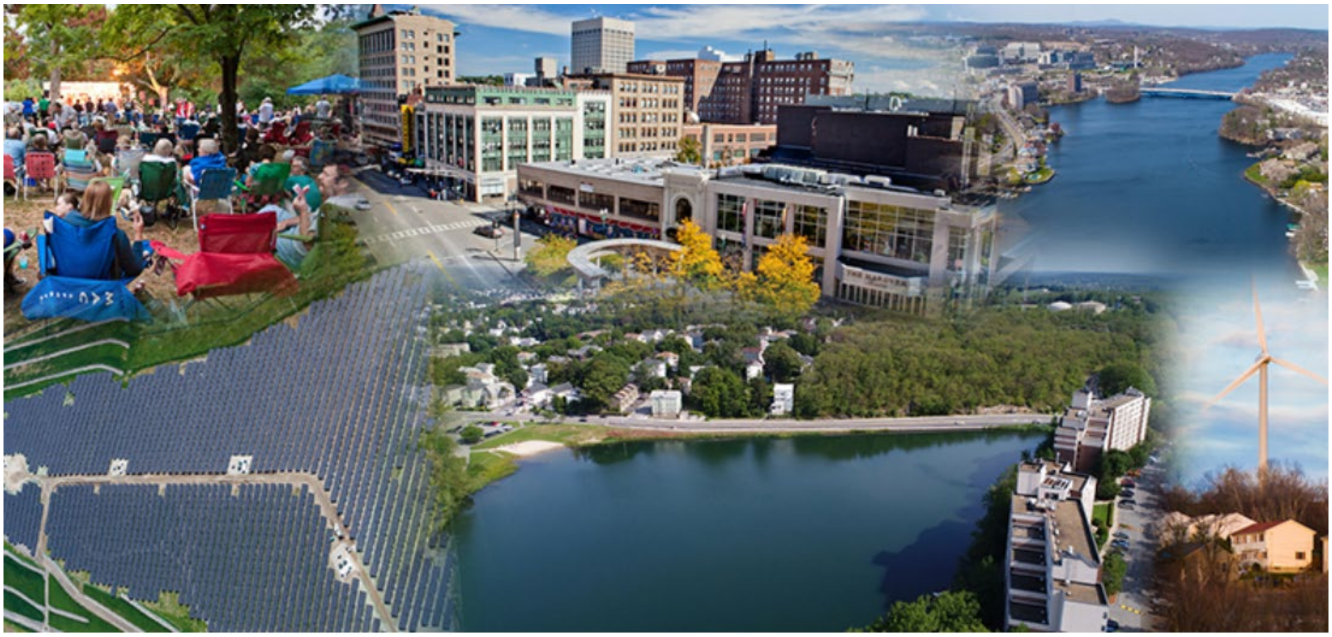


City of Worcester 2009 & 2019 **Inventories** of the Community and Municipal **Greenhouse Gas Emissions**

August 2022

CITY OF WORCESTER, MASSACHUSETTS
DEPARTMENT OF SUSTAINABILITY & RESILIENCE
Authored by: Kim Lundgren Associates, Inc.

Contents

ACRONYMS

CH_4: Methane

CO_2: Carbon Dioxide

GHG: Greenhouse Gas

GWP: Global Warming Potential

$MTCO_2e$: Metric Tons of Carbon Dioxide Equivalent

MMBtu: Metric Million British Thermal Unit

N_2O: Nitrous Oxide

VMT: Vehicle Miles Traveled

EXECUTIVE SUMMARY

This report summarizes the City of Worcester's 2009 and 2019 greenhouse gas (GHG) emissions for community activities and municipal operations to better understand key sources of emissions and drive action towards the highest mitigation opportunities.

The City of Worcester completed its 2009 and 2019 Community and Municipal Greenhouse Gas (GHG) Inventories.

The purpose of this effort was to advance the City towards the Green Worcester Plan's goal (III-1) of eliminating 100% of GHG emissions citywide.

This Inventory reports emission estimates in a format compliant with generally accepted guidance and reporting requirements such as the Local Government Operation Protocol, CDP, and the Global Covenant of Mayors. The year 2009 was chosen as the baseline and 2019 was chosen because it was the last complete year of "normal" activities before the pandemic impacted the daily lives of city residents, Worcester's municipal operations, and all associated emissions. 2020 and 2021 reports will be completed once all 2021 data is available.

The highest sources of emissions from both Worcester's community activities and municipal operations were found to be the energy used in buildings and the fossil fuels burned for transportation. 92% of community-scale GHG emissions come from buildings and transportation. Natural gas use in buildings is growing, as the number of buildings increase and existing buildings switch from fuel oil. Transportation demand is also rising, aligning with state and national trends, however, transit is growing at a faster pace than private vehicles in Worcester. Other sources of emissions include waste generation, off-road transportation, wastewater treatment, and energy use for water treatment and delivery.

Between 2009 and 2019, the emissions from Worcester's community activities decreased by 3% and those from Worcester's municipal operations decreased by 16%, demonstrating Worcester's commitment to sustainability as well as the limitations of the government's direct influence over community activities. The City can directly influence its own operations and therefore its emissions, however its impact on the community is limited to the success of policies, incentives, and education. For reference, municipal operations represent approximately 2.5% of community emissions.

Figure 1: Worcester's Community & Municipal Emissions by Sector, 2019 (MTCO2e, Metric Tons of Carbon Dioxide Equivalent)

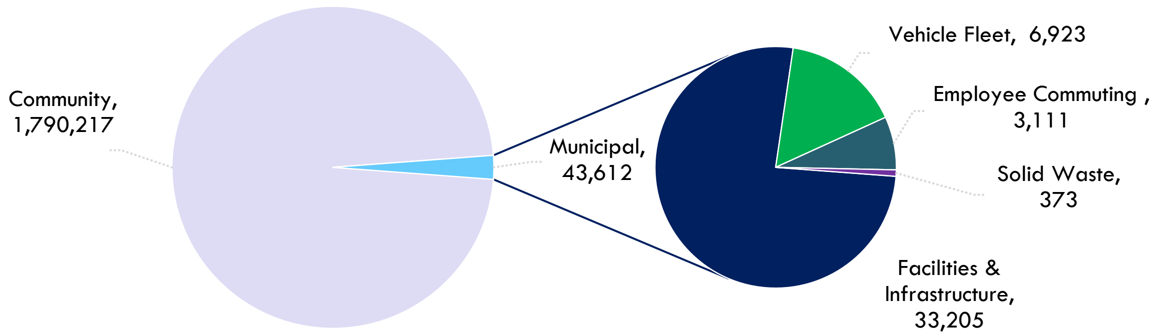


Figure 2: Worcester Community Emissions by Sector (highest 4), 2019

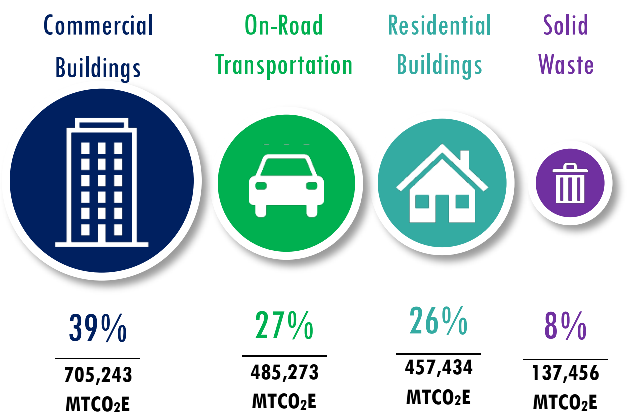


Figure 3: Worcester Municipal Emissions by Sector (highest 4), 2019

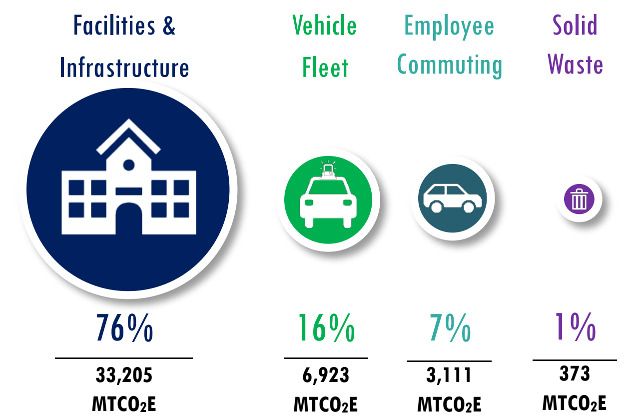


Figure 4: Worcester Community Emissions by Source (highest 4), 2019

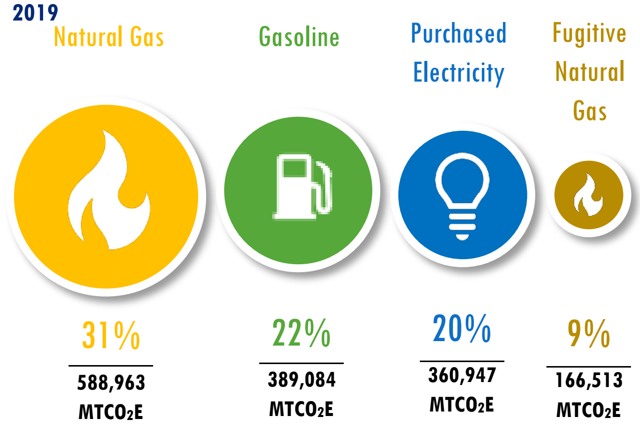
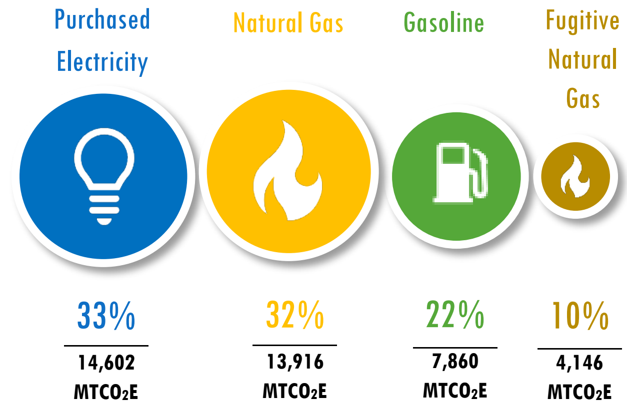


Figure 5: Worcester Municipal Emissions by Source (highest 4), 2019



Community and Municipal Emissions: All Data Tables

City of Worcester Community GHG Emissions Trends, 2009 & 2019 (MTCO2e)

