City of Cambridge
Community-wide Greenhouse Gas Emissions Inventory Report

Prepared by DNV GL
May 2017

City of Cambridge

Community-wide Greenhouse Gas Inventory Report

June, 2017

Prepared by DNV GL in partnership with the Metropolitan Area Planning Council (MAPC)

Acknowledgements

This 2012 greenhouse gas inventory was developed for the City of Cambridge Community Development Department. The inventory was compiled with the assistance from the Department of Public Works, Eversource, and the Massachusetts Water Resource Authority (MWRA). It is intended to provide the City of Cambridge with a community-wide greenhouse gas inventory using the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC), establish an emissions baseline for the City, and initiate the process for updating the City's Climate Action Plan.

Project Consultant: DNV GL: Betty Seto, Jim Leahy, Matthew Fitzgerald, Benjamin Butterworth

MAPC: Manisha Bewtra, Ani Krishnan, Eliza Wallace, Kate Ito

Cambridge City Staff: Susanne Rasmussen, Bronwyn Cooke, John Bolduc

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1. Executive Summary

The City of Cambridge is pleased to present the 2012 Community-wide Greenhouse Gas (GHG) Emissions Inventory. Emissions Inventories are developed to help community and government leaders understand how GHG emissions are generated from various activities in the community. Emissions accounting standards and protocols are used to assist cities in compiling emissions data at both the community scale and at the government operations scale.

Cambridge has conducted annual government operations GHG emissions inventories since 2008[1]. Community-wide GHG inventories were previously completed in 1990, 1998, and 2010, however data sources, methodologies and documentation have since improved drastically

This Inventory was generated to help the City of Cambridge benchmark community-wide emissions, and define future goals for emissions reductions. The community-wide inventory follows the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) developed by the World Resources Institute, C40 Cities, and ICLEI Local Governments for Sustainability and required by The Global Covenant of Mayors for Climate and Energy (GCoM)[2], of which Cambridge is a member.

The calendar year 2012 was chosen as the baseline year for this inventory based on availability and quality of data. The team determined that data from 2012 would provide the most reliable results based on early discussions with the organizations that manage much of the data needed for analysis. An additional benefit of selecting 2012 as the community-wide inventory baseline year is that it also coincides with the City's 2012 Municipal Operations Inventory. Scheduling municipal operations and community inventories to occur on the same years will enable improved coordination between municipal-level and community-level emission reduction goals.

Our findings indicate that the City of Cambridge emitted nearly 1.5 million metric tons of carbon dioxide equivalent ($MTCO_2e$) in 2012 from the residential, commercial, institutional, industrial, transportation, and waste management sectors[3]. Sectors that were expected to have de minimis

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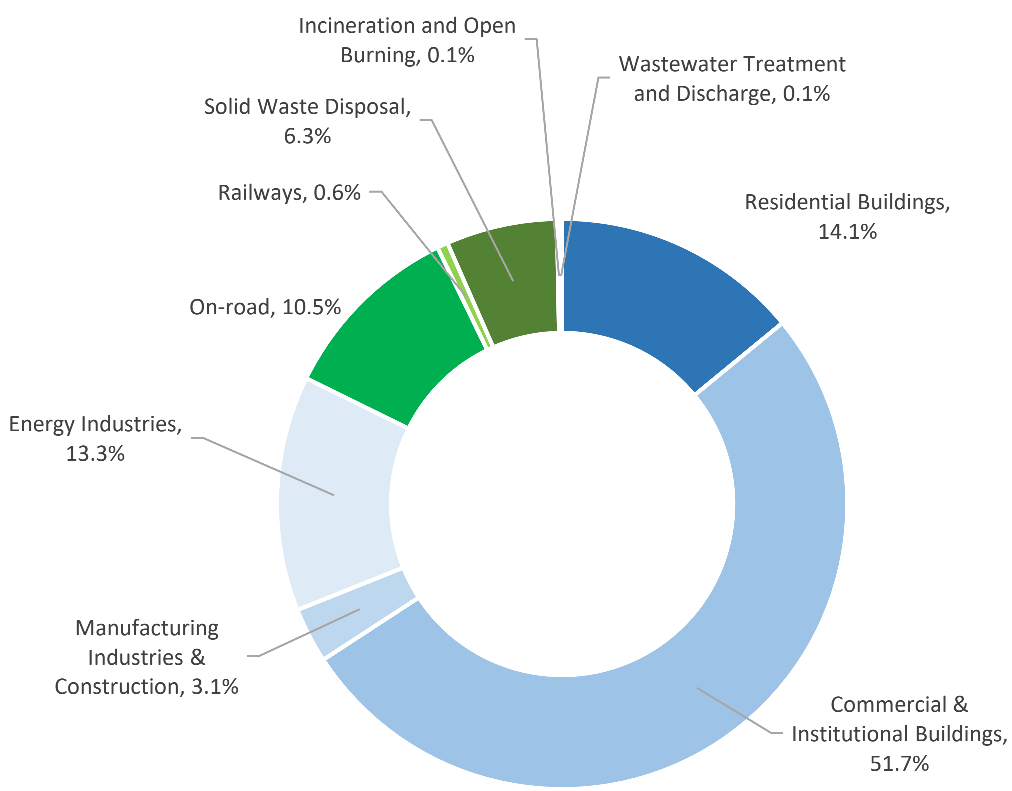
[1] See 2012 Municipal Operations Inventory Report

[2] The Global Covenant of Mayor's for Climate and Energy is the new designation for the Compact of Mayors. The Compact of Mayors was launched by UN Secretary, C40 Cities Climate Leadership Group (C40), ICLEI – Local Governments for Sustainability (ICLEI) and the United Cities and Local Governments (UCLG) –with support from UN-Habitat, the UN's lead agency on urban issues.

[3] Carbon dioxide equivalent (CO_2e) is a unit of measure that normalizes the varying climate warming potencies of all six GHG emissions, which are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons

emissions or impractical data collection efforts were not estimated. This includes emissions from agricultural or mining activities, industrial processes, and product use. Documentation of their exclusion is provided. Figure 1 provides a summary of the various sources of emission by sub-sector.

Figure 1: Cambridge community-wide emissions by sub-sector



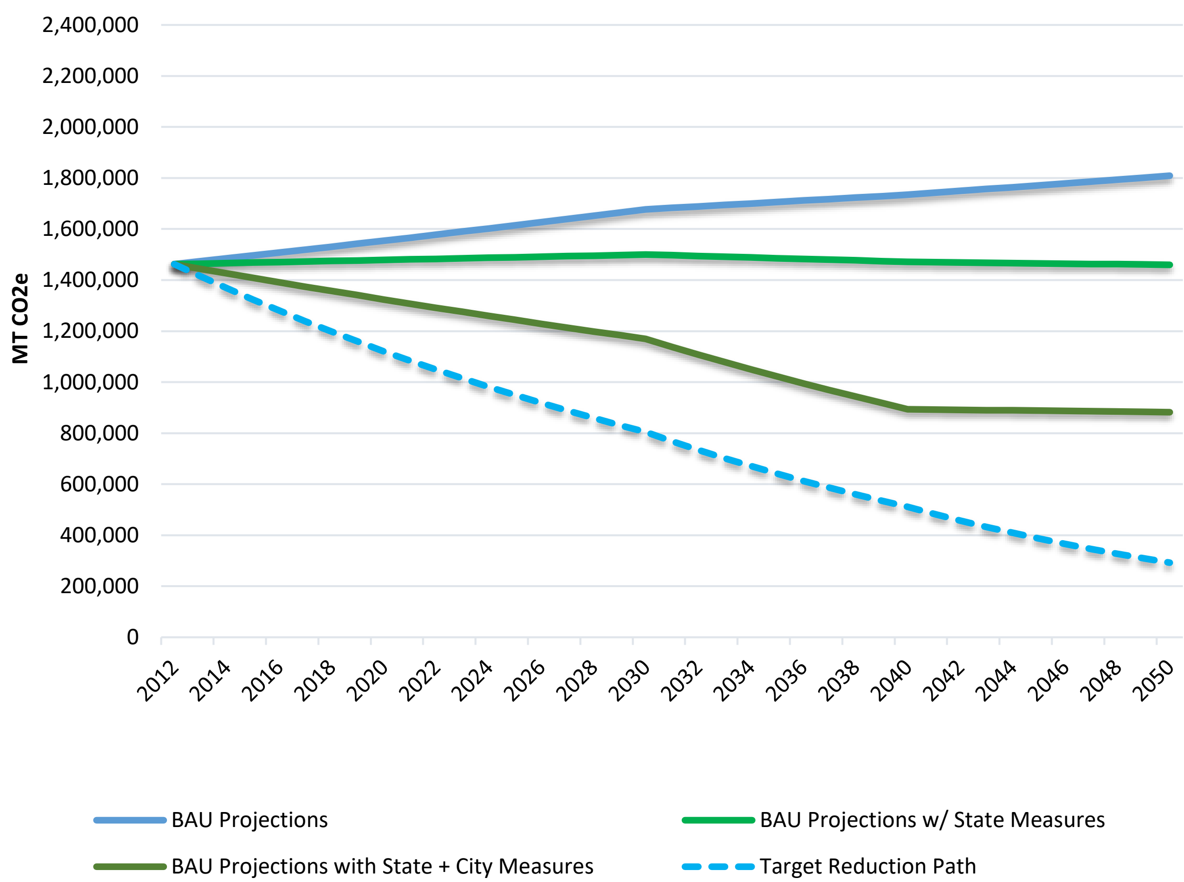
The 2012 baseline year was also used as the basis for forecasting emissions trajectories in the future. These trajectories take into account anticipated growth as well as select measures currently in place that are expected to reduce GHG emissions in the future. The forecast years, 2030, 2040 and 2050, were chosen so the forecasts align with the City's Net Zero Action Plan and the Climate Protection Action Committee's (CPAC) goals and objectives. Between 2015 and 2040 the City will also undertake a series of actions identified in the Net Zero Action Plan, which are anticipated to result in significant emissions reductions from the buildings sub-sector. In

(PFCs), and sulfur hexafluoride (SF_6). For example, one metric ton of methane is equivalent to 21 metric tons of CO_2e. One metric ton of nitrous oxide is 310 metric tons of CO_2e.

forecasting community-wide emissions, we took into account reductions in energy use by existing and new buildings through energy efficiency improvements as well as increases in solar generation capacity within Cambridge, which is expected as a result of the Net Zero Action Plan.

The results of the forecast will be used to determine if Cambridge is on target to reach its 2050 GHG reduction goal; and if not, provide an understanding of what areas need new strategies or what programs or policies need adjustments to reach those goals. Taking into account the State and City measures with readily determined impacts, the forecast indicates that the City will come up short of the 80% reduction goal for 2050.

Figure 2: Forecast emissions scenarios and emissions reduction



2. Introduction

The City of Cambridge and local organizations have long supported the scientific consensus that climate change is a real and threatening global anthropogenic phenomenon, and that not taking action risks the economic foundations, health and vitality of the community. This community-wide inventory is an important step towards protecting local businesses and residents from the potential impacts of climate change.

