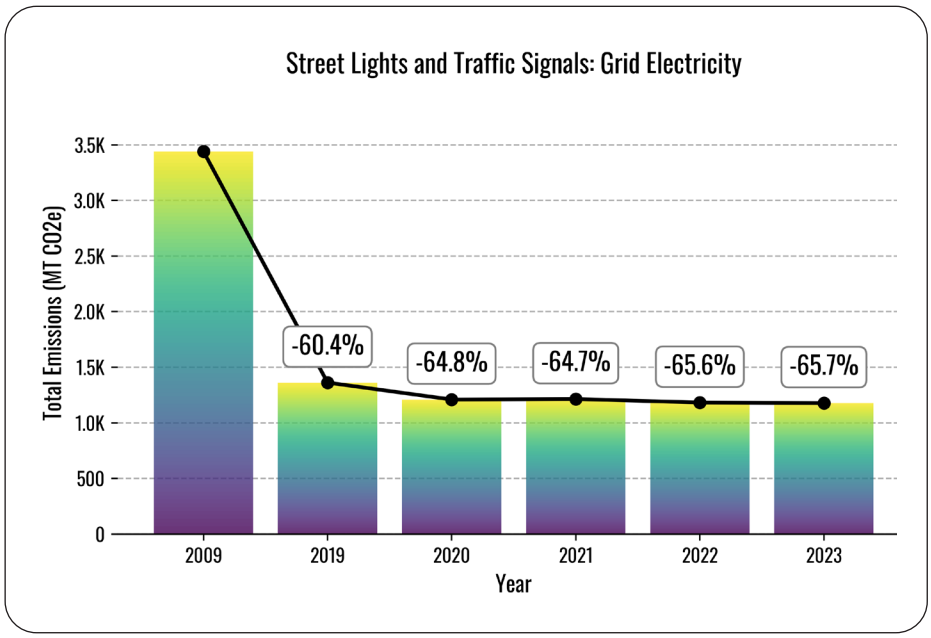

FIGURE 65: STREETLIGHTS AND TRAFFIC SIGNALS GRID ELECTRICITY EMISSIONS AND CHANGES RELATIVE TO THE 2009 BASELINE.

VEHICLE FLEET

Gasoline Consumption

Emissions from gasoline consumption by the municipal Vehicle Fleet increased by 11.9% in 2023 relative to the baseline year. Municipal fleet gasoline emissions and the changes relative to the 2009 baseline can be seen in Figure 66.