GHG Emissions Source	2009	2019	Change over Time
Residential Buildings	**492,659**	**457,434**	**-7%**
Electricity	161,448	120,288	-25%
Natural Gas	192,760	209,346	9%
Fugitive Natural Gas	57,422	62,363	9%
Oil	79,299	63,708	-20%
Propane	1,729	1,729	0%
Commercial Buildings	**782,031**	**705,243**	**-10%**
Electricity	383,587	238,758	-38%
Natural Gas	297,536	349,617	18%
Fugitive Natural Gas	88,635	104,150	18%
Oil	12,272	12,718	4%
On-Road Transportation	**414,446**	**485,273**	**17%**
Gasoline	333,382	389,084	17%
Diesel	75,723	90,720	20%
Electric	N/A	401	N/A
Transit	5,341	5,068	-5%
Off-Road Transportation	**3,791**	**5,247**	**38%**
Commuter Rail	1,580	2,150	36%
Aviation	2,211	3,098	40%
Solid Waste	**150,241**	**137,456**	**-9%**
MSW Incinerated	99,511	107,049	8%
Landfill Waste in Place	46,777	26,454	-43%
Yard Waste	3,954	3,954	0%
Water Treatment and Delivery	**2,180**	**1,501**	**-31%**
Wastewater Treatment	**1,529**	**1,566**	**2%**
Total	**1,846,877**	**1,793,719**	**-3%**

Worcester Municipal GHG Emissions Trends, 2009 & 2019 (MTCO2e)

GHG Emissions Source	2009	2019	Change over Time
Municipal Buildings	**38,088**	**31,843**	**-16%**
Natural gas	14,245	13,916	-2%
Electricity	17,833	13,239	-26%
Fuel Oil No.2	1,759	539	-69%
Diesel	8	3	-63%
Fugitive Natural Gas	4,244	4,146	-2%
Streetlights and Traffic Signals	**3,441**	**1,362**	**-60%**
Electricity	3,441	1,362	-60%
Vehicle Fleet	**7,034**	**6,923**	**-2%**
Gasoline	4,541	4,749	5%
Diesel	2,492	2,174	-13%
Employee Commuting	**3,104**	**3,111**	**0%**
Gasoline	3,104	3,111	0%
Solid Waste	**342**	**373**	**9%**
Waste Incinerated	342	373	9%
Total	**52,008**	**43,612**	**-16%**

INTRODUCTION

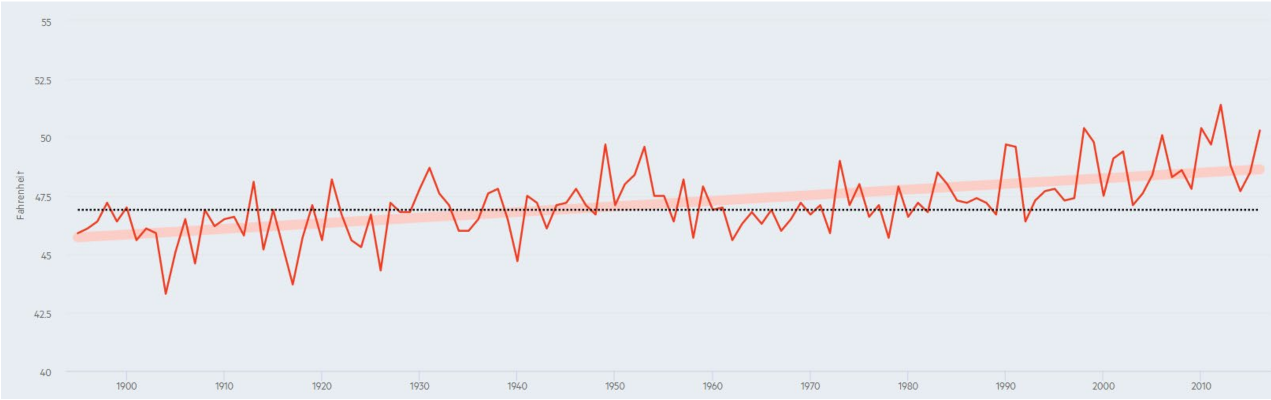
This report was developed for the Department of Sustainability and Resilience within the City of Worcester, Massachusetts in support of the City's commitment to sustainability.

The Worcester Department of Sustainability and Resilience aims to achieve ambitious climate goals as part of the Green Worcester Sustainability and Resilience Strategic Plan, which was accepted by City Council on April 27, 2021. The Green Worcester Plan is Worcester's roadmap to becoming the greenest mid-size city in the country. The City of Worcester developed a greenhouse gas (GHG) inventory to advance toward the Green Worcester Plan goal (III-1) of eliminating 100% of GHG emissions citywide. This inventory helps to evaluate and prioritize the sources of emissions with the greatest potential impact, as well as provides a point of reference for evaluating emissions reduction progress going forward.

Our atmosphere contains a mix of many different types of gases, including the oxygen we breath and water vapor which condenses to clouds and rain. Greenhouse gases are compounds that trap heat and historically having a steady balance of these gases helped regulate the Earth's temperature at a steady average. We have tipped that balance by releasing ever-increasing amounts of GHGs primarily through the burning of fossil fuels (like natural gas, coal, and gasoline) but also from waste management and industrial processes. As the level of GHGs in the atmosphere increases, the heat that would normally escape into space is trapped and reflected to earth, amplifying the "*Greenhouse Effect*." It has caused an increase in the global average temperature that we can see here in Massachusetts and Worcester, driving many extreme weather events as documented in the Worcester Municipal Vulnerability Preparedness Plan[1]. While the city is taking steps to reduce those vulnerabilities, we must also work to address the root causes of climate change.

This GHG emissions inventory report covers calendar years 2009 and 2019. By focusing on these two years, we can begin to look at our trends in the decade from when the City of Worcester took early steps to reduce emissions from its operations as well as throughout the community. This inventory includes the three primary GHGs—carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), with the results organized by sector and source. GHGs are typically reported in units of CO_2 equivalents, or CO_2e. This accounting convention normalizes the relative amount of warming produced by different gases with the use of global warming potential (GWP) multipliers. For the non-CO_2 gases, CH_4 and N_2O, calculations use GWP values from the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report assessed over a 100-year time horizon.

Figure 6. Annual Temperature Average in Massachusetts, 1900-2010

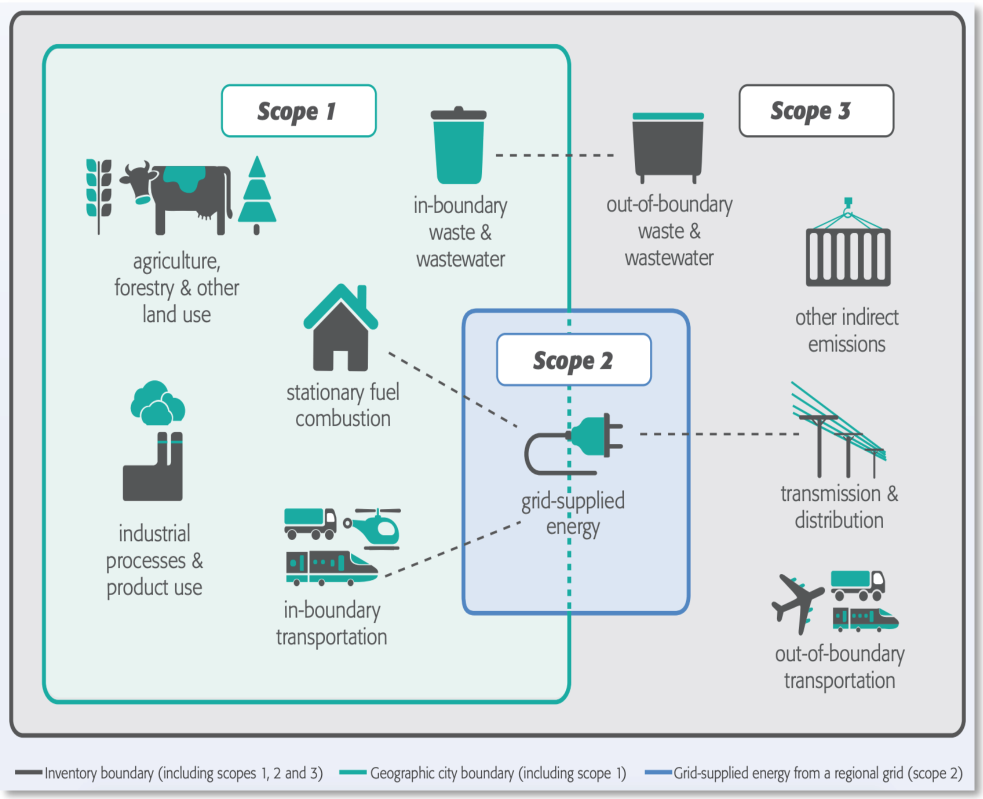


Source: Northeast Regional Climate Center

[1] City of Worcester Municipal Vulnerability Preparedness Plan. 2019. www.worcesterenergy.org/leading-by-example/resilient-worcester/mvp

Calculations in this inventory were guided by the Local Government Operations Protocol for municipal sources, as well as the US Community Protocol and Global Protocol for Community Scale Emissions Inventories. Together these resouces help to define the scope of the assessment and accounting framework that is consistent with local government and community climate action planning throughout the nation and globe. For example, by adehering to the Scopes Framework illsutrated below, Worcester's emissions and efforts to reduce them can be more easily aggregated with the collective efforts of all communities who are acting on climate.

Figure 7: GHG Inventory Scope Diagram, GPC



The City of Worcester includes emission estimates for Scope 1 and 2 sources and partial Scope 3.

Scope 1 includes sources that occur within our boundary, like direct **fossil fuel combustion.**

Scope 2 includes **purchased electricity** that is consumed in boundary but generated throughout the region.

Scope 3 emissions include emissions out of our boundary like **waste & wastewater treatment.**

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

The data used to generate regional GHG emissions estimates were drawn from local and national sources that capture and report activity data from multiple sectors across the City. For more information about specific data sources, please refer to the Methodology section at the end of this report.

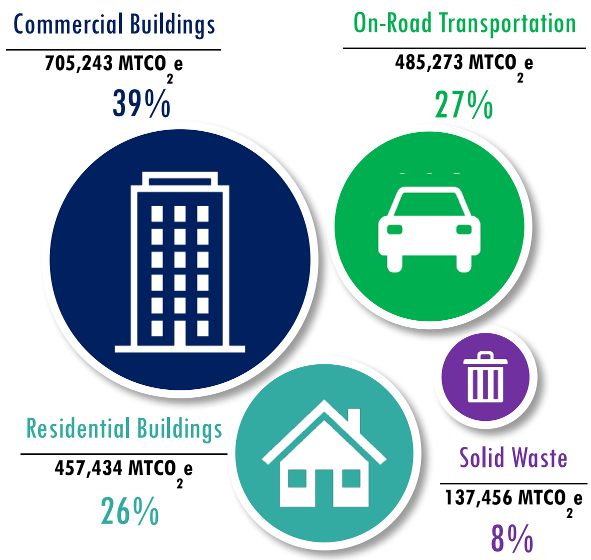
COMMUNITY GHG EMISSIONS

The community GHG emissions data was generated from community activities that take place within the geographic boundary of the City of Worcester. These activities include residential and commercial buildings' energy use (including municipal buildings), public and personal transportation, and waste disposal, among others.