As a signatory of the Global Covenant of Mayors for Climate and Energy (GCoM)[4], the City has committed to reducing GHG emissions and developing strategies to mitigate the effects of climate change. Being part of the GCoM provides the City access to a global network of hundreds of cities worldwide which are also committed to GHG emissions from city-level activities, and enhancing the community resilience.

The inventory provides a baseline from which the City, its residents, businesses, and institutions can plan and implement strategies that reduce emissions from activities such as transport, waste management and energy use. It allows the City to identify actions to reduce emissions, such as responsible investments into cleaner energy generation, energy efficiency, and resource efficiency. The ability of Cambridge to quantify its community-wide emissions enables and encourages other local and global communities to quantify and curb their emissions as well.

2.1 Objective of the Greenhouse Gas Inventory

In cooperation with other local governments across the U.S. and the world, Cambridge has made a commitment to addressing the challenge of climate change. Many local governments have authority or influence over land use and transportation patterns, as well as solid waste disposal, building design, and other key issues related to GHG emissions. Thus, local governments can encourage residents, businesses, public sector entities and other organizations within their boundaries, to reduce emissions through local policies and programs designed to increase sustainability.

[4] The Global Covenant of Mayor's for Climate and Energy is the new designation for the Compact of Mayors. The Compact of Mayors was launched by UN Secretary, C40 Cities Climate Leadership Group (C40), ICLEI – Local Governments for Sustainability (ICLEI) and the United Cities and Local Governments (UCLG) –with support from UN-Habitat, the UN's lead agency on urban issues.

The objective of the 2012 Community-wide GHG Inventory was to quantify GHG emissions from community-wide activities and help the City reduce and manage climate change impacts. The results of this inventory will be used to help forecast and assess potential trends in emissions from 2012 to 2030, 2040 and 2050, and to determine if the City is on track to meet GHG reduction targets. Ultimately this inventory provides a necessary foundation for advancing and enabling Cambridge to set future emissions reductions targets, and engage specific market sectors in actions to reduce emissions.

2.2 Understanding a Greenhouse Gas Emissions Inventory

Greenhouse gas emissions inventories are developed to help government leaders and community members understand the GHG emissions generated from the various activities in their community. For cities, GHG emissions are generally compiled at both the government operations scale and community scale.

Emissions associated with government operations, such as fuel use from fleet vehicles and energy use in city government buildings, are included as part of the community-wide inventory. These emissions are a subset of the community inventory. For example, the data in the community inventory on commercial energy use includes energy consumed by municipal buildings, and vehicle-miles-traveled estimates include miles driven by municipal fleet vehicles. Details on the missions from municipal operations are also presented in a separate inventory report.

This report presents the GHG emissions from the Cambridge community as a whole. The community-wide inventory follows the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) which was developed by the World Resources Institute, C40 Cities, and ICLEI Local Governments for Sustainability. This protocol is required to be compliant with The GCoM of which Cambridge is a member.

2.3 Global Protocol for Community-Scale Greenhouse Gas Emission Inventories

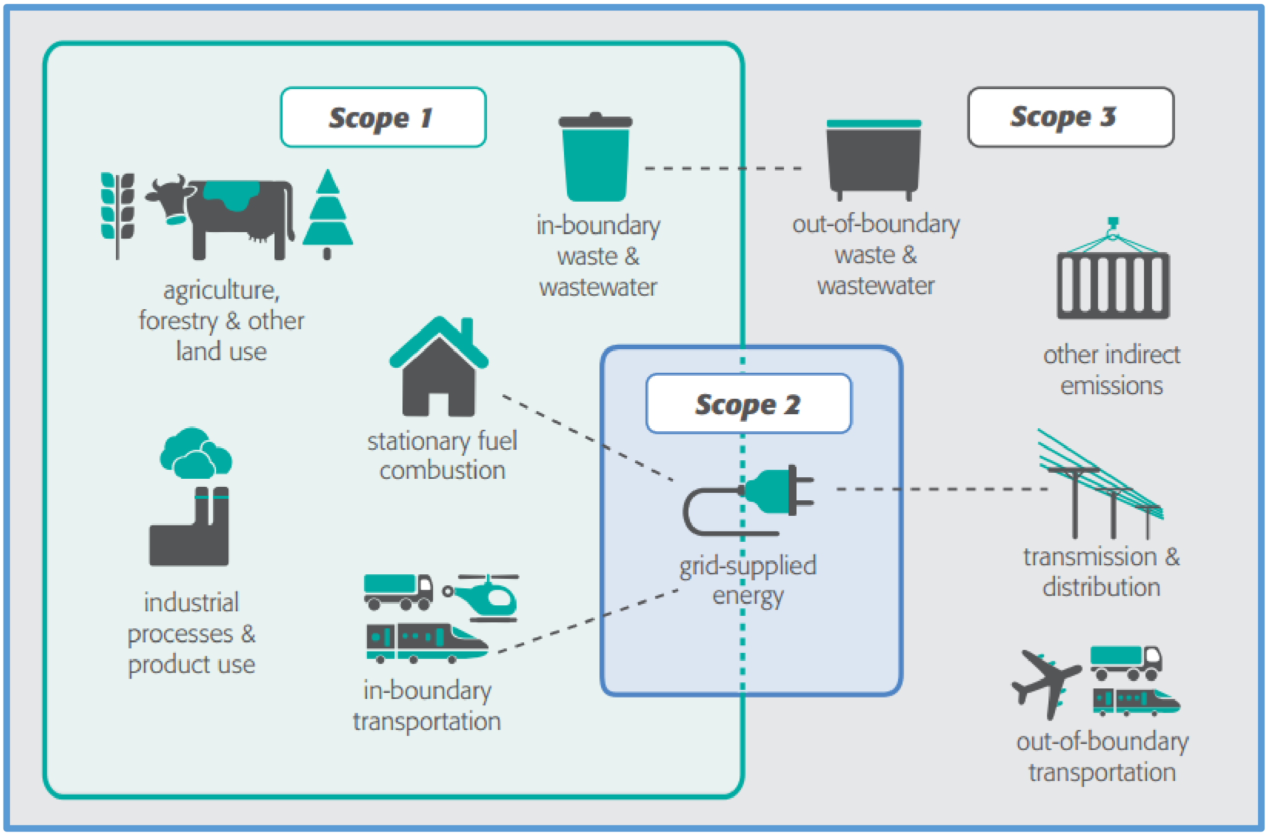
The GPC was designed to provide guidance to local governments across the globe on developing community GHG emissions inventories. It establishes the reporting requirements for all community GHG emissions inventories and provides detailed accounting guidance for quantifying GHG emissions associated with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

Using this protocol advances the City's efforts to reduce and manage climate change impacts and assists the City in fulfilling its commitments to the Global Covenant. The inventory provides the necessary foundation to advance and enable Cambridge's work towards reaching GHG reduction targets. Establishing an emissions baseline helps the City better understand sources of emissions within the City, and in turn helps the City develop targeted strategies to reduce emissions, engage specific market sectors to promote emissions reductions, and track the community's progress towards meeting their goals.

2.4 Emission Sectors and Sources

Emissions associated with city activities can result from sources within the city boundaries as well as outside the city boundaries. To distinguish these emissions the GPC categorizes emissions as Scope 1, Scope 2, and Scope 3. Scope 1 emissions are those emissions generated within the city boundary. Scope 2 emissions are associated with energy supplied by a grid which may or may not cross the city-boundary. This includes emissions from grid supplied electricity, natural gas or steam. Scope 3 emissions are those emissions that occur outside of the city boundary but are caused by activities within the city (e.g. car transport originating outside the city to a place of employment within the city). Figure 3 shows which sources are associated with each of the scopes.

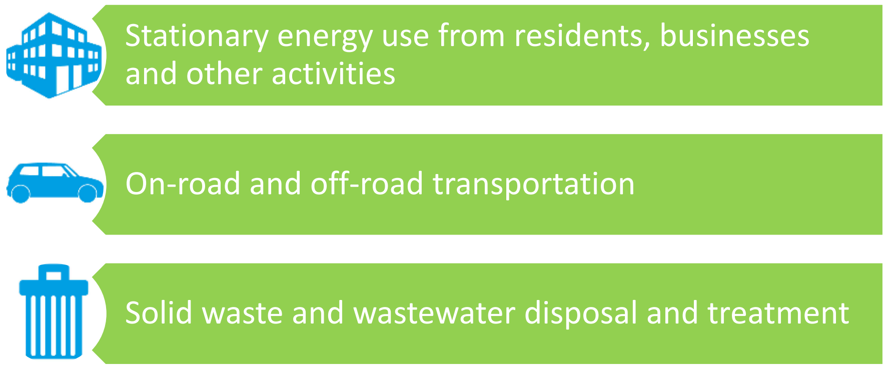
Figure 3: Sources and boundaries of emissions according to the GPC



*Source: GPC

The GPC requires that cities report their emissions in one of two ways – according to the Scopes Framework or using the City-Induced Emissions Framework. The Scopes Framework totals emissions by scope. The City-Induced Framework covers select Scope emissions sources using two reporting levels: BASIC and BASIC+. BASIC includes Scope 1 and 2 emissions from stationary energy and transportation sources, as well as Scope 1 and 3 emissions from waste. BASIC+ involved more challenging methods and calculations and should only be used when adequate data is available.

The Cambridge community-wide inventory accounts for emissions from the following sources, as required by the GPC BASIC framework:



We assessed the possibility of including emissions in the BASIC+ category including product use, industrial processes, and land-use as part of the inventory, however, due to the limited data for these activities, they were ultimately excluded from the report.

Error! Reference source not found. summarizes the sectors, emissions sources, and energy types included in the community-wide GHG inventory. Table 2 provides a summary of the sectors and fuel types by reporting framework.

Table 1: Sectors and emissions in the GHG inventory

Sector	Sub-sector	Emissions sources	Energy types
Stationary Energy	Residential	Energy use in residential buildings as well as losses from distribution systems	Electricity Natural gas Petroleum Products
	Commercial	Energy use in commercial, government and institutional buildings as well as losses from distribution systems	
	Manufacturing and Construction	Energy use in industrial facilities, and processes as well as losses from distribution systems and construction equipment	
	Energy Industries	Stationary combustion of fuel in various equipment, such as boilers and generators.	Various – may include natural gas, propane, and diesel

Transportation	Transportation	All on-road vehicles Railways Off-road vehicles/equipment	Gasoline Diesel Electricity
Waste	Solid Waste	Landfills Incineration of waste generated in the city	Landfill gas (methane)
	Wastewater	Process and fugitive emissions from treating wastewater	Not applicable

Table 2: Sectors included in Cambridge GHG inventory by reporting framework

Sector	Sub-sector	Scope 1	Scope 2	Scope 3
Stationary Energy	Residential – Natural Gas / Fuel Oil Use	•		
	Residential – Electricity Use		•	
	Commercial – Natural Gas / Fuel Oil Use	•		
	Commercial – Electricity Use		•	
	Manufacturing and Construction – Fuel Use (including vehicles)	•		
	Manufacturing and Construction – Electricity Use		•	
	Energy Industries	•		
	Electricity Distribution System Losses			•
	Nat. Gas Distribution System Losses	•		
Transportation	Vehicle Travel On-road (Fuel Use)	•		
	Vehicle Travel On-road (Electricity Use)		•	
	Public Transit (Fuel Use)	•		
	Public Transit (Electricity Use)		•	
	Electricity Distribution System Losses			•
Waste	Solid Waste – Landfill Disposal			•
	Solid Waste – Incineration			•
	Wastewater Treatment			•

• = included in inventory
= Required for BASIC reporting
= Required for BASIC+ reporting

2.5 Geographic Boundary

Cambridge has undertaken this community-wide Greenhouse Gas Inventory primarily to advance the City's efforts towards mitigating climate change. The ability to influence and support actions to reduce emission in the community is limited by social, economic, organizational and physical boundaries. It's important that the boundaries for the emissions inventory are well defined so that we can develop successful action plans. The GPC requires that cities identify a geographic area for the inventory that most appropriately serves the purpose of the inventory. Since the purpose of this inventory is to inform successful mitigation strategies, we chose to utilize the administrative boundary of the City of Cambridge as the boundary for the community-wide inventory.