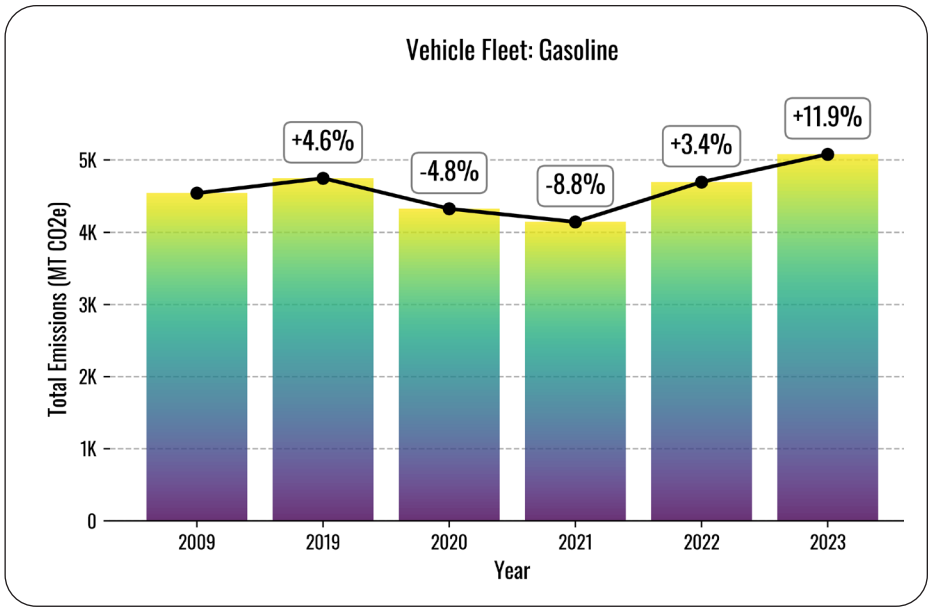

FIGURE 66: VEHICLE FLEET GASOLINE EMISSIONS AND CHANGES RELATIVE TO THE 2009 BASELINE.

Diesel Consumption

Diesel consumption by the municipal Vehicle Fleet decreased by 10.9% as compared to the baseline year. This emission trend is shown in Figure 67 while comparing changes relative to the 2009 baseline.

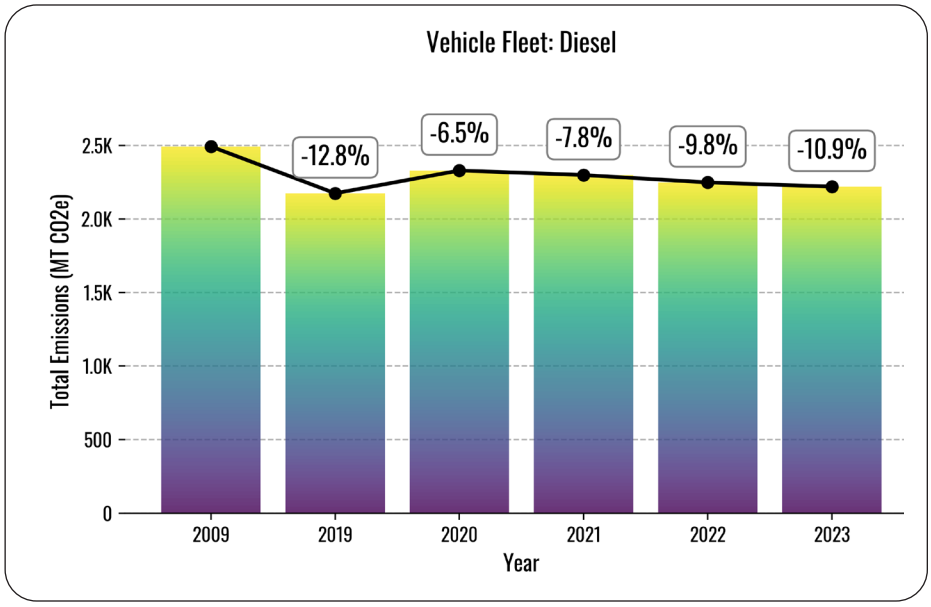

FIGURE 67: VEHICLE FLEET DIESEL EMISSIONS AND CHANGES RELATIVE TO THE 2009 BASELINE.

EMPLOYEE COMMUTING

Emissions from employee commuting increased by 10.8% compared to the baseline year. This sector was estimated on employee counts and average commuting distances, for more information please refer to Appendix B. Figure 68 shows the emissions from employees commuting through the sample period with changes relative to the 2009 baseline.