Overview

In 2019, the City of Worcester's community activities generated 1,793,719 ($MTCO_2e$), which is 3% lower than its overall emissions 2009: 1,846,877 $MTCO_2e$.

Figure 8: City of Worcester Community Emission by Sector, 2019



Less than 1% of emissions stem from other sources such as off-road transportation, wastewater treatment, and energy use for water treatment and delivery.

GHG inventories can be performed at many different levels, ranging from national to state level, corporate-wide, even down to a personal household inventory. Inventories developed at different scales present information in a variety of different formats due to variations in data collection, reporting requirements, and inventory guidance. The inventories may also emphasize different aspects of the GHG accounting process or results according to the participant's ability to reduce emissions.

Community scale inventories are a unique mix of approaches most relevant to informing local action. For example, state and community inventories treat on-road traffic similarly; however, communities account for GHGs associated with building electricity usage instead of focusing on power plants. This approach maintains a focus on the value of energy conservation, which all community members can participate in. These are important differences to keep in mind when comparing the results of different types of inventories.

Community Trends

Community activities change over time and therefore the GHG emissions associated with those activities change as well. According to the U.S. Census Bureau, the City of Worcester grew by 2 percent, or 4,383 people between 2009 and 2019.

Despite this growth, estimated GHG emissions decreased by 3%, or 53,158 $MTCO_2e$. Worcester's emissions per capita decreased 5% from 10.2 $MTCO_2e$/person to 9.6 $MTCO_2e$/person. It must be noted that although overall emissions decreased, emissions associated with transportation increased by 16% and 38% for on-road and off-road transportation, respectively.

Figure 9: Worcester Community GHG Indicators, 2009 to 2019

Overall GHG Emissions ($MTCO_2e$)

2009	1,846,877
2019	1,790,217

↓ 3%

Residential Emissions Intensity ($MTCO_2e$ per household)

2009	7.2
2019	6.4

↓ 12%

Light-Duty Vehicle Miles Traveled (VMT per Capita)

2009	4,429
2019	5,181

↑ 17%

Residential Energy Intensity (MMBtu per household)

2009	91
2019	87

↓ 4%

Waste per capita (Lbs. per person)

2009	479
2019	466

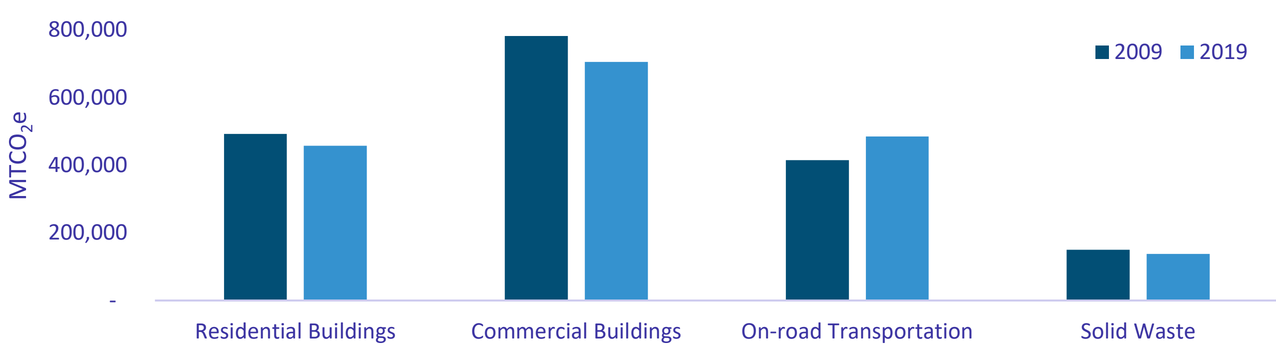
↓ 3%

Commercial Energy Use (Millions MMBTU)

2009	9.2
2019	9.6

↑ 4%

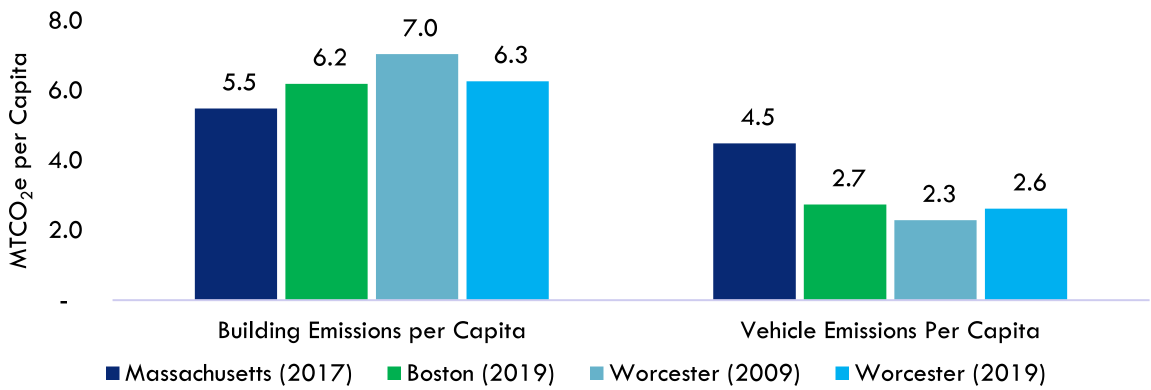
Figure 10: Worcester Community GHG Emissions Trends, 2009 & 2019



Comparing emissions intensity of different areas can illustrate the challenges and opportunities that cities have when it comes to addressing climate change. The City of Worcester's emissions intensity in 2019 was 9.7 $MTCO_2e$/person. This was lower than that of the 2017 value for the State of Massachusetts[2] of 10.6, but slightly higher than that of the City of Boston's[3] in 2019, 9.2 MTCO2e/person. Figure 11 illustrates a comparison across Worcester, Boston, and the State of Massachusetts for energy used in buildings from electricity and other fuels. Urban areas like Worcester and Boston have a higher concentration of commercial structures and building energy use relative to their population than the State average.

Within transportation, there may be overall more traffic in urban areas, but due to transit and density, the rates per-capita are lower compared to the state as a whole. We might expect that Boston would have lower vehicle emissions due with high transit ridership on the subway, but it may be offset by the overall larger number of people traveling to the City each day as compared to Worcester.

Figure 11: Worcester Community GHG Emissions Intensity Benchmarks, 2009 & 2019



How much is 1,793,719 Tons of CO_2?

Comparisons to peers are useful for understanding how well we are doing compared to others, but other kinds of equivalencies illustrate the physical quantity of emissions we generate. While our GHGs come from all kinds of sources, 1.793 million tons of CO2 is the same as 9,904 railcars full of coal. That would be a train that stretches from Worcester to Boston over 2 and half times!

Another common measure of carbon is how much is stored in trees. It would take over 29 million newly planted seedlings growing for 10 years to capture that quantity of emissions. A mature forest roughly 1/3 the size of Massachusetts could capture that much carbon in a single year.

Equivalencies calculated with US EPA GHG Equivalencies Calculator: https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

[2] Calculated from Massachusetts Annual GHG Inventory 1990-2017 Appendix C. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

[3] Calculated from City of Boston 2005-2019 GHG Inventory Report. https://www.boston.gov/sites/default/files/file/2021/10/City%20of%20Boston%202005-2019%20GHG%20Inventory%20Report.pdf

BUILDINGS

The GHG emissions presented in this sector were generated from the energy use in residential and commercial buildings within the geographic boundary of the City of Worcester.

Overview

Figure 12: Buildings Emissions (as part of the Total Emissions), 2019 (%)

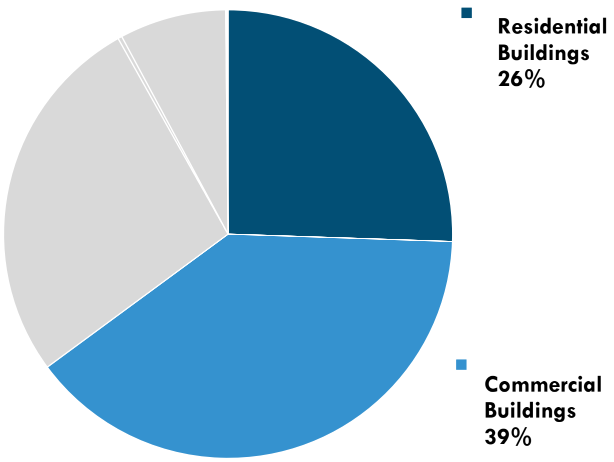
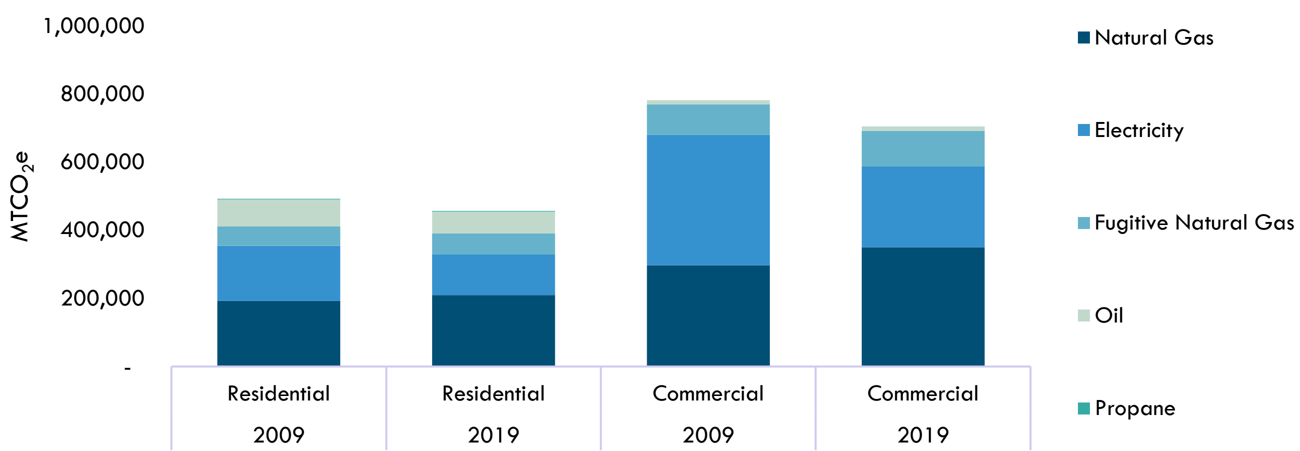


Table 1: Building Emissions, 2009 & 2019 ($MTCO_2e$)

Year	Residential ($MTCO_2e$)	
2009	492,659	↓
2019	457,434	7%
Year	**Commercial ($MTCO_2e$)**	
2009	782,031	↓
2019	705,243	10%
Year	**Total Buildings ($MTCO_2e$)**	
2009	1,274,690	↓
2019	1,162,676	9%

Figure 13: Building Emissions by Source, 2019



Electricity

Worcester's electricity use decreased from 2009 to 2019, but GHGs fell much further due to the greater supply of clean energy stemming from the State Renewable Portfolio Standard requirements. Looking forward, we expect electricity use to increase as we electrify buildings' heating and our transportation system. Special attention may be needed to ensure that we can continue to track building electricity use separate from transportation to understand how these changes are progressing and adjust our reduction strategies in response.