Establishing a community-wide inventory that is focused on the emissions occurring within the administrative boundary enables us to develop emissions forecasts and reductions that directly relate to the future of the City, and our goals for reducing City-wide emissions. As outlined in the GPC, establishing this geographic boundary does not exclude emissions related to City activities that occur outside the City limits (e.g. electricity generation or landfilled waste emissions).

2.6 Baseline Year and Forecast Years

The calendar year 2012 was chosen as the baseline year for this inventory based on availability and quality of data. The team determined that data from 2012 would provide the most reliable results based on early discussions with the organizations that manage the data needed for analysis. An additional benefit of selecting 2012 as the community-wide inventory year is that it also coincides with the City's 2012 Municipal Operations Inventory. Timing municipal operations and community inventories to occur on the same years will enable improved coordination between municipal-level and community-level emission reduction goals.

For the forecast years, we chose to use 2030, 2040 and 2050 to align the City's Net Zero Action Plan, and Climate Protection Action Committee's (CPAC) Roadmap for the City's role in the global response to climate change. Between 2015 and 2040 the City will undertake a series of actions identified in the Net Zero Action Plan that are anticipated to result in significant emissions reductions in the buildings sub-sector. The CPAC roadmap also provides a framework for actions to reduce emissions 80% by 2050. In addition, the 2050 goals align with the State's commitment to reduce emissions reductions 80% by 2050 according to the Global Warming Solutions Act of 2008.

Aligning the emissions forecast years with these time horizons may also result in the added benefit of placing Cambridge's greenhouse gas inventory and reduction goals on the same timeline as other goals outlined in the forthcoming Envision Cambridge plan relating to housing, mobility, climate, and the environment.

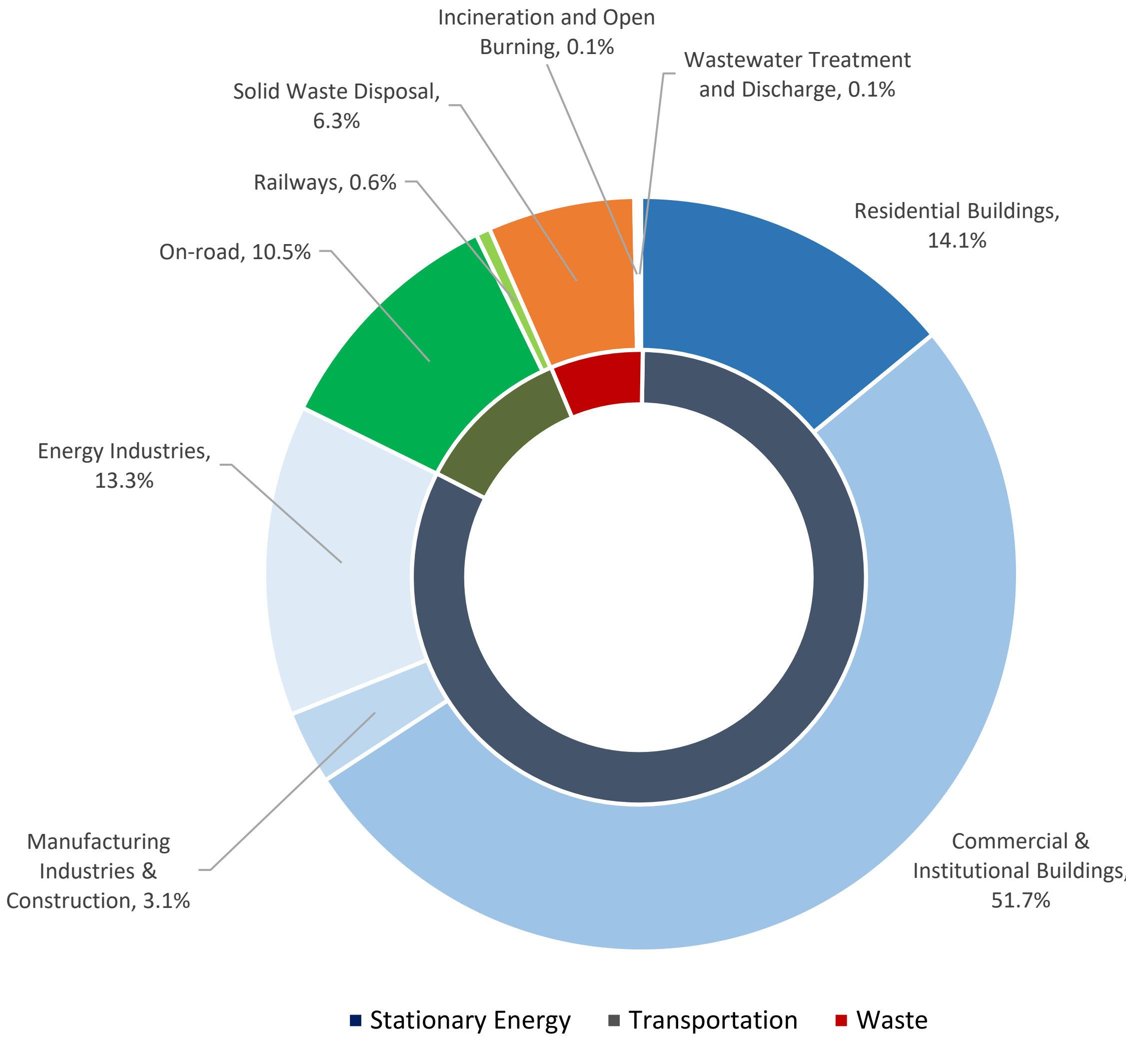
3. Inventory Results

3.1 2012 Emissions Inventory Summary

The results of the community-wide inventory show that the carbon dioxide equivalent (CO2e)[5] emissions from activities in the City of Cambridge were approximately 1.46 million metric tons in 2012. The emissions were generated in the residential, commercial, industrial, transportation, and waste management sectors. This inventory did not include emissions from agricultural activities nor does it include emissions from industrial processes and product use. Figure 4 provides a summary of total citywide GHG emissions by the various activities.

[5] Carbon dioxide equivalent is a unit of measure that normalizes the varying climate warming potencies of all six GHG emissions, which are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). For example, one metric ton of methane is equivalent to 21 metric tons of CO_2e. One metric ton of nitrous oxide is 210 metric tons of CO_2e.

Figure 4: Community-wide emissions by sector and sub-sector (2012)



As shown above, emissions from stationary energy use accounted for 82% of the emissions in Cambridge. Energy use in commercial buildings was found to be the largest contributor to emissions followed by energy use in the residential building sub-sector. Table 3 provides the emissions subtotals by sector and sub-sector.

Table 3: 2012 Community-wide emissions by sector and sub-sector

Sector	Total Emissions (MT CO2e)	Subsector	Total Emissions (MT CO2e)
Stationary Energy	1,202,956	Residential Buildings	205,495
		Commercial & Institutional Buildings	756,703
		Manufacturing Industries & Const.	45,851
		Energy Industries	194,907
Transportation	162,938	On-road	153,993
		Railways	8,945
Waste	96,342	Solid Waste Disposal	92,051
		Incineration and Open Burning	2,145
		Wastewater Treatment and Discharge	2,146
Total emissions	**1,462,236**		**1,462,236**

3.2 Stationary Energy

Emissions associated with the stationary energy category result from the use of electricity, natural gas, and fuel oil within the City's boundaries. Most of this energy use occurs in buildings, although some energy use may occur in other equipment, such as outdoor lighting, traffic control signals, or sewer or water pumps. Electricity and natural gas use is provided by Eversource and fuel oil consumption is estimated based on regional data (see section 5.1 for detailed methodology).

Buildings

A summary of energy use in each building sub-sector in 2012 and resulting emissions are shown in Table 4. Figure 5 shows a breakdown of emissions by energy use (electricity, natural gas, and fuel oil) and Figure 6 shows the breakdown of emissions by building sub-sector and fuel-use.

Table 4: 2012 Building energy use and emissions

SubSector	Nat. Gas (mmbtu)	Electricity (mmbtu)	Fuel Oil (mmbtu)	Emissions (MT CO2e)
Residential Buildings	1,663,351	861,167	297,204	193,180
Commercial & Institutional Buildings *	6,173,305	4,323,234	110,787	700,362
All	**7,836,656**	**5,184,400**	**407,991**	**893,542**

*Commercial & Institutional includes the portion of emissions from the Manufacturing Industries and Construction (MI&C) sub-sector that are associated with buildings, but not the off-road emissions that are included in the MI&C sub-sector or T&D losses.