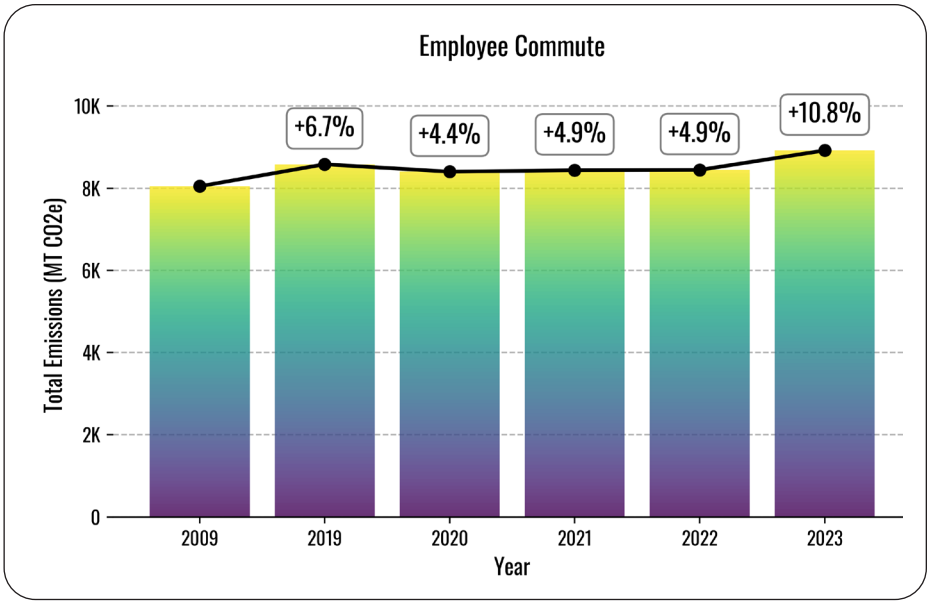

FIGURE 68: EMPLOYEE COMMUTE EMISSIONS AND CHANGES RELATIVE TO THE 2009 BASELINE.

SOLID WASTE

Solid Waste emissions from municipal disposal have risen by 30.8% between 2009 and 2023. Figure 69 shows the trend in solid waste emissions with changes relative to the 2009 baseline. This emission category was calculated based on employment figures from the city, and more information can be found in Appendix B.

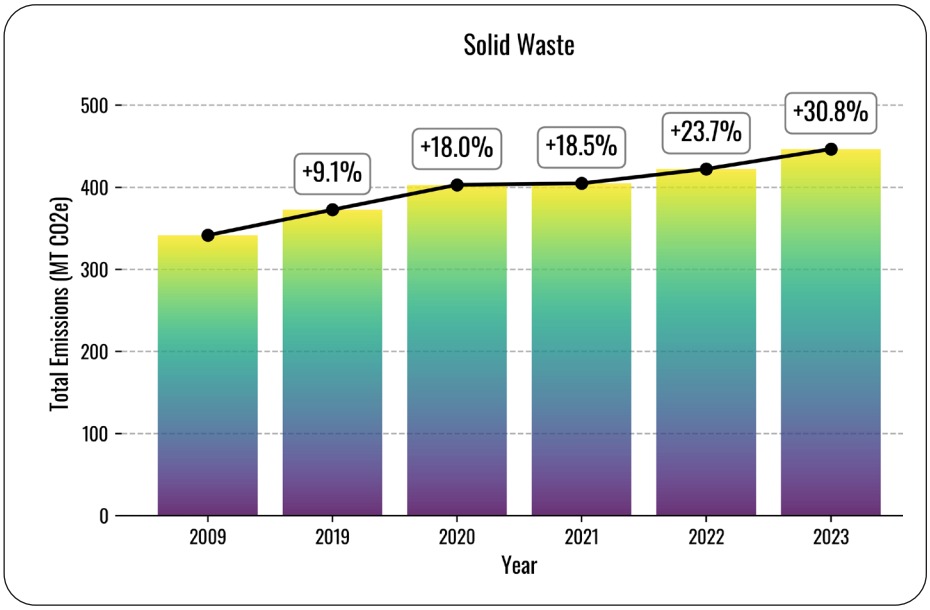

FIGURE 69: SOLID WASTE EMISSIONS AND CHANGES RELATIVE TO THE 2009 BASELINE.

WATER AND SEWER

Electricity

Waste and Sewer grid electricity use decreased by 18.7% in 2023 in relation to the baseline year of 2009. This sector is also influenced by the changing emission factor that other municipal sources rely on. Figure 70 shows the municipal water and sewer electricity emissions within the sample period accompanied by changes relative to the 2009 baseline.