Table 2: Building Electricity Emissions & Consumption, 2009 & 2019 (MTCO2e)

Year	Residential ($MTCO_2e$)		Commercial ($MTCO_2e$)		Total Buildings ($MTCO_2e$)	
2009	161,448	↓	383,587	↓	545,036	↓
2019	120,288	26%	238,758	38%	359,046	34%
Year	**Residential (MWH)**		**Commercial (MWH)**		**Total Buildings (MWH)**	
2009	426,880	↓	1,014,230	↓	1,441,110	↓
2019	415,778	3%	825,276	19%	1,241,055	14%

How is Renewable Energy accounted in the Inventory?

Renewable Portfolio Standard: Between 2009 and 2019, the electricity grid for the region became 33% less carbon intensive due to the increase in renewable energy generated and supplied to the grid. Due to the Massachusetts' Renewable Energy Portfolio Standard, our state is required to add 1-2% renewable energy into the grid fuel mix each year.

Electricity Aggregation Program: In 2020, Worcester launched a Municipal Electricity Aggregation Program, which doubled the amount of renewable energy in the electricity supply above state-mandated amount for residents and businesses of the City. Therefore, future updates to the GHG inventories will reflect the significant reductions in building related emissions caused by the Program.

Emission Factors: This inventory uses the CO_2 emissions factor provided by the ISO New England Electric Generator Air Emissions Report and for completeness, the CH_4 and N_2O emission factors from the U.S. EPA eGRID program. The ISO New England territory is smaller than the eGRID region and thus better represents the generation mix that is influenced by State level policy.

Natural Gas

Table 3: Building Natural Gas Emissions, 2009-2019 (MTCO2e)

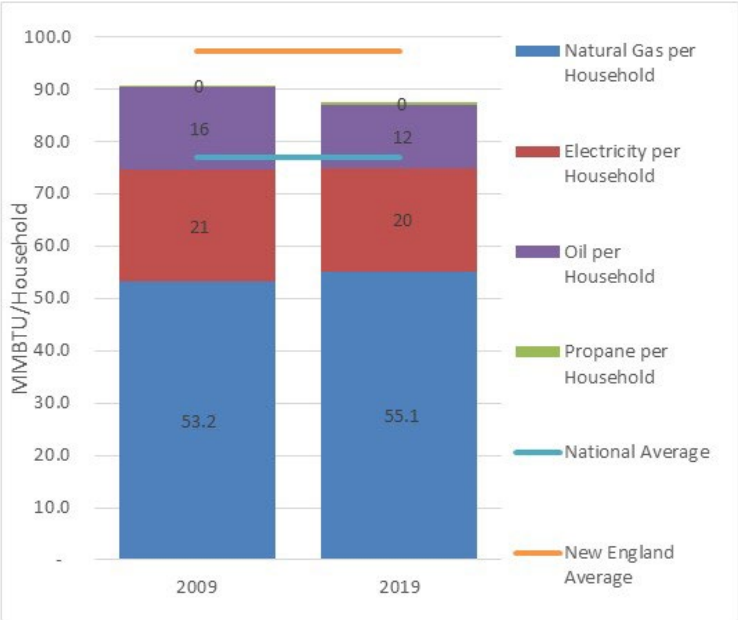
Year	Residential ($MTCO_2e$)		Commercial ($MTCO_2e$)		Total Buildings ($MTCO_2e$)	
2009	192,760	↑	297,536	↑	490,296	↑
2019	209,346	9%	349,617	18%	558,963	14%

While electricity consumption and emissions have decreased, natural gas emissions increased by 9% in the residential sector and 18% in the commercial sector. This increased natural gas' share of GHGs from 39% to 46% in the residential sector and 38% to 50% in the commercial sector. When normalized by the number of households, natural gas was the only energy use type to increase between 2009 and 2019, observing a 4% increase from 53.2 MMBTU per household to 55.1 MMBTU per household. Over the same period, electricity user per household decreased by 7%.

Residential Sector

Overall, the number of houses in Worcester increased by 5% from 2009 and 2019 and total energy use in homes increased by 1%. Energy use per household, however, decreased by 4% from 90.8 to 87.3 MMBTU per Household, likely due to advances in buildings' energy efficiency as well as compliance of new homes built since 2009 with the Building Stretch Code, a voluntarily adopted code by the city as part of its Green Community Designation to make new homes more energy efficient.

Figure 14: Residential Energy Use per Household, 2009 & 2019



Average for a Single Family Detached Home (MMBtu per Household)

U.S.	New England
77.1	97.3

EIA Residential Energy Consumption Survey, 2015.
https://www.eia.gov/consumption/residential/data/2015/

Weather Normalization

Weather can often make it difficult when comparing energy use during separate years.

Data limitations prevent a community-wide weather normalization. What we do know is that there were fewer heating degree days and more cooling degree days in 2019 as compared to 2009[1]. These forces would have put pressure in opposite directions from the usage trends observed.

TRANSPORTATION

The GHG emissions presented in this sector gathered data for personal and commercial vehicle use, public transportation, aviation, and freight hauling within the geographic boundary of the City.

Overview

Figure 15: Transportation Emissions (as part of the Total Emissions), 2019

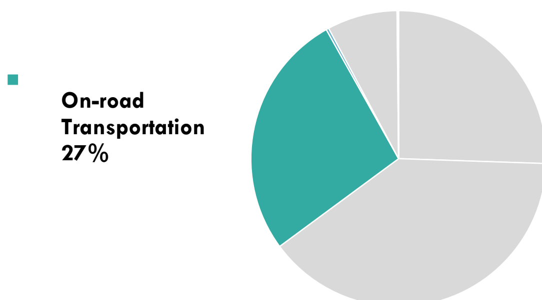


Table 4: Transportation Emissions, 2009-2019

Year	On-Road ($MTCO_2e$)	
2009	414,446	↑
2019	485,273	17%
Year	**Off-Road ($MTCO_2e$)**	
2009	3,791	↑
2019	5,247	38%
Year	**Total Transportation ($MTCO_2e$)**	
2009	418,237	↑
2019	490,520	17%

Transportation demand has increased across all modes which is consistent with national trends. A positive trend for Worcester is that transit use has been growing at a faster pace than private vehicles. In addition, private transportation is beginning to shift to electric vehicles which currently emit roughly 1/4 of the GHGs as compared to the combustion powered vehicles. This difference will continue to widen as electricity becomes even cleaner.

Figure 16: Carbon Intensity of Travel Modes

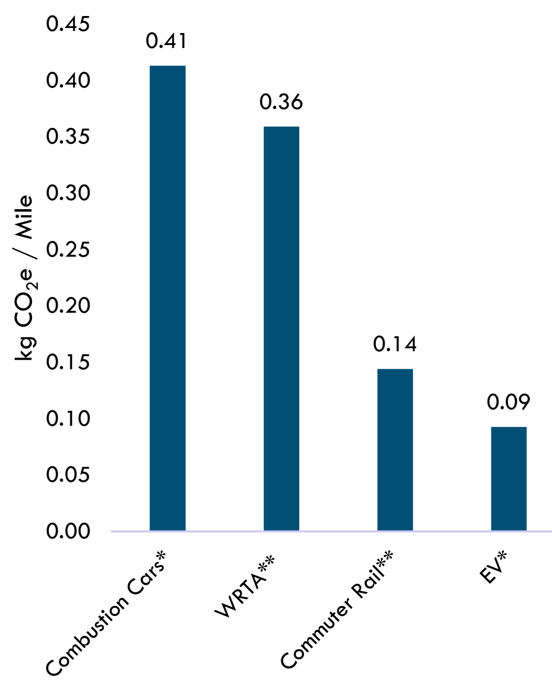


Table 5: Worcester Miles Traveled, 2009 & 2019

Mode	2009	2019	% Increase
Passenger Vehicles*	801,849,627	943,133,515	18%
Heavy Duty Trucks*	45,771,543	54,837,063	20%
Electric Vehicles *	0	13,201,515	N/A
WRTA Bus**	9,611,835	14,111,090	47%
Commuter Rail**	10,963,368	14,916,616	36%

**Vehicle Miles*
***Passenger Miles*

WASTE, WASTEWATER TREATMENT, & WATER DELIVERY

The GHG emissions data presented in this sector was generated from residential and commercial solid waste disposal, wastewater treatment, and water treatment & delivery within the geographic boundary of the City of Worcester.

Overview

Figure 2: Other Emissions (as part of the Total Emissions), 2019

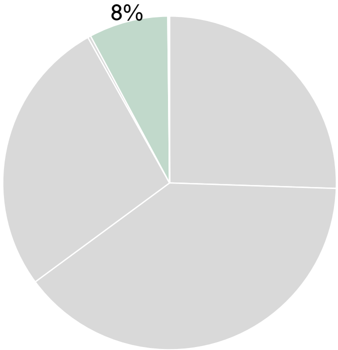


Table 6: Other Emissions, 2009-2019

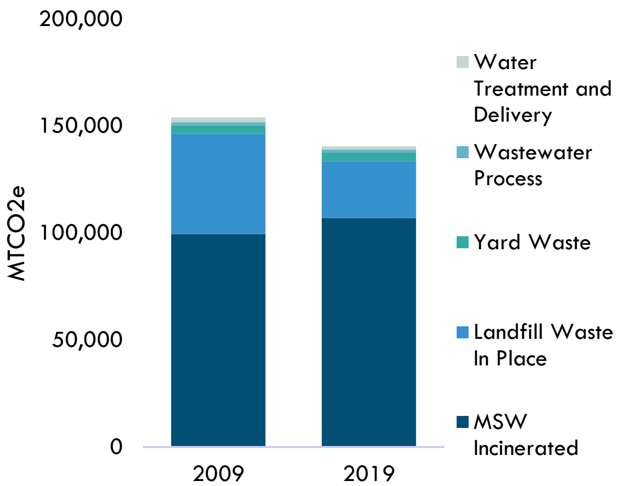
Year	Waste ($MTCO_2e$)	
2009	150,241	↓ 9%
2019	137,456	
Year	**Wastewater ($MTCO_2e$)**	
2009	1,529	↑ 2%
2019	1,566	
Year	**Water Treatment & Delivery ($MTCO_2e$)**	
2009	2,180	↓ 31%
2019	1,501	

Solid waste emissions are generated from the disposal and incineration of solid waste, the emissions from the closed Greenwood Street Landfill, and composting yard waste.