Figure 5: Building energy use by fuel type

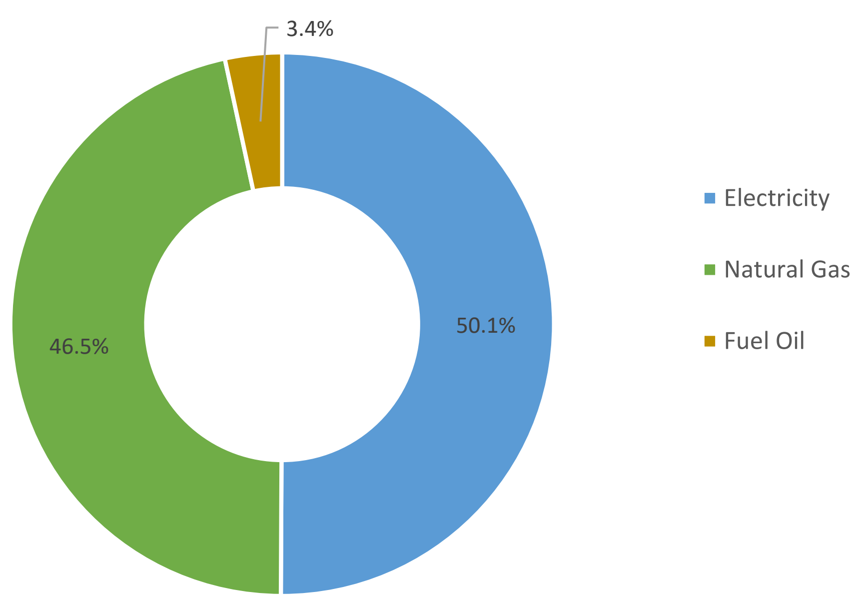
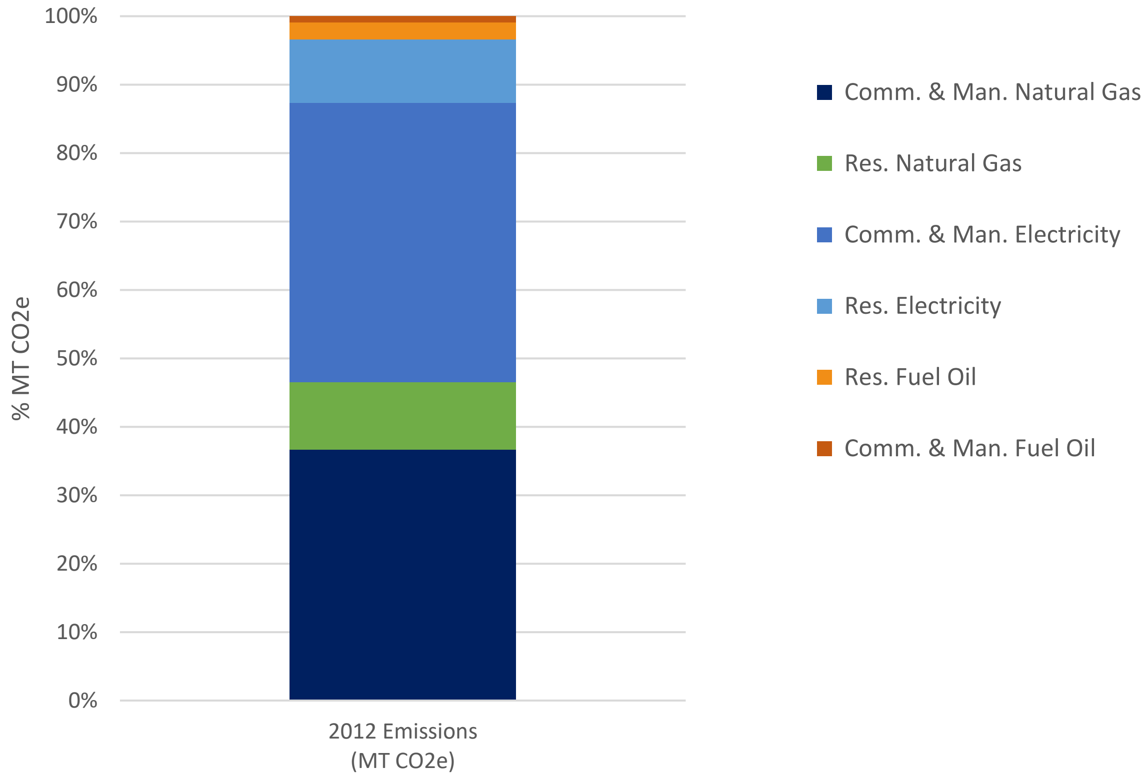
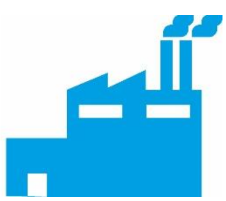


Figure 6: Building emissions by sub-sector and fuel type



Energy Industries



There are four large generators in the City: The Kendall Cogeneration Station, the MIT Central Utilities Plant, the Harvard University Blackstone Plant, and the Biogen plant. As described in Section 5: Inventory and Forecasting Methodology, emissions from the energy industries sub-sector do not need to be included in BASIC reporting. The Kendall cogeneration plant was excluded from the inventory because it supplies the regional grid, and is taken into account in the ISO New England emissions factor for electricity use. The other 3 plants were included in the inventory, as they primarily provide energy to buildings in Cambridge, rather than to the grid. Although the plants included primarily supply energy to buildings in Cambridge, they remain in the energy industries sub-sector, rather than in the buildings sub-sector. Emissions for these three plants, as reported to the EPA were 194,907 MT of CO2e.

Losses from distribution systems

Emissions associated with distribution system losses are also included in Stationary Emissions. Losses occur in both the distribution of electricity and natural gas. Electrical losses happen from inefficiencies in the equipment while natural gas losses often occur from leaking pipes. For electricity, a loss factor of 8.58% was used based on estimates from the U.S. Energy Information Administration. This resulted in an estimated loss of 3,045,138 MWh of electricity which is equivalent to 46,751 MT CO2e.

For natural gas, estimated losses were based on studies natural gas system leakage in greater Boston. Using a factor of 0.6% annual loss, we estimated that in Cambridge 473,151 therms of natural gas we loss which is equivalent to 24,572 MT of CO2e emissions.

Off-road and construction equipment

Emissions from off-road equipment and construction activity were included as part of Stationary Energy, and make up a portion of the total emissions for the Manufacturing Industries and Construction sub-sector. Using the EPA emissions modeling tool called MOVES, we estimated emissions from industrial equipment, lawn and garden equipment, and light commercial equipment to be 39,539 MT CO2e for 2012, and emissions from construction activities to be 7,616 MT CO2e.

3.3 Transportation Emissions

Transportation emissions include emissions from all on road vehicle travel from passenger and commercial vehicles that are registered in the City; on-road travel for the portion of on road public transit that occurs in the City’s geographic boundary (trackless trolley and buses); and, off-road travel for the portion of the off road public transit that occurs in the City’s geographic boundary (commuter rail and light rail)

Emissions from passenger and commercial vehicles registered in the City of Cambridge are estimated using data available from the Massachusetts Vehicle Census (MAVC). This includes information on the total number of passenger and commercial vehicles registered, the average miles traveled per year, the fuel type and estimated fuel use based on the model and year of the vehicle.

Emissions from both on and off road public transportation were estimated using fuel use and service information made available by the MBTA. The modes of public transit that serve

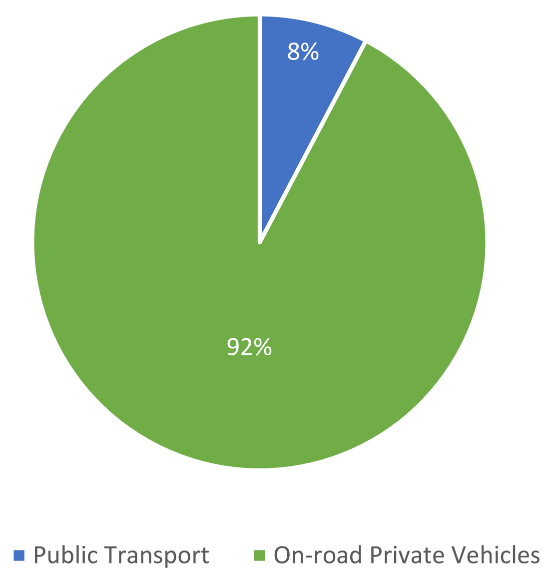
Cambridge include the commuter rail, the red and green subway line (E line), trackless trolleys and buses (bus routes 71, 72, 73, and 77A). The commuter rail uses diesel. The subway line and trackless trolleys run entirely on electricity. The buses use a mix of diesel and compressed natural gas.

A summary of transportation emissions for 2012 is included in Table 5. Figure 7 and shows the proportion of emissions from privately owned vehicles and from public transit systems in Cambridge.

Table 5: 2012 Transportation emissions

Category	Subcategory	2012 Emissions (MTCO2e)
On-road and Rail Public Transit	MBTA Bus	3,061
	Trackless Trolley	1,118
	Red Line (Heavy Rail)	7,088
	E Line (Light Rail)	310
	Commuter Rail (Fitchburg Line)	967
	All On-Road Public Transit	4,178
	All Rail Public Transit	8,366
	All Public Transit	12,544
On-road Private Transit	All On-road Private Transit	149,815
	Total emissions	**162,358**

Figure 7: Transportation emissions sources



3.4 Waste – Solid Waste Disposal

Solid waste is generated by residents and visitors, businesses, public entities, and other organizations in the community. There are two main sources of emissions from solid waste management: waste sent to landfill and waste sent to incineration. Landfilled waste results in methane emissions as organic materials decompose in the anaerobic (non-oxygen) environment of a landfill. Organic materials (e.g., paper, plant debris, food waste, and so forth) generate methane while non-organic materials do not (e.g., metal, glass, and so forth). Incineration of waste results in CO2, CH4, and N2O emissions as the waste is burned.

Landfill emissions estimates are based on a variety of factors, including whether it is an open or closed landfill, the volume of waste, and whether or not the landfill has a landfill gas collection system. For landfilled waste, the GPC requires accounting for methane emissions. These emissions were estimated using the Methane Commitment Model, which assigns the total lifetime emissions from the amount of waste sent to landfill in a given year to the emissions inventory for that same year in which it was generated. Waste disposal amounts were provided by the Cambridge Department of Public Works. The estimated emissions from waste sent to landfill was 95,051 MT CO2e.

According to the GPC, emissions associated with the waste generated within the City boundary that is incinerated outside the City are included for BASIC reporting. As mentioned in Section 3.6, ~65% of solid waste in Massachusetts is sent to incineration facilities where it is used to generate electricity. Using DPW records and estimates of waste generated by commercial business and hauled away by private haulers, we estimated emissions from waste sent to incineration were 2,145 MT CO2e.

3.5 Waste - Wastewater

Wastewater treatment results in process and fugitive emissions of methane and/or nitrogen oxide (N2O). Wastewater from Cambridge is treated at the Deer Island wastewater treatment plant in Boston. No methane was released from the treatment process in 2012 as the facility used 97.3% of the methane produced during wastewater treatment for heating the digester tanks, according to MWRA records. Methane that is not used to heat the digester tanks is diverted to a cogeneration system where it is used to heat buildings and generate electricity via steam turbine generators. Because of this, methane emissions associated with the treatment process were excluded from the 2012 community-wide inventory.

The N2O emissions occur as a bi-product of wastewater after it is discharged into waterways. Based on the population of Cambridge and the amount of protein consumed per capita referenced in U.S. EPA literature, we estimated the total emissions associated with wastewater treatment for the City to be 2,146 MT CO2e.