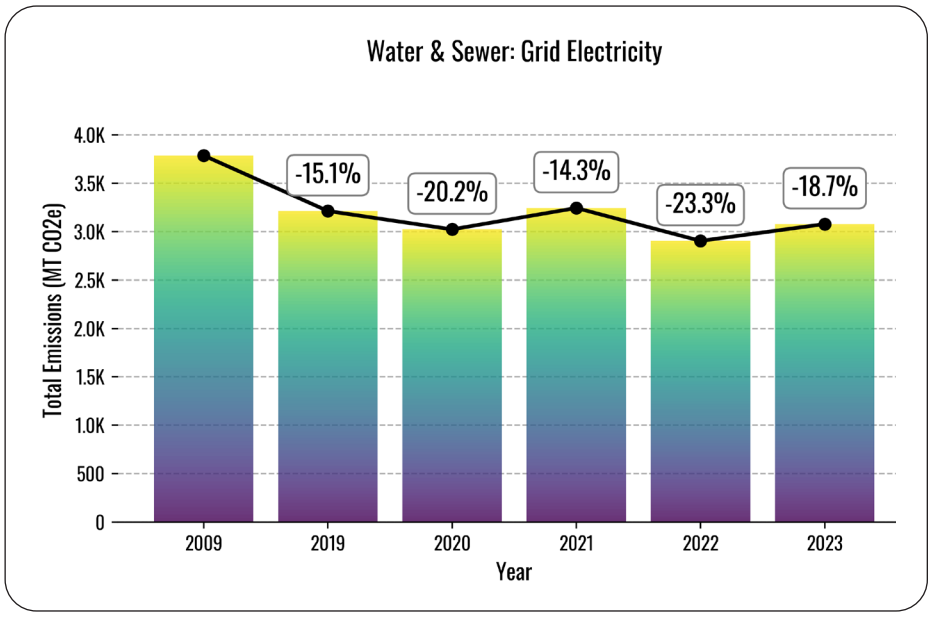

FIGURE 70: WATER AND SEWER GRID ELECTRICITY EMISSIONS AND CHANGES RELATIVE TO THE 2009 BASELINE.

Natural Gas

The emissions from Water and Sewer natural gas combustion have fluctuated over the years. Emissions from this source peaked in 2020 and declined after. This resulted in an 18.7% increase in emissions by 2023 as compared to a 2009 baseline. This trend can be observed in Figure 71 with changes relative to the 2009 baseline.