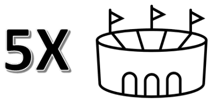
Wastewater emissions are generated from the chemical processes to clean and discharge wastewater that take place at the Upper Blackstone Clean Water wastewater treatment plant.

Lastly emissions from water treatment and delivery are generated by the energy, typically electricity, used to move and supply drinking water to residents and businesses within the city.

Figure 18: Emissions from Waste & Water Activities, 2009 & 2019



In 2019, Worcester generated enough solid waste to fill the DCU Arena more than 5 times.



MUNICIPAL GHG EMISSIONS

The GHG emissions presented in this sector were generated from all municipal operations within the City of Worcester. These activities include 90+ governmental buildings' energy use, municipal vehicle fleet use, employee commuting, and waste disposal from the government buildings.

Overview

Figure 19: Worcester Municipal Emissions as a Portion of the Community Emissions, 2019

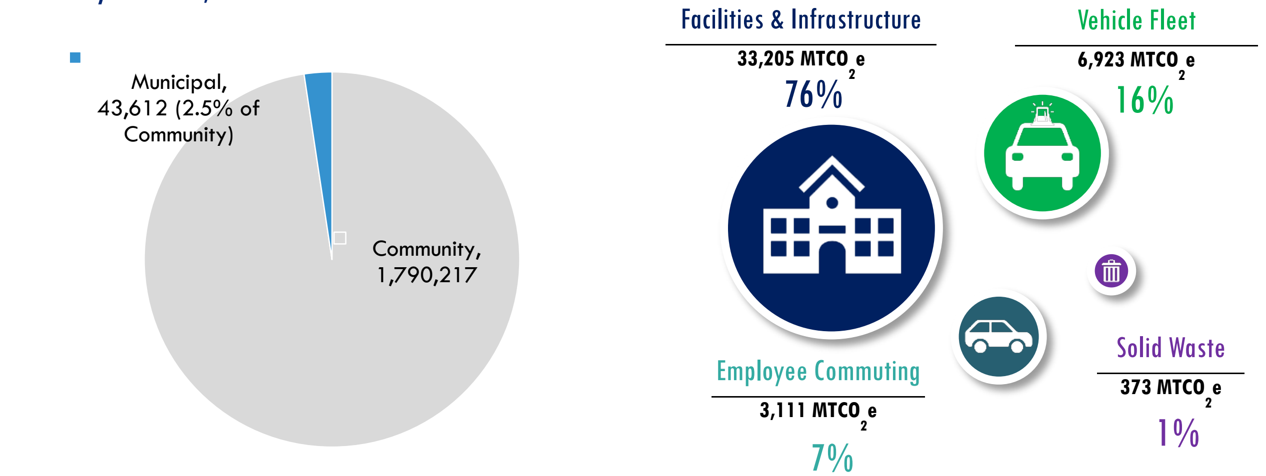
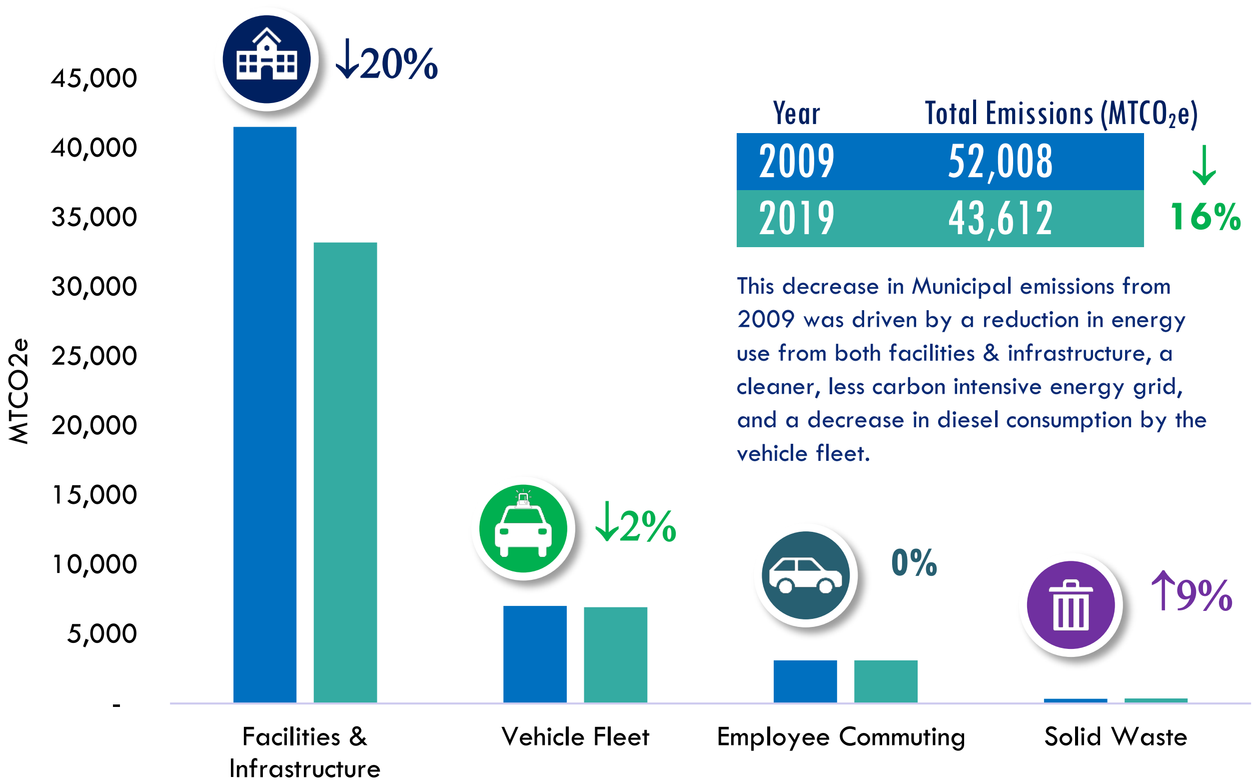


Figure 20: Worcester Municipal Emissions by Sector, 2009 & 2019 (MTCO2e)



Year	Total Emissions ($MTCO_2e$)
2009	52,008
2019	43,612

↓ 16%

This decrease in Municipal emissions from 2009 was driven by a reduction in energy use from both facilities & infrastructure, a cleaner, less carbon intensive energy grid, and a decrease in diesel consumption by the vehicle fleet.

FACILITIES & INFRASTRUCTURE

The GHG emissions presented in this sector were generated from the energy used in Worcester's municipal buildings, water & sewer systems, streetlights & traffic signals, and open space facilities & infrastructure.

Overview

Figure 31: Municipal Facilities & Infrastructure Emissions, 2019

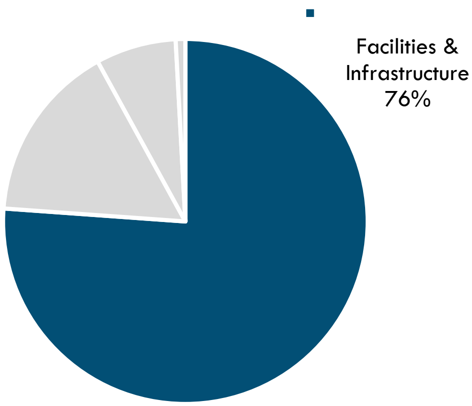
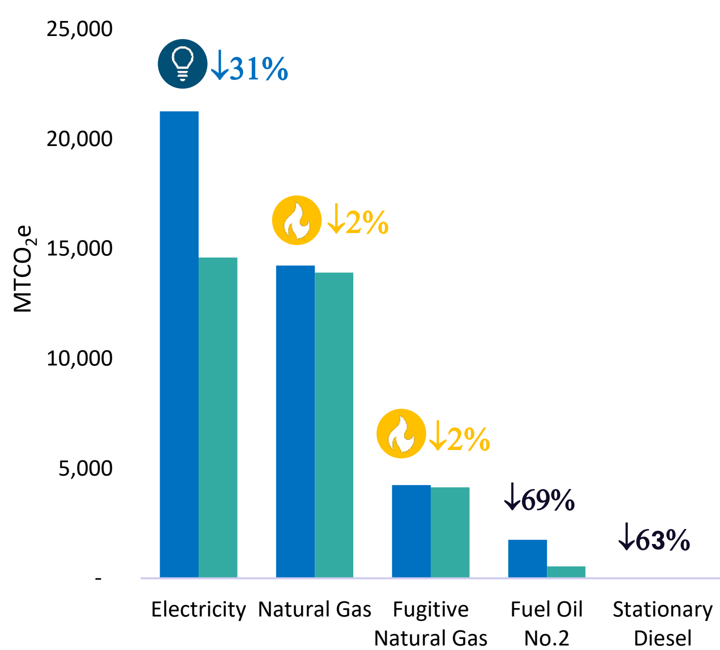


Table 7: Municipal Facilities & Infrastructure Emissions, 2009 & 2019

Sector	2009 $MTCO_2e$	2019 $MTCO_2e$	% Change
Municipal Buildings	32,444	26,668	↓18%
Water & Sewer	4,491	3,914	↓13%
Streetlights & Traffic Signals	3,441	1,362	↓60%
Open Space	1,153	1,261	↑9%

Figure 22: Municipal Facilities & Infrastructure Emissions by Source, 2009 & 2019



Leading by Example:

The City of Worcester has made a commitment to addressing its direct emissions from municipal operations through programs such as Worcester's Energy Savings Performance Contract, signed in 2011. Through this program, Worcester has:

- Replaced approximately 14,000 incandescent bulbs in streetlights to LEDs
- Implemented energy conservation measures (ECM)'s across 92 of the City's largest facilities
- Installed solar systems on public properties including Worchester's schools, water filtration plants, and the Greenwood Landfill. Together over their entire lifetime, these renewable energy projects have saved over 48 million kWh.