4. Emissions Forecasts

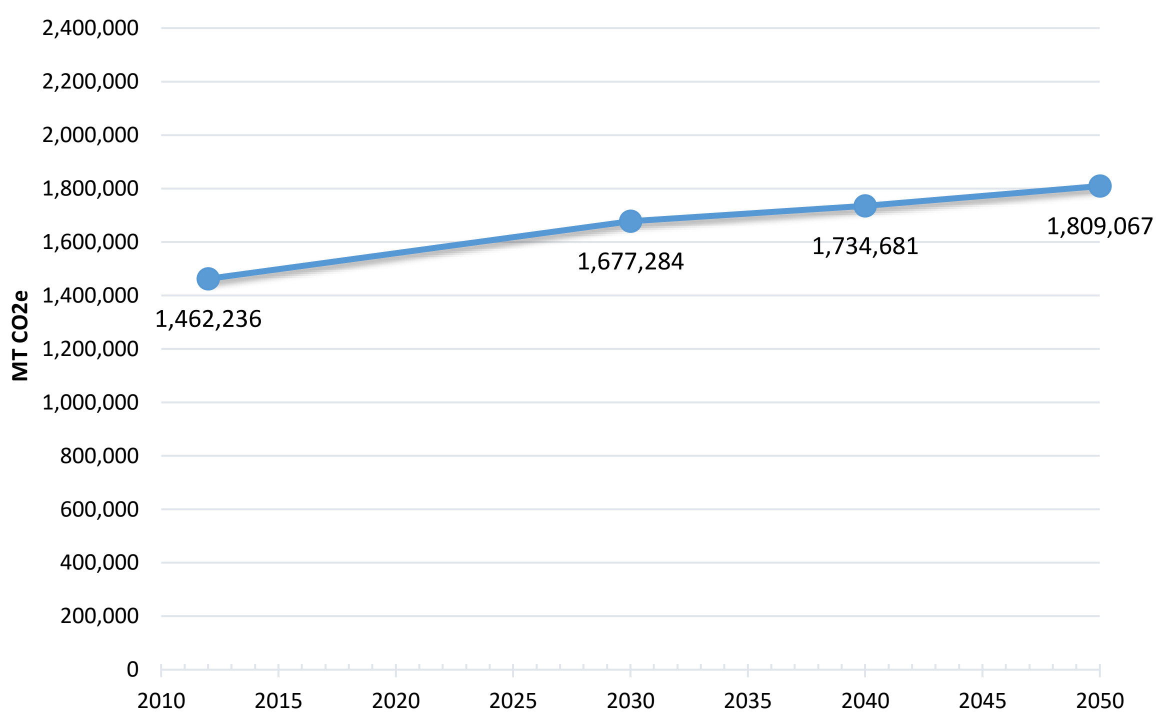
Conducting an emissions forecast is an essential step in developing strategies to reduce GHG emissions. Projecting emissions based on growth scenarios and comparing to potential reductions from policies and actions taken (referred to collectively as “measures” in this section) provides insight into whether a specific target level of reduction will be achieved by a particular year. As part of the community-wide inventory, emissions forecasts were created to estimate future emissions out to 2030, out to 2040 and then out to 2050 using the 2012 baseline as a starting point.

The forecasts represent three different scenarios; one business-as-usual (BAU) scenario and two scenarios that include federal, state and local measures that will have an effect on the BAU emissions during those time periods.

Business-as-Usual Emissions Forecast

The "business-as-usual" (BAU) emissions forecast represents a calculation of how GHG emissions would change based on projections for jobs, housing, and population growth, and in the absence of any measures aimed at reducing GHG emissions. Figure 8 summarizes the BAU forecast for the City out to the selected forecast years.

Figure 8: Forecasted business-as-usual emissions for 2030, 2040, 2050



Emissions Forecast with State Measures

State measures such as the California Clean Car Standards (which Massachusetts law requires the Commonwealth to adopt) and the Massachusetts Renewable Energy Portfolio Standard

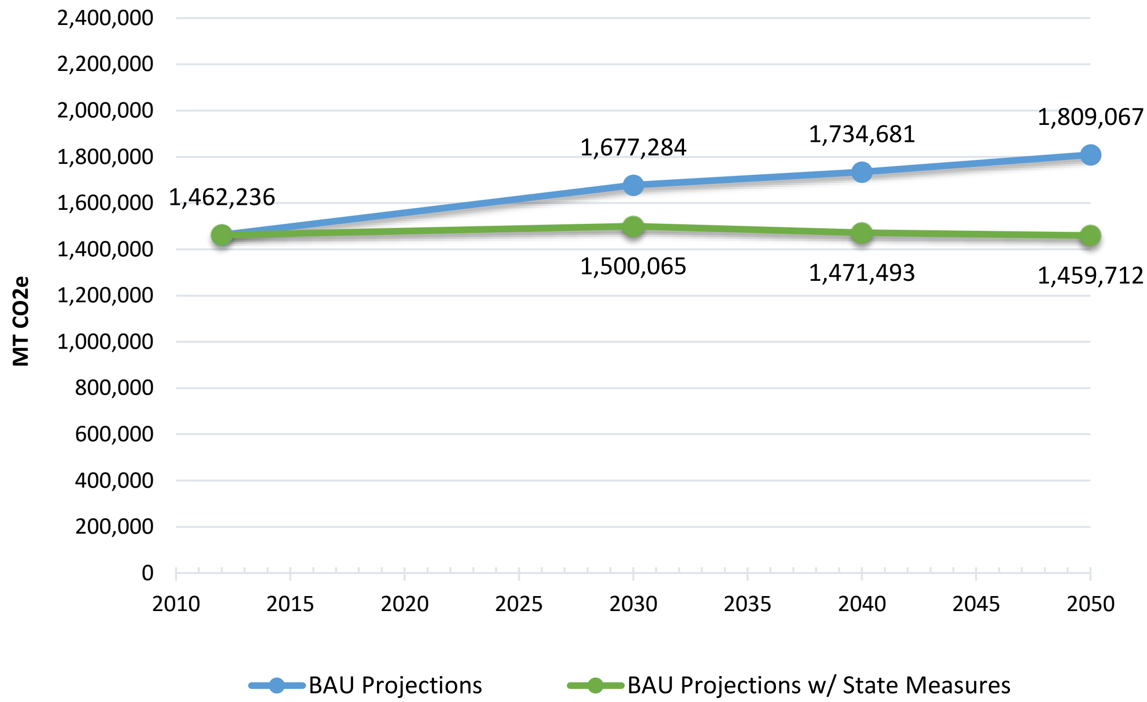
(RPS) have the potential to significantly reduce future emissions in Cambridge. It is important to incorporate these State measures into the emissions forecast so the City has an accurate estimate of what portion of their emissions reduction target will be satisfied by State measures and what portion will need to be satisfied by City measures.

Table 6 summarizes the projected BAU emissions in Cambridge (top row), the projected emissions avoided by State measures (middle rows), and the remaining BAU emissions (bottom row). Figure 9 provides a visualization of the projected BAU emissions and the projected BAU plus avoided emissions from State measures.

Table 6: 2030-2050 Business-as-usual emissions factoring in State measures

Description	2030	2040	2050
BAU Emissions (MT CO2e)	1,677,284	1,734,681	1,809,067
Emissions Reduction from Vehicle Efficiency Standards + EV Market Growth (MT CO2e)	-68,742	-83,700	-90,896
Emissions Reduction from RPS (MT CO2e)	-108,477	-179,488	-258,459
Remaining BAU Emissions w/ State Measures (MT CO2e)	1,500,065	1,471,493	1,459,712

Figure 9: Forecasted emissions for BAU and State measures only scenarios for 2030, 2040 & 2050



Emissions Forecast with State and City Measures

The City also currently has a variety of measures in place aimed at reducing emissions. We considered the impact of these measures in the emissions forecast to understand their possible long-term effect on future emissions. Table 7 provides a list of the City measures taken into account in the forecast.

Table 7: List and description of City measures quantified

City Measure	Description of Measure
1. Reduce Emissions from Municipal Operations	Cambridge has adopted a target of reducing emissions from municipal operations to 30% below 2008 levels by 2020.

2. Net Zero Emissions from New & Existing Buildings	Cambridge has adopted a plan that would require all new buildings in the community to be Net Zero Emissions (NZE) by 2030 and existing buildings, in aggregate, to be ZNE by mid-century.
3. Solar Installations in Cambridge	Cambridge has adopted a target of 60 MW of installed solar capacity in the community by 2020 and 160 MW of installed solar capacity in the community by 2040 as part of the Net Zero Action Plan.
4. Reduce Vehicle Miles Travelled by Vehicles Registered in Cambridge	Cambridge has adopted a target of reducing VMT from vehicles registered in Cambridge 5% below 2010 levels by 2020.
5. Reduce Vehicle Ownership Per Household Rate	Cambridge has adopted a target of reducing community vehicle ownership per household 15% below 1990 levels by 2020.
6. Reduce Residential Waste Collected by the City Trash Service	Cambridge has adopted a target of reducing residential waste collected by the City trash service 30% below 2008 levels by 2020 and 80% below 2008 levels by 2050.

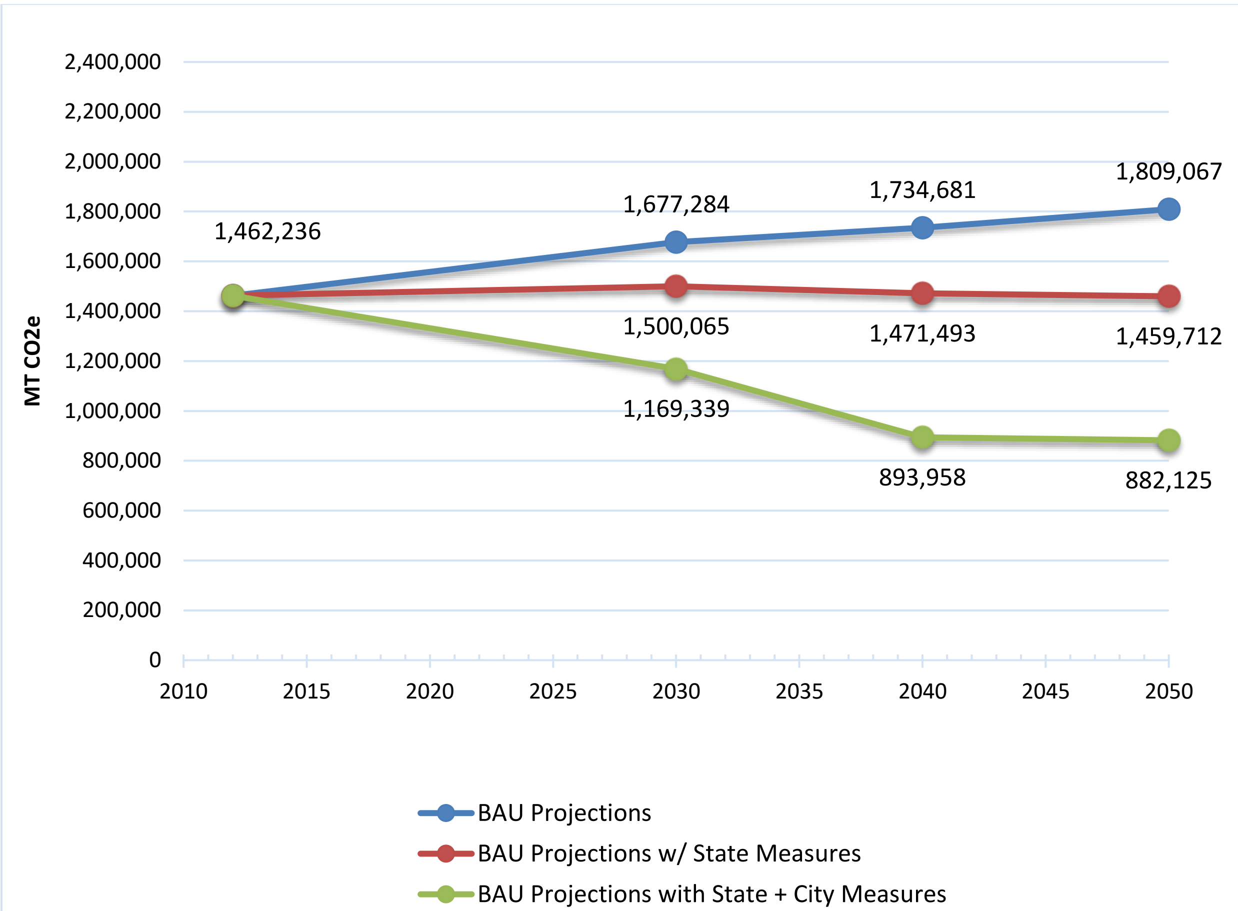
Table 8 summarizes the projected BAU emissions in Cambridge (top row), the projected BAU plus emissions avoided by State measures (second row), and the projected BAU plus the cumulative emissions avoided by both State and City measures. We also provided the expected emissions remaining once all State and City measures are implemented. Figure 10 provides a visualization of these three forecast scenarios.