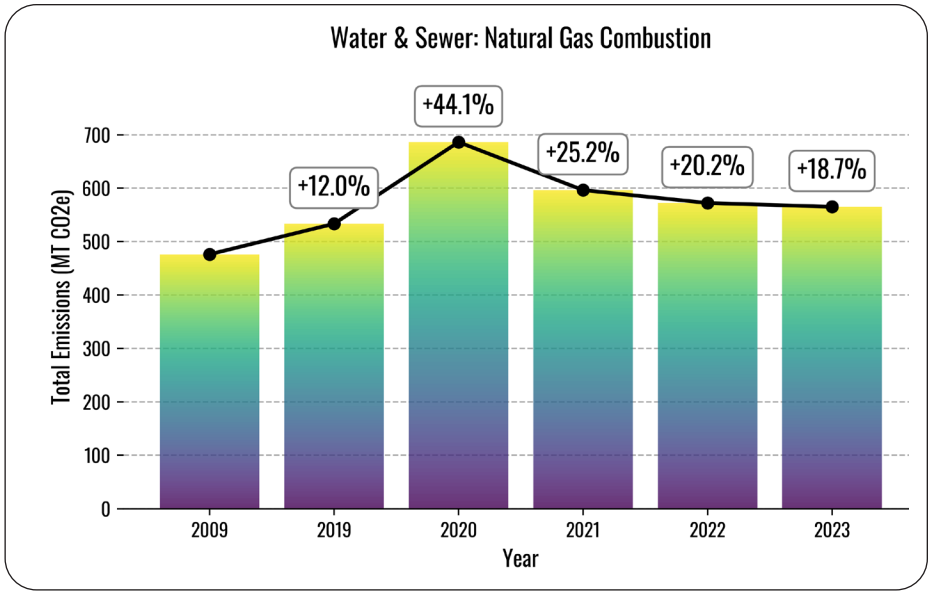

FIGURE 71: WATER AND SEWER NATURAL GAS EMISSIONS AND CHANGES RELATIVE TO THE 2009 BASELINE.

Propane

Although no emissions were reported for 2009 and 2019 from propane use in the Water and Sewer sector, this sector has increased from 2020 to 2023. Although the rise in emissions seems significant, this source only accounts for 0.05% of municipal emissions in 2023.

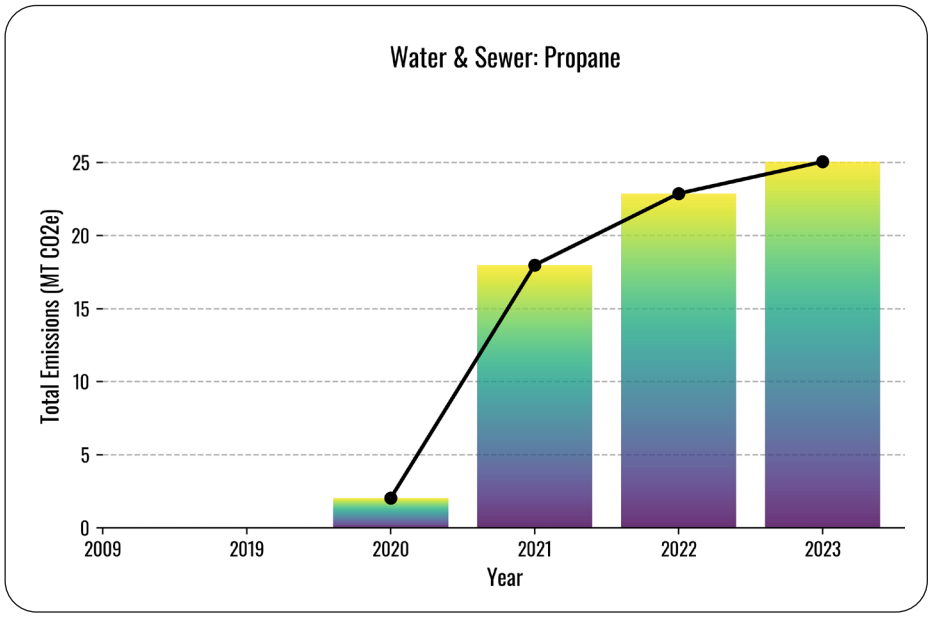

FIGURE 72: ANNUAL EMISSIONS FROM WATER AND SEWER PROPANE USE (NO 2009 BASELINE FOR COMPARISON)

Diesel from stationary energy

Diesel from **stationary energy** in the Water and Sewer sector was only tracked for one year in 2009. Afterwards there are no reported emissions from this source.