VEHICLE FLEET & EMPLOYEE COMMUTING

The GHG emissions presented in this sector were generated from the fuel used by City of Worcester's vehicle fleet and City employees commuting to and from work.

Overview

Figure 43: Municipal Vehicle Emissions, 2019

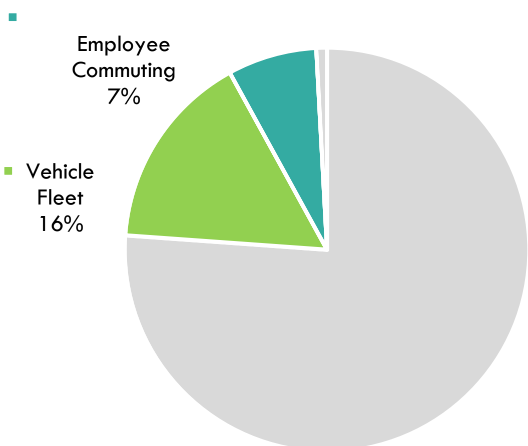


Table 8: Municipal Vehicle Emissions, 2009 & 2019

Sector	2009 $MTCO_2e$	2019 $MTCO_2e$	% Change
Gasoline	4,541	4,749	↓13%
Diesel	2,492	2,174	↑5%
Employee Commuting	3,104	3,111	0%

The City of Worcester's vehicle fleet fuel use and emissions are broken down by fuel type, gasoline, and diesel. The City collects fuel consumption data based by department and fuel pump location but does not track specific vehicle consumption data. With additional information, the City can identify more emissions intensive vehicles and prioritize them for replacement.

Employee Commuting:

Employee Commuting emissions are estimated based on the amount of full- and part-time employees as well as full- and part-time school employees working for the City. These estimates are based on several assumptions including number of commuting trips per year, length of commuting trip, the average fuel economies for passenger vehicles in 2009 and 2019, and the mode of transportation for all employees. While employee commuting is not directly controlled by the City of Worcester and is considered a Scope 3 source of emissions, including them will allow Worcester to demonstrate the impact of adding EV charging facilitating other low carbon transportation options for employees and leads by example for other Worcester employers.

LOOKING FORWARD

Over the last 10 years, the city welcomed 20,000 more residents, yet at the same time reduced its community-wide greenhouse gas emissions by 3%, demonstrating that it is possible for the city to grow in population with the commensurate economic development and still reduce carbon emissions. t

Further reduction of the greenhouse gas emission is one of the most important goals in the city's 2021 Green Worcester Plan, with the ultimate vision of becoming a net-zero city and only using renewable energy by 2045. We believe that recent technological advances (making renewable energy more affordable and building systems' electrification sustainable) as well as alignment of policies at different levels of government make this goal achievable.

This report allowed us to measure the baseline, to identify the largest contributors, to set up strategies for reduction of emissions, and to continue benchmarking our progress over time toward the goal of becoming the greenest mid-sized city in the country.

We confirmed through this exercise that the majority of our emissions come from buildings and transportation. The main strategies that will have the highest impact to reduce our contribution to climate change include investing in:

- Building energy efficiency and deep retrofits where possible, to cut on energy demand
- Electrification both buildings and transportation, and
- Increasing renewable electricity sources.

Using 2019 as a new benchmark, we will be able to illustrate the impact of the 2020 start of the Worcester Community Choice Aggregation program to speed our transition to 100% clean electricity.

As we look forward towards implementation of the Green Worcester Plan, the technologies for transitioning from fossil fuels in our buildings and transportation system will continue to improve.

Emerging micromobility options could begin to close last mile gaps in transit access and greatly expand the number of destinations a resident can reach without a full-size vehicle.

The stage is set for rapid reduction in greenhouse gas emissions as all levels of government, businesses, and individuals work toward the same goal.

The City of Worcester is committed to continue to lead by example and build upon the results it has already achieved to deliver local services efficiently and in a way that reduces the threat of climate change to our community.

COMMUNITY METHODOLOGY

The data used to generate regional GHG emissions estimates were drawn from sources that capture activity data from multiple sectors across the city of Worcester. This inventory uses 100-year horizon Global Warming Potential values from the IPCC 5th Assessment Report. Except where noted, this inventory follows methods and emissions factors sourced from the US Community Protocol[4] and aligns with the reporting conventions defined by the Global Protocol for Community Scale Emissions Inventories (GPC)[5].

Energy

Electricity

Data Sources

Data Provider	Year(s)	Data Type	Categorization
MassSave[6]	2019	Electricity Consumption	Community wide consumption by customer class data provided by power utilities in the region. Residential, Commercial & Industrial.
National Grid	2009	Electricity Consumption	Historic electricity use was recorded from National Grid, received by City of Worcester in 2010.
eGRID emission factors NEWE Region[7]	2009, 2019	Emission Factors	EPA eGRID: NEWE CH_4 and N_2O Factors.
ISO New England Electric Generator Air Emission Report[8]	2009, 2019	Emission Factors	ISO New England CO_2 factor.

Methodology

- Collect activity data from MassSave database
- Subtract the estimated electricity used for electric vehicles from residential and commercial electricity consumption.
    - *Assumption: Half of the total electric vehicle electricity consumption came from residents' homes and half came from commercial buildings.*
- Multiply electricity consumption by eGRID & ISO emission factors to estimate emissions.

Natural Gas

Data Sources

Data Provider	Year(s)	Data Type	Categorization
Eversource	2009, 2019	Natural Gas Consumption	Community wide consumption by customer class data provided by power

[4] https://icleiusa.org/us-community-protocol/
[5] https://ghgprotocol.org/greenhouse-gas-protocol-accounting-reporting-standard-cities
[6] https://www.masssavedata.com/Public/GeographicSavings?view=C
[7] https://www.epa.gov/egrid/power-profiler#/
[8] https://www.iso-ne.com/static-assets/documents/2020/05/2019_air_emissions_report.pdf

			utilities in the region. Residential, Commercial & Industrial.
U.S. EPA's Emission Factors for Greenhouse Gas Inventories[9]	2009, 2019	Emission Factors	Residential, Commercial

Methodology

- Obtain gas consumption data from Eversource.
- Multiply natural gas consumption by EPA emission factors.

Fugitive Natural Gas

Data Sources

Data Provider	Year(s)	Data Type	Categorization
McKain, K., et al. February 17, 2015. Methane emissions from natural gas infrastructure and use in the urban region of Boston, Massachusetts. PNAS, 112(7), 1941-1946.[10]	2009, 2019	Natural gas leakage rates in transmission & distribution.	All natural gas distribution (Residential & Commercial)

Methodology

- Identify estimated regional natural gas leakage rates by region and utility provider.
- Multiply leakage rate (2.7%) by residential and commercial natural gas consumption.
- Multiply estimated leakage by EPA emission factors.

Fuel Oil

Data Sources

Data Provider	Year(s)	Data Type	Categorization
City of Worcester Assessor Database	2009, 2019	Representative account of the homes, commercial buildings, and industrial facilities using fuel oil.	Residential, Commercial, Industrial
MA Department of Energy Resources, Massachusetts Household Heating Costs	2009, 2019	Approximate Heated Square Footage per Household and Average consumption per household.	Residential
Commercial Buildings Energy Consumption Survey[11]	2009, 2019	Commercial Fuel oil energy intensity: Fuel oil used per square foot of commercial space from EIA's Commercial Buildings Energy Consumption Survey.	Commercial

Methodology:

Residential

- Estimate total number of households and household square footage using fuel oil for heating from assessor database records.

[9] https://www.epa.gov/climateleadership/ghg-emission-factors-hub
[10] http://www.pnas.org/content/112/7/1941.full
https://static1.squarespace.com/static/5936d98f6a4963bcd1ed94d3/t/5ceed28be5e5f0ccf6d107d3/1559155339091/Fixing+MA+gas+leaks+pays+for+itself_AEC_29May2019.pdf
[11] https://www.eia.gov/consumption/commercial/data/2012/c&e/pdf/c35.pdf

- Multiply total household square footage by fuel oil per square foot.
- Multiply consumption estimates by EPA emission factors.

Commercial

- Estimate total number of commercial & industrial properties using fossil fuels for heating.
- Subtract the known quantity of natural gas accounts.
    - *Assumption: Remaining properties use fuel oil for heating.*
- Estimate the average square footage of a commercial space.
- Multiply remaining accounts average square footage to calculate the total commercial square footage heated by fuel oil.
- Multiply total square footage by the average fuel oil energy intensity.
- Multiply consumption estimates by EPA emission factors.

Note that within fuel oil, the assessor database had incomplete coverage for heating fuels used. For residential buildings, it was assumed that existing data provided a representative sample of the community and the relative proportion of those were scaled up to the full population of buildings in the city. For commercial buildings the number of fuel oil heated buildings was estimated based on the difference between the number of buildings and the number of commercial natural gas accounts reported by Eversource.

Propane

Data Sources

Data Provider	Year(s)	Data Type	Categorization
City of Worcester Assessor's Database	2009, 2019	Representative account of the homes, commercial buildings, and industrial facilities using propane.	Residential
MA Department of Energy Resources, Massachusetts Household Heating Costs	2009, 2019	Approximate Heated Square Footage per Household and Average consumption per household.	Residential

Methodology:

- Estimate total number of households and household square footage using propane for heating.
    - *Non-residential propane omitted due to lack of data on typical use patterns*
- Multiply approximate heating square footage per household by average gallons of propane consumed per household to calculate a gallons of propane per square foot intensity.
- Multiply total household square footage by propane per square foot.
- Multiply consumption estimates by EPA emission factors.

On-road Transportation

Passenger Vehicles – Gasoline & Diesel

Data Sources:

Data Provider	Year	Data Type	Categorization
MassDOT VMT[12]	2019	VMT by Jurisdiction	Community-wide
U.S. Federal Highway Administration, Office of Highway Policy Information. Travel Monitoring: Traffic Volume Trends, Massachusetts Urban VMT[13]	2019, 2009	Urban VMT by State	State-Wide
U.S. Community Protocol for Accounting and Reporting of Greenhouse Gas Emissions. Version 1.2. July 2019, Appendix TR: Transportation & Other Mobile Emission Activities and Sources[14]	2009, 2019	Default vehicle mix values	National
U.S. Department of Energy's Alternative Fuel Data Center, Average Fuel Economy of Major Vehicle Categories[15]	2009, 2019	Average MPG (fuel efficiency) by Vehicle Type.	National
U.S. EPA's Emission Factors for Greenhouse Gas Inventories[16]	2009, 2019	Emission factors by vehicle type and amount of fuel consumed.	National

Methodology:

- Download daily 2019 VMT by jurisdiction from State resources.
- Sum daily VMT and multiply by 365 to calculate Annual VMT.
- Calculate proportion of 2019 urban VMT to 2009 urban VMT.
- Multiply proportion of urban VMT to 2019 annual VMT.
- Multiply Annual VMT by National default vehicle mix values to estimate VMT per vehicle type.
- Multiply VMT by vehicle type estimates by EPA emission factors to estimate emissions.
- Multiply VMT by vehicle type estimates by DOE's Average Fuel Economy by vehicle type to estimate fuel consumption.