Table 8: 2030-2050 Emissions forecast factoring in State + City measures

Category	2030	2040	2050
Business-as-usual Emissions	1,677,284	1,734,681	1,809,067
Emissions Avoided from State Measures	-177,218	-263,189	-349,355
Emissions Avoided from City Measures	-330,727	-577,535	-577,586

Remaining Emissions with State + City Measures Implemented	1,169,339	893,958	882,125

Figure 10: Forecasted emissions for BAU, State measures only and State & City measures scenarios for 2030, 2040 & 2050



These forecasts indicate that while City and State measures will have a significant impact on emissions generated in the future, they are not enough to reach the goal of an 80% reduction by 2050. To reach an 80% reduction in the next 33 years, Cambridge needs to reach an annual generated emissions level of ~292,000 MT CO_2e – a 66% reduction beyond the current projection. It's important to remember however, that not all measures currently in place at both the State and City that impact future emissions could be accounted for in these forecasts. We did not include in the forecast the impacts of measures such as purchasing 100% renewable electricity for municipal operations, or increasing renewables through a community aggregation program. Only those measures whose impacts were readily quantifiable were considered here.

5. Inventory and Forecasting Methodology

5.1 Quantifying Greenhouse Gas Emissions

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

Activity Data (units) x Emission Factor = Emissions (MT CO2e)

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

Known emission factors are used to convert energy usage or other activity data into quantities of emissions generated by the activity. Emissions factors are usually expressed in therms of emissions per unit of activity data (e.g. metric tons of CO_2 per kWh of electricity). There are seven greenhouse gases of concern according to the GPC – carbon dioxide (CO2), methane (CH4), Nitrous Oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF6), and nitrogen trifluoride (NF3). Each of these are assigned a CO2 equivalent factor based on their potential to trap heat relative to CO2, also called its global warming potential (GWP). Emissions can then be consistently reported by the total CO2 equivalent (CO2e) which is arrived at by multiplying the emissions for each gas by its GWP.

Appendix A contains a detailed description of the emission factors and methodologies used, and any assumptions made in this inventory. Key activity data are listed in the sections that follow. All data that was compiled for the 2012 inventory was collected in a manner that was transparent and repeatable for future inventories. Should a new data source become available, such as more reliable fuel oil emissions or backup residential diesel generators, they can be added accordingly.

5.1.1 Stationary Energy – Electricity

Most of the electricity consumed in Cambridge is produced by power generators located in Massachusetts, other New England states, and Canada. Electricity used in Cambridge is generated using a mix of natural gas, nuclear, coal, hydroelectric, and other renewable sources, and is supplied to electricity consumers through a regional grid. For community-wide inventories, electricity consumption is primarily a Scope 2 emissions source.

Grid-supplied electricity is provided throughout the City and powers the residential, commercial, and industrial sub-sectors, in addition to City infrastructure and transport systems. The City of Cambridge has a single electricity provider, Eversource (excluding any electricity provided locally by the cogeneration facilities), that transmits and distributes electricity from the various power generators. As such, Eversource was the primary source for gathering electricity consumption data in the City. We gathered real consumption data aggregated at the sub-sector level to determine the annual electricity consumption (kWh/year). Reported emissions from all grid-supplied electricity consumed within the City's boundaries were reported as Scope 2 emissions.

A grid-based average emission factor was used to determine the emissions. The emissions factor used for grid supplied electricity is provided in Table 9 and is based on data from ISO New England[6].

Table 9: ISO New England 2012 electricity system emissions rate

Regional Transmission Organization	CO_2 Emission Factor (lbs CO2 / MWh)	CO_2 Emission Factor (MT CO2 / kWh)
ISO New England	719	0.00033

5.1.2 Stationary Energy – Natural Gas

The primary uses for natural gas in the City of Cambridge are for space heating, water heating equipment, and cogeneration stations, which burn fuel to generate both electricity and steam for heating. The emissions from these sources are defined as Scope 1 emissions according to the GPC. Grid-supplied natural gas is provided throughout the City and is primarily used by the

[6]ISO New England. "2012 ISO New England Electric Generator Air Emissions Report" www.iso-ne.com/static-assets/documents/genrtion_resrcs/reports/emission/2012_emissions_report_final_v2.pdf

residential, commercial, and industrial building sub-sectors for heat and hot water production. Eversource was also the primary source of information for natural gas consumption in the City, as there are no other utilities that distribute natural gas in Cambridge.

In accordance with Section 6.3 of the GPC metered natural gas use data, measured in therms and aggregated by each building sub-sector, was used as the source of the annual consumption.

Because Eversource-specific emission factors for natural gas emissions were not available, a universal emission factor provide by the Climate Registry[7] was used to calculate natural gas emissions. The emissions factor used for natural gas consumption is provided in Table 10.

Table 10: Natural gas consumption emissions rate

Type of Emission	CO_2 Emission Factor (kg CO2 / MMBtu)	CO_2 Emission Factor (MT CO2 / Therm)
Natural Gas Consumption	53.06	0.0053

*Note CH4 or N2O are not included because these emissions are considered to be de minimis

For the four large cogeneration facilities located in the City, fuel consumption and emissions data were gathered from publicly available reports provided on the U.S. EPA's Greenhouse Gas Reporting Program website (https://ghgdata.epa.gov/ghgp/main.do#). The four facilities include: The Veolia Kendall Cogeneration Station, the MIT Central Utilities Plant, the Harvard University Blackstone Plant, and the Biogen plant. Because ISO New England electricity emission factors includes emissions from plants that are at least 25 MW in capacity, the Kendall Cogeneration Station – a 256 MW steam and electric plant – was excluded from the inventory. Emissions from the other 3 plants were included as stationary energy emissions. While energy generation facilities within the City that supply energy to the local grid are not required for BASIC reporting, we included the MIT Central Plant, the Harvard University Blackstone Plant and the Biogen plant in the inventory because the energy they supply is used in buildings in Cambridge and we felt this provided a more accurate estimate of the emissions associated with building energy use.

The GPC also requires the losses from natural gas distribution systems be accounted for in emissions inventories. We reviewed several studies on the subject of gas leakage from the distribution system network in and around the Boston. Based on an article written for the

[7] 2015 Climate Registry Default Emissions Factors, released April 2015

Proceedings of the National Academy of Sciences[8] we determined that an average leakage rate of 0.6% was appropriate for the inventory. Using this rate we calculated the overall emissions factor for gas leaked from the distribution systems to be 0.04628 MT CO2e/leaked therm based on volume of gas, density of the gas, the fraction of methane delivered and the carbon dioxide content.

5.1.3 Stationary Energy – Fuel Oil

Energy use in residential, commercial and industrial sub-sectors in Massachusetts communities includes fuel oil consumption as well. While electricity and natural gas is distributed to Cambridge by one utility, fuel oil is supplied by many different private distributors. Because customer data could not be collected from each distributor, consumption was estimated using community-specific assumptions. Any limited fuel oil usage by the Kendall Station, Blackstone plant, and MIT CUP is accounted for in the U.S. EPA Greenhouse Gas Reporting Systems reports.

For the residential sub-sector, total fuel oil use was estimated based on the number of housing units in Cambridge by type, a percentage of units determined to be heated with fuel oil from the "American Community Survey (ACS) 2010-2014 5-Year Community Estimate.", and the State average for fuel oil use and expenditures for different housing types.

Massachusetts has a lower concentration of single family homes and a higher concentration of two- to four-unit apartments. To account for this a weighted New England Average Consumption based on the percentage breakdown of housing unit types in Massachusetts was used. Standard GHG emissions factors for fuel oil was then applied to the total gallons of estimated fuel oil used in the residential sub-sector.

For the Commercial & Institutional and Manufacturing Industries & Construction sub-sectors, fuel oil use estimates were based on the total number of employees, the type of establishments by Primary Building Activity (PBA), and the average expected fuel use per employee for each PBA according to the US Energy Information Administration's Commercial Building Energy Consumption Survey (CBECS) 2003.

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McKain. 2015. "Methane emissions from natural gas infrastructure and use in the urban region of Boston, Massachusetts." *Proceedings from the National Academy of Sciences, vol. 112*, February: 1941-1946.

In accordance with Section 6.3 of the GPC, the emissions from these Stationary Energy sources were calculated by multiplying the estimated fuel use by the corresponding emission factors for the fuel.

5.1.4 Stationary Energy – Off-Road Vehicles and Equipment

Mobile machinery emissions that occur off public roadways were also included in this inventory. The off-road mobile activities are categorized according to the source from which they occur. For the purposes of the GPC, only activities in the City (Scope 1) emissions were included.

The off-road emissions data was derived from a publicly available U.S. EPA emission modeling system called the Motor Vehicle Emission Simulator (MOVES). MOVES estimates emissions for mobile non-road sources at the national and county level for criteria air pollutants, greenhouse gases, and air toxics. In accordance with Section 6.3 and 7.7 of the GPC, the community-wide inventory used the modeling tool MOVES2014a data, disaggregated by sub-sector, and allocated to Cambridge proportionally.

The MOVES2014 modeling tool multiplies equipment population, average load factor expressed as an average fraction of available power, available power in horsepower, hours of use per year, and emission factors with deterioration and/or new standards. Emissions are then temporally and geographically allocated to counties using appropriate allocation factors. The emissions output for this assessment was restricted to the Middlesex County geographic bounds, the smallest subdivision possible in the model. Cambridge proportional emissions data were extracted from the county-level data for Middlesex County based on a variety of factors. Table 11 summarizes the methodologies used for each of the off-road emission sources.

Table 11: Off-road emissions sources and methodologies

Off-Road Mobile Emission Source	Proportionality Multiplier Source	Category
Commercial Activity	Retail Jobs Ratio	Commercial
Industrial Activity	Manufacturing Jobs Ratio	Industrial
Lawn and Garden	Percentage of Permeable Surface Area	Commercial
Construction	PA of NY WIP Method	Commercial

Commercial and Industrial activity is correlated with job sector data, and thus jobs were used to allocate a portion of Middlesex county emissions to Cambridge. Lawn and Garden activity is allocated using the ratio of landscaped area in Cambridge versus the total landscaped area in Middlesex County (determined by a GIS geospatial analysis). Construction related fuel emissions were estimated using the work-in-place (WIP) method and fuel factor from the "GHG and Criteria Air Pollutants Emissions Inventory for the Port Authority of New York and New Jersey", CY 2011. The WIP method uses an established emissions rate estimate per dollar of construction value (i.e. the dollar amounts for construction contracts). The total annual cost of construction in Cambridge was determined using the "Cambridge Open Data, Commercial and Multifamily Building Permits, Building Cost of Construction."