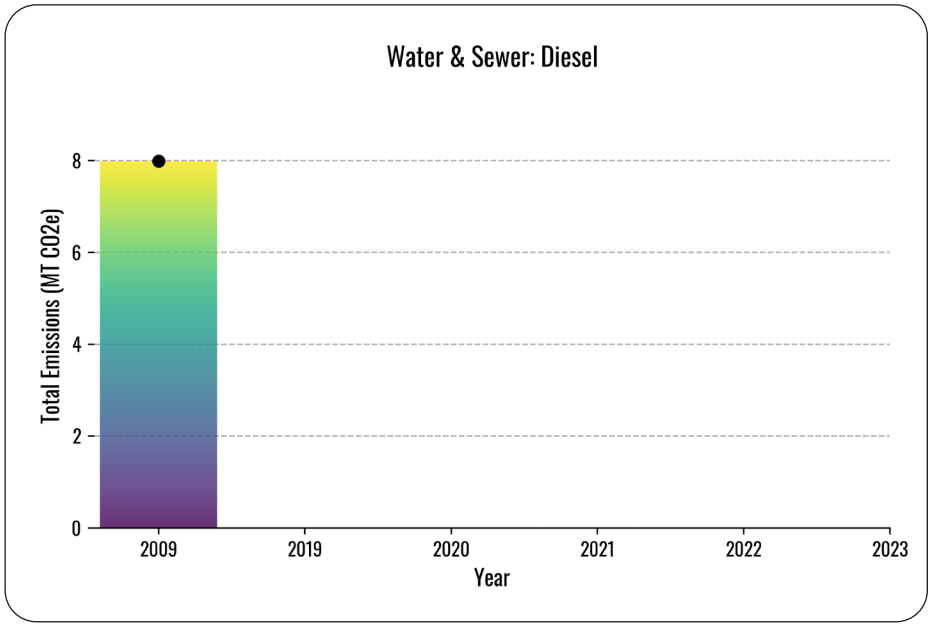

FIGURE 73: ANNUAL EMISSIONS FROM WATER AND SEWER DIESEL USE (ONLY USED IN 2009)

Fuel Oil

The emissions from Water and Sewer fuel oil usage show a fluctuating trend over the years. This resulted in a 47.3% reduction in emissions from this source by 2023. Figure 74 shows the emissions from water and sewer fuel oil along with percentage changes relative to the 2009 baseline.

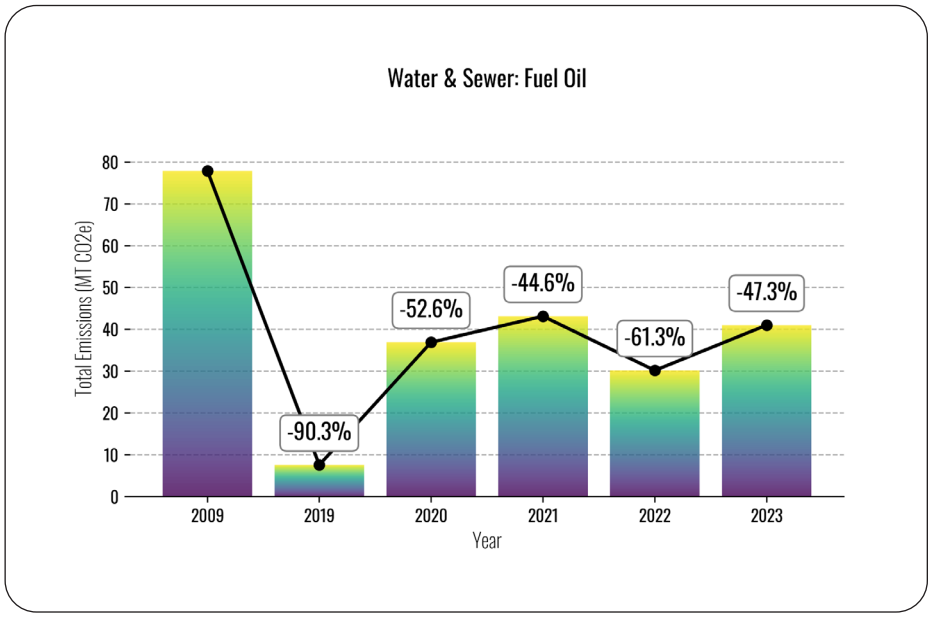

FIGURE 74: WATER AND SEWER FUEL OIL EMISSIONS AND CHANGES RELATIVE TO THE 2009 BASELINE.