Passenger Vehicles – Electric

Data Sources:

Data Provider	Year	Data Type	Categorization
U.S. Department of Energy's Alternative Fuel Data Center, Electricity Sources and Emissions Tool[17]	2019	Electric vehicle kWh consumption per mile traveled	National
N/A Assumption of 0.7%	2019	% of registered vehicles in state	State

Methodology:

[12] https://gis.massdot.state.ma.us/DataViewers/vmt/
[13] https://www.fhwa.dot.gov/policyinformation/travel_monitoring/tvt.cfm
[14] https://static1.squarespace.com/static/5d1e51dd2a98da000183bc20/t/5db5c0c14f74010ee4dac0b2/1572192454524/Appendix+D+-+Transportation+and+Other+Mobile+Emission+Activities+and+Sources+-+U.S.+Community+Protocol.pdf
[15] https://www.afdc.energy.gov/data/categories/fuel-consumption-and-efficiency https://afdc.energy.gov/data/10310
[16] https://www.epa.gov/climateleadership/ghg-emission-factors-hub
[17] https://afdc.energy.gov/vehicles/electric_emissions_sources.html

- Multiply estimated VMT for gasoline passenger vehicles by the estimated MA state EV adoption rate to calculate an estimate VMT for EVs.
    - *Assumption: All EV's replace gasoline passenger vehicles, not light duty trucks, or diesel-powered vehicles.*
- Subtract mileage from gasoline passenger vehicle VMT to avoid double counting.
- Multiply estimated VMT by DOE's national average kWh/mile value to calculate total kWh consumed by EV's.
- Subtract half of estimated EV kWh use from both residential and commercial building electricity consumption to avoid double counting.
    - *Assumption: Half of EV kWh use is consumed from residential buildings and the other half is consumed from commercial buildings.*
- Multiply electricity consumption by eGRID & ISO emission factors to estimate emissions.

Transit

Data Sources:

Data Provider	Year	Data Type	Categorization
US Bureau of Transportation National Transit Database. Worcester Regional Transit Authority Agency Profile.[18]	2009, 2019	Gasoline, Diesel, & Electricity Consumption	Community-wide

Methodology:

- Sum fuel consumption from data collected.
- Multiply Transit fuel consumption by EPA emission factors to estimate emissions.

Off-road transportation

Aviation

Data Sources:

Data Provider	Year	Data Type	Categorization
Federal Aviation Administration Traffic Flow Management System Counts & Aviation System Performance Metrics[19]	2009, 2019	Departure & Arrival counts	By airport and aircraft type
International Civil Aviation Organization Airport Air Quality Manual[20]	2009, 2019	Landing & Take off Emission Factors	By aircraft type

Methodology:

- Calculate total departures by aircraft with the FAA TFMSC data to calculate total operations. Exclude military operations from count. Accounting for departing aircraft only follows general guidance provided by the GPC[21].
- Crosswalk FAA aircraft types with ICAO aircraft types to match appropriate emissions factors.

[18] https://www.transit.dot.gov/ntd/transit-agency-profiles
[19] https://aspm.faa.gov/
[20] https://www.icao.int/environmental-protection/Documents/Publications/FINAL.Doc%209889.Corrigendum.en.PDF
[21] https://ghgprotocol.org/greenhouse-gas-protocol-accountingreporting-standard-cities

- Multiply FAA total operations by aircraft by the landing & take off emission factors from ICAO to estimate emissions by aircraft.

Note that aviation only includes the fuel for landing and take-off operations, not the entire length of the flights.

Railways

Data Sources:

Data Provider	Year	Data Type	Categorization
Ridership and Service Statistics - Thirteenth Edition - 2010 Massachusetts Bay Transportation Authority[22]	2009	Ridership, Average commuter mileage	Commuter Rail
Massachusetts Bay Transportation Authority, Open Data Portal[23]	2019	Ridership	Commuter Rail

Methodology:

- Aggregate total ridership counts.
- Multiply ridership by milage from Worcester to South Station.
- Multiply commuter milage estimates by EPA emission factors.

Solid Waste

Residential Incinerated Waste

Data Sources:

Data Provider	Year	Data Type	Categorization
Massachusetts Department of Environmental protection, Recycling and Solid Waste Survey[24]	2009, 2019	Residential Waste Incinerated	# of Households, Surveyed Households, Households served by Municipal Trash program
US Community Protocol Method SW.2.2.	N/A	Emissions Factors for Mixed MSW	N/A

Methodology:

- Divide the total waste collected by households served by the Municipal Trash Program to calculate the tons of waste disposed by household.
- Subtract households served by the Municipal Trash Program by total number of households to calculate remaining households not served by municipal collection.
- Multiply tons of waste disposed by household value by the estimated remining household value to calculate estimate additional waste not served by municipal collection.
- Add estimated additional waste to total waste reported.
- Calculate emissions using standard factors for incineration of mixed MSW.

[22] https://www.cambridgema.gov/-/media/Files/CDD/FactsandMaps/transdata/mbta_bluebook_2010.pdf
[23] https://mbta-massdot.opendata.arcgis.com/
[24] https://www.mass.gov/lists/recycling-solid-waste-data-for-massachusetts-cities-towns

Commercial Incinerated Waste

Data Sources:

Data Provider	Year	Data Type	Categorization
Massachusetts Department of Unemployment Assistance, Labor Market Information, Municipal Employment Data[25]	2009, 2019	Commercial Employment	Worcester Average employment by industry.
CalRecycle: Cascadia Consulting Group. Targeted Statewide Waste Characterization Study: Waste Disposal and Diversion Findings for Selected Industry Groups. June 2006[26]	2009, 2019	Disposal Rate by industry	Commercial waste disposed per person per industry
US Community Protocol Method SW.2.2.	N/A	Emissions Factors for Mixed MSW	N/A

Methodology:

- Multiply average employment by industry by the average disposal weight per person per industry to estimate the tonnages of waste disposed by industry in Worcester.
- Sum all estimated tonnages by industry to calculate a community total.
- Calculate emissions using standard factors for incineration of mixed MSW.

Composted Waste

Data Sources:

Data Provider	Year	Data Type	Categorization
City of Worcester Public Works	2009, 2019	Green waste collected	Community-wide
Global Protocol for Community Scale Emissions Inventories	N/A	Emissions factors for Biological Treatment	N/A

Methodology:

- Convert volume to tonnages with standard bulk density of uncompacted yard waste.
- Calculate N_2O and CH_4 emissions from composting. All CO_2 is omitted in this case as it is biogenic.

Landfill Waste-In-Place

Data Sources:

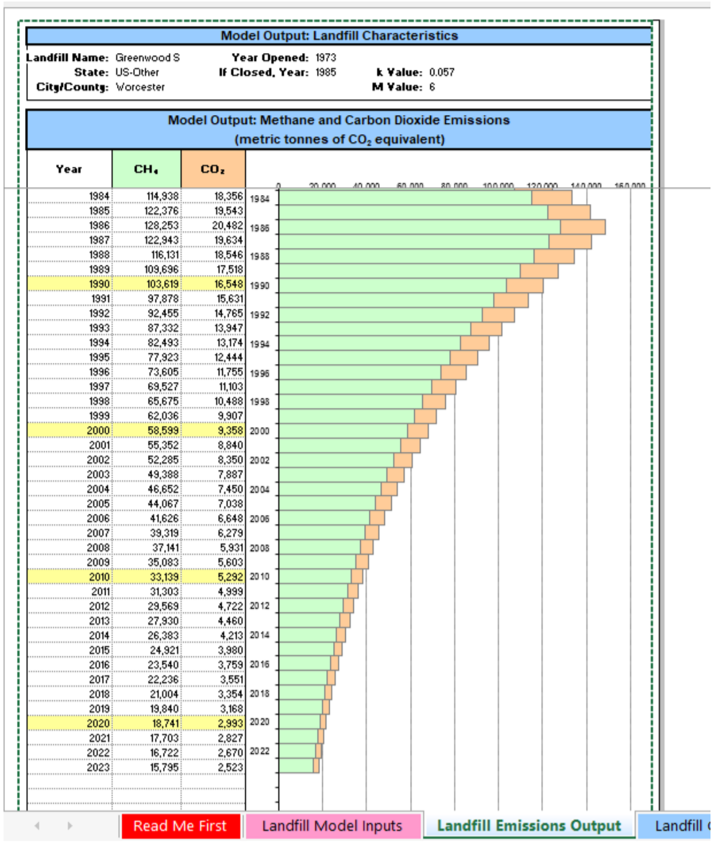
Data Provider	Year	Data Type	Categorization
California Air Resources Board First Order Decal Landfill Model	2009, 2019	Modeled CH_4 landfill gas	Greenwood Landfill

Methodology:

- First order decay inputs were run for landfill receiving 225,000 tons of mixed MSW annually from 1973 to 1985.

[25] https://lmi.dua.eol.mass.gov/lmi/MunicipalEmploymentData/LmiTown?A=000501
[26] https://www2.calrecycle.ca.gov/WasteCharacterization/PubExtracts/2014/GenSummary.pdf

- Moisture (k) value set to 0.057.
- Outputs for both 2009 and 2019 were obtained from the same model run.
- Raw outputs for methane in terms of $MTCO_2e$ using IPCC 2nd Assessment Global Warming Factors were converted back to $MTCH_4$ before final adjustment to 5th Assessment values



Year	CH_4	CO_2
1984	114,938	18,356
1985	122,376	19,543
1986	128,253	20,482
1987	122,943	19,634
1988	116,131	18,546
1989	109,696	17,518
1990	103,619	16,548
1991	97,878	15,631
1992	92,455	14,765
1993	87,332	13,947
1994	82,493	13,174
1995	77,923	12,444
1996	73,605	11,755
1997	69,527	11,103
1998	65,675	10,488
1999	62,036	9,907
2000	58,599	9,358
2001	55,352	8,840
2002	52,285	8,350
2003	49,388	7,887
2004	46,652	7,450
2005	44,067	7,038
2006	41,626	6,648
2007	39,319	6,279
2008	37,141	5,931
2009	35,083	5,603
2010	33,139	5,292
2011	31,303	4,999
2012	29,569	4,722
2013	27,930	4,460
2014	26,383	4,213
2015	24,921	3,980
2016	23,540	3,759
2017	22,236	3,551
2018	21,004	3,354
2019	19,840	3,168
2020	18,741	2,993
2021	17,703	2,827
2022	16,722	2,670
2023	15,795	2,523

Figure 24. Screenshot of FOD Calculator, depicting phase out of landfill gas generation.