5.1.5 Transportation – Vehicle travel on-road

There are several methodologies recommended by the GPC for calculating on-road transportation emissions. In accordance with Section 7.3 of the GPC, we used the resident activity method to quantify on-road transportation emissions. This method quantifies emissions from transportation activity undertaken by City residents and businesses that garage their vehicle in the City. There are a few key benefits of the resident activity method. The data used for the resident activity methodology is free and will be available to the City on an annual basis. Secondly, the resident activity methodology is a good approach when double counting with other cities in the region is a concern. If each city only quantifies the impact of vehicles registered in their city, the complications that arise from allocating cross-boundary trips to multiple jurisdictions can be avoided.

The Massachusetts Vehicle Census (MAVC) data was used to estimate emissions from vehicles registered in Cambridge. The MAVC is a catalog of information about vehicles registered in the Commonwealth from 2009 to 2014. The MAVC combines information from vehicle registrations, inspection records, mileage ratings, and other sources to document the ownership and mileage history of each vehicle. The MAVC was mined for passenger and commercial vehicles garaged in Cambridge for vehicle inspections during quarter 2 of 2012. The data accounts for cars garaged in Cambridge including commercial vehicle fleets and rental cars available in Cambridge.

The MAVC provided the data on the number of vehicles in Cambridge, average vehicle miles travelled (VMT), average fuel efficiency of vehicles and fuel consumption of vehicles broken down by both fuel type and passenger vs. commercial vehicles. Fuel types included gasoline, diesel, flex fuel, hybrid, and electric. Table 12 provides a summary of data collected.

Table 12: Detailed attributes reported for on-road vehicles garaged in Cambridge

Attribute	Details
Count	Total vehicles based city/ town vehicle is registered in
Average Miles per Day	Average daily mileage for vehicles with a valid inspection record
Average VMT per Day	Average daily mileage for vehicles with a valid inspection record multiplied by the vehicle count
Average VMT per Year	Average daily mileage for vehicles with a valid inspection record multiplied by the vehicle count and by 366 (2012 was a leap year)
Average VMT by Vehicle per Year	Average annual mileage divided by the count of vehicles with a valid inspection record
Average Fuel Efficiency (mpg)	Average fuel economy for vehicles with valid mileage estimates, weighted by average daily mileage. Calculated as total estimated fuel consumption (gal_per_day) for vehicles with valid mileage estimates and fuel economy ratings, divided by total daily miles for same vehicles.
Fuel Consumption per Year	Average VMT per year divided by the average fuel efficiency

Diesel and gasoline emission factors used are from The Climate Registry (TCR) and the electricity emission factor is from ISO New England as provided in Table 13.

Table 13: Public transit emission factors

Fuel Type	Emission Factor	Emission Factor Units	Source
Gasoline	0.01032	MT CO2e / gallon	TCR
Diesel	0.01033	MT CO2 / gallon	TCR
Electricity	0.000353802	MT CO2 / kWh	ISO New England

Electric Vehicle VMT Data

For electric vehicles, the MVAC provided the number of vehicles registered in Cambridge and the VMT by these vehicles. However, the MVAC data did not include data on electric vehicle fuel efficiency. To estimate the electricity consumed by electric vehicles in the MVAC database, electric vehicle fuel efficiency was estimated based on the vehicle fuel efficiency of the top three selling electric vehicles in 2012 in the United States. The efficiency of the 2012 Nissan Leaf (0.34 kWh/mile), 2012 Chevrolet Volt (0.36 kWh/mile), and 2012 Toyota Prius Plug-in (0.29 kWh/mile) were averaged to come up with an average electric vehicle fleet efficiency of 0.33 kWh/mile. Using this average electric vehicle fleet efficiency, the electricity consumption associated with VMT by electric vehicles in the MVAC database was calculated.

Electric Vehicle Charging Station Data

Scope 2 electricity emissions associated with the on-road transportation sub-sector were also quantified. For this inventory, we contacted ChargePoint, an electric vehicle (EV) charging network company to discuss charging station usage and configurations. In 2012, the City of Cambridge worked with ChargePoint to install 25 EV charging stations[9]. ChargePoint provided the number of EV charging ports in 2012 and their total electric fuel use for the year as shown in Table 14.

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[9] City of Cambridge, CDD. 2012. "Electric Vehicle Charging Stations." www.cambridgema.gov/CDD/News/2012/05/electricvehiclechargingstations.aspx

Table 14: EV charging ports and electric fuel use in Cambridge (2012)

Total ChargePoint Ports	Electric Fuel (MWh)	Average Fuel Use per Station (MWh)
25	14.47	0.5788

For the 2012 inventory, electric consumption from all 25 stations in the On-Road Transportation Emissions data was included. A number of these charging stations are known to be located behind existing building meters (i.e. the electric consumption for these stations is included in the electricity use of the building), but because we were unable to confirm which stations are behind existing meters and which aren't, all of the consumption was used. This means that there may be some double counting of the electricity used by charging stations, as they are included here, but are likely also included in the buildings sub-sectors. However, at this time the amount that is potentially double counted is very small.

5.1.6 Transportation – Public transit

The City of Cambridge is served by four modes of public transit - heavy rail (commuter rail and the red line), light rail (the green E line), trackless trolleys (routes 71, 72, 73, and 77A), and buses. Trackless trolley and bus emissions were calculated in accordance with Section 7.3 of the GPC. Heavy rail, light rail, and commuter rail emissions were quantified in accordance with Section 7.4 of the GPC. The commuter rail trains use diesel fuels in their operation while buses use both diesel and compressed natural gas (CNG) for fuel. The red line, green line and trackless trolleys operate on electricity. Diesel and CNG emission factors were from TCR and electricity emission factor was from ISO New England as provided in Table 15.

Table 15: Public transit emission factors

Fuel Type	Emission Factor	Emission Factor Units	Source
Diesel	0.01033	MT CO2e / gallon	TCR
CNG	0.05306	MT CO2 / MMBTU	TCR
Electricity	0.000353802	MT CO2 / kWh	ISO New England

Emissions estimates for each mode of transport are primarily based on the percent of VMT traveled within the City compared to the overall system-wide VMT. Table 16 provides a summary of the Cambridge route miles versus the system route miles.

Table 16: MBTA routes miles estimates

Transit Type	Cambridge Route Miles	System Miles	Cambridge pct
Red line (heavy rail)	4.2	39.1	10.7%
E line (light rail)	0.4	22.8	1.8%
Fitchburg line (commuter rail)	3.4	438.5	0.8%
Transit Type	**Cambridge VMT**	**System VMT**	**Cambridge pct**
Trackless trolley	898,588.8	1,601,904.0	56.1%
Bus	1,439,501.7	40,933,536.6	3.5%

Commuter Rail

To estimate the amount of diesel fuel consumed by the Commuter rail within the City of Cambridge, the total system-wide diesel fuel consumption in calendar year 2012 was multiplied by the percentage of the commuter rail track system contained within Cambridge. We counted both revenue and non-revenue commuter rail diesel consumption.

Electricity Based Heavy Rail, Light Rail, Trackless Trolley

Transit electricity usage associated with the red line, green line and trackless trolleys was first broken down by transit mode based on annual vehicle miles travelled for each mode. In calendar year 2012, of the total VMT for modes that use electricity, 78.4% was from heavy rail (red, blue, orange lines), 19.4% was from light rail (green lines), and 2.2% was for trackless trolley lines. We applied these percentages to the system-wide estimate of electricity used for the transit system to arrive at system-wide estimates for each mode.[10]

[10] This calculation assumes that electricity usage per vehicle mile traveled is roughly similar between heavy rail, light rail, and trackless trolley. Ideally, this value would be further weighted by an electricity efficiency factor.

We then estimated the percentage of electricity use for each mode that should be allotted to Cambridge. For heavy rail, this estimate was based only on the percentage of the system's heavy rail track that lies within the boundaries of Cambridge (10.7% or 4.2 of 39.1 system miles). For light rail and trackless trolley, the Cambridge percentage was based on an estimate of annual vehicle miles traveled.

Light Rail VMT was estimated based on the schedules published in the 2014 edition of the MBTA's Blue Book. MAPC estimated a weekday, Saturday, and Sunday frequency by line, then calculated an estimate of the annual number of trips by line using the following formula:

*Annual count = (weekday * 254) + (Saturday * 54) + (Sunday * 58)*[11]

This frequency was then multiplied by total route length of the corresponding line to arrive at annual VMT by line. The length of the E line contained within the City of Cambridge was multiplied by number of annual E line trips to arrive at an E line VMT estimate for the City. The percentage of VMT within the City of Cambridge was multiplied by the light rail electricity estimate for 2012 to arrive at an estimate for Cambridge's contribution.

Trackless Trolley VMT was estimated based on General Transit Feed Specification (GTFS) schedule data from March 2012.12 MAPC created a relational database to connect the calendar table to the trip table by the service ID, which is a unique identifier for days that have the same schedule. Trip counts were then determined by line and service, then selected the maximum number of trips for each line for a Wednesdays, Saturdays, and Sundays. MAPC came up with an annual estimate for number of trips by line using the formula above.

This frequency was multiplied by the total mileage of each route and the route length contained within the City of Cambridge to arrive at a percentage of trackless trolley VMT within the City. This percentage was then multiplied by the system-wide estimate of trackless trolley electricity use to arrive at an estimate for Cambridge's use.

Bus

For buses that operate in the City, MAPC estimated diesel and CNG consumption by busses within Cambridge by applying the percentage of revenue bus VMT within the City to the system-

[11] 2012 was a leap year, which gave it one extra week day. Two holidays changed week day schedules to Saturday schedules, and five holidays changed week days to a Sunday schedule.
[12] Archived GTFS data can be found here: http://www.gtfs-data-exchange.com/agency/massachusetts-bay-transportation-authority/

wide diesel and CNG consumption by busses from calendar year 2012.[13] MAPC estimated bus VMT using GTFS data following the same method as for trackless trolley VMT.

5.1.7 Waste – Solid Waste Disposal

For the City of Cambridge, solid waste consists mainly of Municipal Solid Waste (MSW), but is collected by various entities. MSW from small residential properties and businesses is collected by the Department of Public Works (DPW) as part of the municipal curbside pick-up programs. MSW from large commercial, multi-family residential complexes and institutions is collected by private haulers that are contracted by the property owners. Detailed data on the total metric tons of solid waste collected by the municipal curbside program is available and used to estimate emissions from that portion of the waste generated in Cambridge. The total metric tons of solid waste collected by private haulers was not available and therefore was estimated based on square-feet of commercial space in Cambridge and a factor for how many metric tons of waste is generated per square-foot. Based on the total metric tons of waste collected by the DPW and the estimated metric tons of waste collected by private haulers, we estimate that about 30% of the waste generated in the City is picked up by the DPW, while the remaining 70% is collected by private haulers.

There are two main sources of emissions from solid waste management: waste sent to incineration and waste sent to landfill. Incineration of waste results in CO2, CH4, and N2O emissions as the waste is burned. Landfilled waste results in methane emissions as organic materials decompose in the anaerobic (non-oxygen) environment of a landfill. Organic materials (e.g., paper, plant debris, food waste, and so forth) generate methane while non-organic materials do not (e.g., metal, glass, and so forth).