LOOKING TOWARDS 2045

The City *of*
WORCESTER

LOOKING TOWARDS 2045

Straight-Line Projection (2024-2045)

Utilizing a simple linear regression analysis based on historical emissions data from 2009 to 2023, we have forecasted emissions for the period spanning 2024 to 2045. This projection assumes a consistent rate of change in emissions over time. According to our analysis, emissions in Worcester are anticipated to decrease by approximately 23.5% by the year 2045, declining from 1.891 million tons of CO2e to 1.447 million tons of CO2e. Following the current trajectory of emission reductions, Worcester will not be able to meet its goals in the Green Worcester Plan by 2045. Figure 75 visualizes this community business as usual forecast between the sample years and 2045.

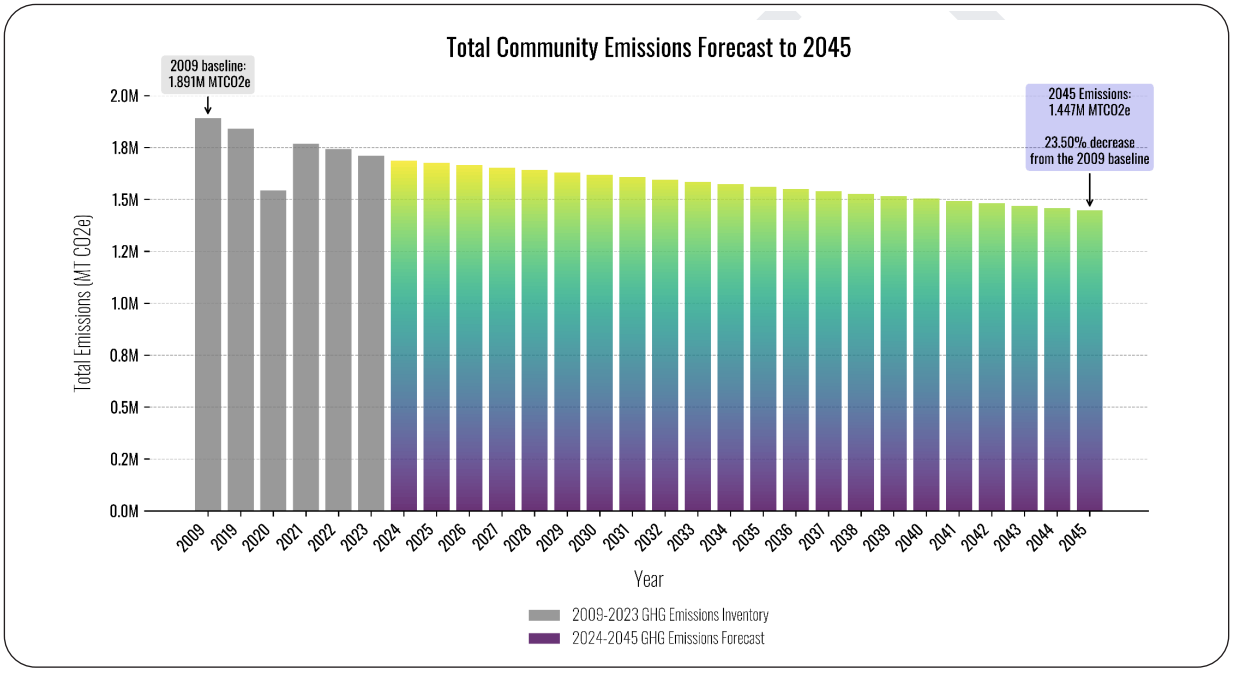

FIGURE 75: LINEAR FORECAST OF THE COMMUNITY GHG EMISSION REDUCTIONS TOWARDS 2045.

Another Business-as-Usual forecast was designed for the municipal operation inventory as well. This forecast also used the historical data from 2009 to 2023 and projected an estimated emissions to a mid-term target year of 2030 and a horizon year of 2050. By 2030 emissions are projected to decrease by approximately 26.5% to 41,840 MT CO2e and by 2045 emissions are projected to decrease by 46.4% to around 30,500 MT CO2e. Figure 76 shows the modeled municipal business as usual scenario between the target years in color, and the sample years shown in gray.