Water Treatment and Delivery

Data Sources:

Data Provider	Year	Data Type	Categorization
Worcester Water Operations Division of Worcester's Department of Public Works & Parks[27]	2020	Water consumption per year	Community-wide
Worcester 2010 GHG Inventory	2005	Average water consumption per day	Community-wide

[27] http://www.worcesterma.gov/uploads/11/31/11313f0e1f1051b6495f519d7699d1c9/water-quality-report.pdf

U.S. Community Protocol for Accounting and Reporting of Greenhouse Gas Emissions. Appendix F: Wastewater and Water Emission Activities and Sources, July 2013.[28]	2009, 2019	Energy Intensity Defaults for Water Treatment & Delivery	National
2019 eGRID emission factors NEWE Region[29]	2009, 2019	Emission Factors	EPA eGRID: 2019 NEWE CH_4 and N_2O Factors.
2019 ISO New England Electric Generator Air Emission Report[30]	2009, 2019	Emission Factors	ISO New England CO_2 factor for 2019 used GHG inventory.

Methodology:

- Extrapolate 2009 and 2019 annual water consumption using the 2005 and 2020 values collected from data sources.
- Calculate a total energy intensity for water use by summing the mid-point energy intensities from the range of values for extraction, conveyance, treatment, and distribution of surface water from the U.S. Community Protocol.
- Multiply estimates annual consumption by the calculated energy intensity to determine the total electricity used for water treatment and distribution.
- Multiply electricity consumption by eGRID & ISO emission factors to estimate emissions.

Wastewater

Data Sources:

Data Provider	Year	Data Type	Categorization
U.S. Census Bureau, Quickfacts[31]	2009, 2019	Population	By City or Census Designated place
U.S. Community Protocol for Accounting and Reporting of Greenhouse Gas Emissions. Appendix F: Wastewater and Water Emission Activities and Sources, July 2013.[32]	2009, 2019	Standard methods for nitrogen from nitrification/denitrification treatments and effluent discharge.	National

Methodology:

- Populations contributing to advanced wastewater treatment plants in each jurisdiction were sourced from the US Census.
- Populations were applied to standard methods for nitrogen from nitrification/denitrification treatments and effluent discharge.

[28] https://static1.squarespace.com/static/5d1e51dd2a98da000183bc20/t/5db5c0f84f74010ee4dac41a/1572192509182/Appendix+F+-+Wastewater+and+Water+Emission+Activities+and+Sources+-+U.S.+Community+Protocol.pdf
[29] https://www.epa.gov/egrid/power-profiler#/
[30] https://www.iso-ne.com/static-assets/documents/2020/05/2019_air_emissions_report.pdf
[31] https://www.census.gov/quickfacts/fact/table/worcestercitymassachusetts/PST045219
[32] https://static1.squarespace.com/static/5d1e51dd2a98da000183bc20/t/5db5c0f84f74010ee4dac41a/1572192509182/Appendix+F+-+Wastewater+and+Water+Emission+Activities+and+Sources+-+U.S.+Community+Protocol.pdf

MUNICIPAL METHODOLOGY

The data used to generate regional GHG emissions estimates were drawn from sources that capture activity data from multiple departments and datasets across the City of Worcester's municipal operations. This inventory uses 100-year horizon Global Warming Potential values from the IPCC 5th Assessment Report. Except where noted, this inventory follows methods and emissions factors sourced from the Local Government Operations Protocol[33].

Energy

Electricity

Data Sources

Data Provider	Year(s)	Data Type	Categorization
City of Worcester Mass Energy Insight Reports[34]	2009, 2019	Electricity Consumption (Solar electricity consumption for 2019 only)	Municipal consumption by facility type (Buildings, Water/Sewer, Streetlights/Traffic Signals, Open Space)
eGRID emission factors NEWE Region[35]	2009, 2019	Emission Factors	EPA eGRID: NEWE CH_4 and N_2O Factors.
ISO New England Electric Generator Air Emission Report[36]	2009, 2019	Emission Factors	ISO New England CO_2 factor.

Methodology

- Collect activity data from Mass Energy Insight by facility type.
- Multiply electricity consumption by eGRID emission factors to estimate emissions.

Note that for maintaining consistency with other calculations in this inventory, facility energy use is aggregated by calendar year and reflects actual usage. The values reported here may differ from other City of Worcester reports that may be presented at a fiscal year aggregation and/or reflect weather-normalized energy use.

Natural Gas, Fuel Oil, & Diesel

Data Sources

Data Provider	Year(s)	Data Type	Categorization
City of Worcester Mass Energy Insight Reports[37]	2009, 2019	Natural Gas, Fuel Oil, & Diesel Consumption	Municipal consumption by facility type (Buildings, Water/Sewer, Open Space)
U.S. EPA's Emission Factors for Greenhouse Gas Inventories[38]	2009, 2019	Emission Factors	By fuel type for natural gas, fuel oil, diesel.

Methodology

[33] https://ww2.arb.ca.gov/local-government-operations-protocol-greenhouse-gas-assessments
[34] https://www.massenergyinsight.net/home
[35] https://www.epa.gov/egrid/power-profiler#/
[36] https://www.iso-ne.com/static-assets/documents/2020/05/2019_air_emissions_report.pdf
[37] https://www.massenergyinsight.net/home
[38] https://www.epa.gov/climateleadership/ghg-emission-factors-hub

- Collect activity data from Mass Energy Insight by facility type.
- Multiply consumption by EPA emission factors.

Fugitive Natural Gas

Data Sources

Data Provider	Year(s)	Data Type	Categorization
McKain, K., et al. February 17, 2015. Methane emissions from natural gas infrastructure and use in the urban region of Boston, Massachusetts. PNAS, 112(7), 1941-1946.[39]	2009, 2019	Natural gas leakage rates in transmission & distribution.	All natural gas distribution

Methodology

- Multiply leakage rate by municipal natural gas consumption.
- Convert leakage volumes to mass of CH_4 and CO_2 equivalent.

On-road Transportation

Vehicle Fleet – Gasoline & Diesel

Data Sources:

Data Provider	Year	Data Type	Categorization
City of Worcester Mass Energy Insight Reports[40]	2009, 2019	Gasoline & Diesel Consumption	Municipal consumption by facility type (Vehicles)
U.S. Department of Energy's Alternative Fuel Data Center, Average Fuel Economy of Major Vehicle Categories[41]	2009, 2019	Average MPG (fuel efficiency) by Vehicle Type.	National
U.S. EPA's Emission Factors for Greenhouse Gas Inventories[42]	2009, 2019	Emission factors by vehicle type and amount of fuel consumed.	National

Methodology:

- Collect gasoline and diesel fuel use data from Mass Energy Insight.
- Calculate CO_2 on the basis of fuel volumes.
- Fuel use data was not associated with specific vehicle types, for simplicity all gasoline was considered to be used by passenger vehicles and diesel by light trucks.
- VMT was estimated with standard average fuel economies for passenger vehicles and light trucks.
- Calculate CH_4 and N_2O with VMT based emission factors for each vehicle and fuel type combination.

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[39] http://www.pnas.org/content/112/7/1941.full https://static1.squarespace.com/static/5936d98f6a4963bcd1ed94d3/t/5ceed28be5e5f0ccf6d107d3/1559155339091/Fixing+MA+gas+leaks+pays+for+itself_AEC_29May2019.pdf
[40] https://www.massenergyinsight.net/home
[41] https://www.afdc.energy.gov/data/categories/fuel-consumption-and-efficiency https://afdc.energy.gov/data/10310
[42] https://www.epa.gov/climateleadership/ghg-emission-factors-hub

Employee Commuting

Data Sources:

Data Provider	Year	Data Type	Categorization
City of Worcester	2009, 2019	Employee Counts	Full-time and part-time municipal and school employees by department & Division.
U.S. Department of Transportation, Bureau of Transportation Statistics, Average Fuel Efficiency of U.S. Light Duty Vehicles[43]	2009, 2019	Average fuel efficiency for light duty vehicles	National
U.S. EPA's Emission Factors for Greenhouse Gas Inventories[44]	2009, 2019	Emission factors by vehicle type and amount of fuel consumed.	National

Methodology:

- Collect Employee counts.
- Multiply employee counts by number of days worked per year and Worcester area average miles traveled per day to estimate total employee commuting mileage.
- Divide VMT by DOT's Average fuel efficiency to calculate fuel consumption.
- Multiply VMT and/or consumption by EPA emission factors.

Solid Waste

Waste Incineration

Data Sources:

Data Provider	Year	Data Type	Categorization
City of Worcester Human Resources	2009,2019	Total Staff	N/A
US Community Protocol Method SW.2.2.	N/A	Emissions Factors for Mixed MSW	N/A

Methodology:

- Solid waste generation by municipal facilities followed previous estimation methods that used city employment to population ratios to estimate the portion of municipal collection that originates from City of Worcester facilities (4%).
- Total waste was calculated by applying 4% to community wide waste collection.
- Emissions calculated with standard emissions factors for incineration of mixed MSW.

[43] https://www.bts.gov/content/average-fuel-efficiency-us-light-duty-vehicles
[44] https://www.epa.gov/climateleadership/ghg-emission-factors-hub

Inventory Updates Recommendations

Calculation approaches and methods used in this inventory reflect a mix of best available data necessary to obtain comparable results between calendar years 2009 and 2019 for a complete mix of sources. Ideally inventory data is always sourced from measurement, however this is frequently not possible in community scale studies and estimations are necessary to fill data gaps. Rarely is it possible to fill gaps at the time an inventory is performed and for data quality to improve upon the next benchmark, new mechanisms should be developed to generate the ideal data to be used in future assessments.

Community Scale

- Review building permitting processes to identify opportunities where changes to building heating fuels are consistently recorded as part of a property tax record.
- Review excise tax records to identify electric vehicles registered within the City to appropriately attribute VMT to this class of vehicles.
- Survey Worcester community businesses and/or private waste hauling firms for solid waste generation rates not captured by municipal collection.

Municipal Scale

- Develop internal tracking of solid waste generated within municipal facilities.
- Meter future electric fleet vehicles such that transportation energy can be tracked independently of building energy.

While not directly utilized by this inventory, it should be noted that the City of Worcester maintains high quality data detailing its use of energy in municipal facilities, such that the impact of investments to deliver public services efficiently are evident. These and other achievements are recorded at WorcesterEnergy.org.