LOOKING TOWARDS 2045

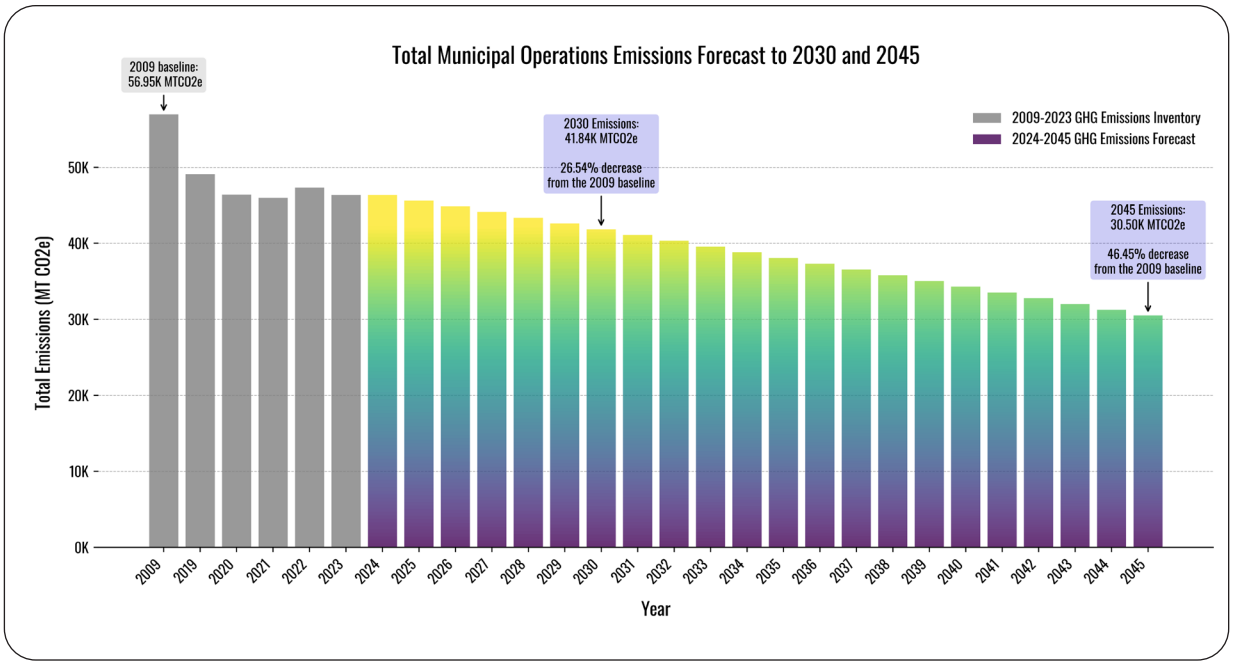

FIGURE 76: LINEAR FORECAST OF THE MUNICIPAL GHG EMISSION REDUCTIONS TOWARDS 2045.

Implications and Considerations

The projected emissions data provides insight into potential future trends in GHG emissions for the City of Worcester. While this linear projection offers a simplified perspective, it is essential to consider that actual emissions may vary due to factors such as changes in population, economic growth, technological advancements, policy interventions, and climate impacts. This does not include projected increases in renewable energy procurement or building electrification.

As we look towards 2045, it is imperative to continue monitoring and managing emissions effectively, implementing strategies and initiatives aimed at reducing emissions and promoting sustainability. By leveraging the insights gained from historical data and projections, the City can develop informed action plans to mitigate climate change impacts and work towards a more resilient and sustainable future.

GREENHOUSE GAS INVENTORY GREENHOUSE GAS INVENTORY GREENHOUSE