On average, ~65% of MSW in Massachusetts is diverted to incineration facilities, and the other 35% goes to a landfill. This data is based on the Massachusetts Department of Environmental Protection (MA DEP) 2014 Solid Waste Update. Cambridge-specific data on percent of waste landfilled vs. incinerated was not available at the time of this report.

In Massachusetts, incinerated waste is used to produce electricity. Emissions generated as a result of incineration out of city boundaries is considered Scope 3 emissions. Incinerated waste

[13] This calculation assumes a geographically even distribution of CNG and Diesel busses. The MBTA does not currently have estimates of fuel mix by bus line.

emissions were estimated using equation 8.6 of the GPC. This equation calculates CO2, CH4, and N2O emission based on the total mass of waste incinerated, the type of waste, and the carbon content for each category of waste.

Emissions from waste sent to landfill are based on a variety of factors, including whether it is an open or closed landfill, the volume of waste, and whether or not the landfill has a landfill gas collection system. Equation 8.3 is used to calculate total methane (CH4) emissions. This is known as the Methane Commitment Model, which calculates total lifetime methane emissions from waste sent to the landfilled in a given year, and then assigns those emissions to the year in which the waste was generated.

Alternatively, a First Order of Decay method can be used to calculate methane emissions from waste sent to landfill, and assign emissions based on the release of the methane over time as the landfill waste deteriorates. However, this method requires historical waste disposal data, which was not available for years prior to 2012.

Equations 8.1, 8.3 and 8.4 require the user to input values for each variable based on the characteristics of the waste generated and the landfill it is sent to. For equation 8.1, Degradable organic carbon (DOC) is calculated based on the proportion of certain types of waste (e.g. food, paper, wood, etc.) in the waste stream. For this inventory, we used DPW Waste Categories from the report "What's in Weekly Household Trash", to determine the characteristics for all waste generated in Cambridge.

Equation 8.3 calculates the CH4 emissions based on the mass of solid waste sent to landfill (MSW), the methane generation potential (Lo), the fraction of methane recovered from the landfill (Lfrac), and the oxidation factor (OX). For this inventory, the Fraction of Methane Recovered in Landfill was assumed to be 0.0 because it could not be determined at the time which landfills Cambridge waste was sent to. An Oxidation Factor of 0.1 was selected because we could say that in all likelihood, the landfills Cambridge sends waste to are managed. These are in accordance with GPC values. The methane generation potential (Lo) is calculated as part of equation 8.4.

The methane generation potential is calculated based on a methane correction factor (MCF), the DOC calculated as part of equation 8.1, the fraction of DOC degraded (DOCf) and the fraction of methane in landfill gas. In accordance with the GPC, the following values were used:

1) A value of 1.00 was input for Methane Correction Factor (MCF) since landfills waste is sent to are actively managed.

2) A default value of 0.6 was input for Fraction of Degradable Organic Carbon Degraded (DOCf).

3) A default value 0.5 was input for Fraction of Methane in Landfill Gas (F).

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

5.1.8 Waste – Wastewater

Wastewater in the City is generated by residents, businesses and industrial processes. All wastewater produced in the City is directed to the Deer Island Treatment Plant in Winthrop, MA. The Massachusetts Water Resource Authority (MWRA) operates the Deer Island facility and was the main source of data used to calculate the GHG emissions from wastewater generation in Cambridge.

For Deer Island, no methane is released from the treatment process. The facility used 97.3% of its methane in 2012 for heating the digester tanks according to MWRA records. The excess is diverted to a cogeneration system where it is used to heat buildings and generate electricity via steam turbine generators. This saves the MWRA approximately $15 million dollars annually in fuel oil costs. Any emissions associated with this process is considered scope 3 and there is no guidance at this time on accounting for the combustion of methane for heat outside the City boundary.

For the Cambridge community-wide inventory, only N2O emissions from wastewater treatment need to be considered (Equation 8.11 of the GPC). This N2O is primarily from disposal of effluent into the ocean. N2O emissions are estimate based on the total population of Cambridge served by the Deer Island Treatment Plant, the per capita protein consumption value, and the fraction of nitrogen in protein. Key variables used to complete this equation can be found in the U.S. EPA Inventory of U.S. Greenhouse Gas Emissions and Sink (1990-2014) [14] including:

[14] EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks, Domestic Wastewater N2O Emissions Estimates

- Annual per capita protein consumption: 34.7 kg/person/yr
- Factor to adjust for non-consumed protein: 1.40 (for countries with garbage disposals)
- Fraction of nitrogen in protein: 0.16
- Factor for industrial and commercial co-discharged protein to sewer system: 1.25
- Nitrogen removed from sludge: 0.0 kg/year (default value)
- Emissions factor for N2O from discharged wastewater: 0.005 kg N2O-N/kg N2O (default value)
- Conversion of kg N2O-N into kg of N2O: 1.57

5.1.9 Forecasting Methodology

Forecasting emissions helps cities understand the future trajectory for emissions with and without intervention based on project growth scenarios. For this inventory, we forecast emissions out to 2030, out to 2040 and then out to 2050 for a business as usual (BAU) scenario (with no local policy influence) and two scenarios that include estimated reductions from select State and City measures that will have an effect on emissions during those time periods. The 2030 forecast time horizon was chosen because it aligns with the time horizons of both the Cambridge Climate Vulnerability Assessment goals and Envision Cambridge. The 2050 forecast time horizon aligns with the time horizon of both the City's commitment and the State's goal of an 80% reduction in GHG emissions by 2050. The 2040 forecast time horizon aligns with the City Net Zero Action Plan, and will serve as an interim year to assist the City in measuring progress between the 2030 and 2050 targets.

To project BAU growth in emissions, the compound annual growth rate in select demographics were used as proxies for the growth rate in corresponding emissions inventory sub-sectors. The Metropolitan Area Planning Council (MAPC) maintains projections of population change, job growth, household growth, and housing demand for the Metro Boston area and it municipalities – including the City of Cambridge. MAPC's projections include two scenarios for regional growth. The "Status Quo" scenario is based on the continuation of existing rates of births, deaths, migration, and housing occupancy. Alternatively, the "Stronger Region" scenario explores how changing trends could result in higher population growth, greater housing demand, and a substantially larger workforce. The BAU scenario uses the MAPC Stronger Region growth values to determine future emissions.

Table 17 summarizes the demographic data used as inputs to determine annual BAU growth rate for the emissions forecast years (2030, 2040, 2050).

Table 17: Emissions forecast demographic growth rates

Sector	Year	Data	Annual Growth Rate: 2012 → Forecast Year	Data Source
Population	2012	106,172	N/A	US Census Bureau
	2030	118,625	0.62%	MAPC, 2014
	2040	123,804	0.55%	MAPC, 2014
	2050	130,787	0.55%	MAPC, 2014
Jobs	2010	105,746	N/A	MAPC, 2015
	2012	108,084	N/A	Calculated
	2030	118,726	0.52%	MAPC, 2015
	2040	123,389	0.47%	MAPC, 2015
	2050	129,365	0.47%	Calculated
Households	2010	44,032	N/A	US Census Bureau
	2012	44,652	N/A	Calculated
	2030	49,640	0.59%	MAPC, 2014
	2040	51,886	0.54%	MAPC, 2014
	2050	54,744	0.54%	Calculated

Expected expansions for the cogeneration facilities were also taken into account. Because the Veolia Kendall Square station was excluded from the inventory, it was also excluded forecasting.

For the forecasts, we considered the following:

- In 2015 the MIT Central Utilities Plant Second Century Plant Expansion plan was developed, with the in-service date of the first of two new CHP units in 2018 followed by the 2nd unit in 2019. The plant is projected to meet all the Institute's energy needs by 2020.

- In 2013 a combustion turbine CHP unit was added to the Harvard Blackstone plant, with a nominal 7.5MW turbine generator and a new Heat Recovery Steam Generator (HRSG).

Table 18 summarizes the BAU growth rates used to forecast future emissions in each sub-sector and the demographic proxy the growth rates are derived from.

Table 18: Emissions forecast annual growth rates used to project emissions by sub-sector

Sector	Subsector	Annual Growth Rate Proxy Used	Annual BAU Growth Rate		
			2012-2030	2012-2040	2012-2050
Stationary Energy	Residential Buildings	Population	0.62%	0.55%	0.55%
	Commercial & Institutional Buildings and Facilities	Jobs	0.52%	0.52%	0.47%
	Manufacturing Industries and Construction	Population & Jobs	0.57%	0.51%	0.51%
	Energy Industries*	Installed Capacity	1.99%	1.27%	0.94%
Transportation	On-road	Households	0.59%	0.54%	0.54%
	Rail	Households	0.59%	0.54%	0.54%
Waste	Solid Waste Disposal	Population & Jobs	0.57%	0.51%	0.51%
	Incineration and Open Burning	Population & Jobs	0.57%	0.51%	0.51%
	Wastewater Treatment and Discharge	Population & Jobs	0.57%	0.51%	0.51%
All Subsectors Weighted Average Growth Rate			0.77%	0.61%	0.56%

*Energy industry growth based on planned or installed capacities after 2012

Federal, state and local measures all play important roles in impacting future emissions in Cambridge. After determining the BAU forecast, we then layered anticipated GHG savings associated with select existing measures for the policy scenario forecast. Key Cambridge-specific measures that were incorporated into the policy scenario forecast included:

- **Net Zero Action Plan:** The Plan's focus on reducing energy use intensity of building and taking advantage of opportunities to increase renewable energy generation will significantly impact future emissions from in the built environment.

- **Climate Protection Action Committee Goals and Objectives:** The updated roadmap addresses future emissions in a range of sectors through goals that include reduced reliance on single occupancy vehicles, efficiency improvements in the built environment and reductions in generated waste.

Key Federal and State measures that were incorporated included:

- **Renewable Portfolio Standard:** Created in 1997, the RPS requires retail electricity suppliers – both distribution companies and other retail suppliers – to buy a percentage of electricity sales from eligible resources.

- **Federal and California Vehicle Efficiency and GHG Standards (CAFE/Pavley):** Beginning with model years 2009-2011, Massachusetts adopted California light-duty vehicle GHG emission standards.

- **Federal Renewable Fuel Standard (RFS) and Regional Clean Fuel Standard:** Massachusetts biofuels law, passed in 2008, instructs the State to pursue development of a low carbon fuel standard (LCFS) on a regional basis.

6. Conclusion

Climate change is a global problem. Through local solutions designed to meet the needs of our community, can we mitigate emissions and avoid the likely impacts. While the challenge of climate change is unprecedented, local-level actions can reduce emissions, increase efficiency, maintain business conditions, and improve quality of life for residents.

The City of Cambridge has taken significant steps to manage, track and reduce emissions in order to better plan for a sustainable future. The results of this inventory show that the large majority of emissions are associated with energy use and in particular energy use in the commercial building sub-sector. The Commercial building sub-sector was shown to account for more than 50% of community-wide GHG emissions. Energy use in buildings represents nearly 82% of emissions in the City. There are several measures the City has underway that will improve energy efficiency in buildings and increase the supply of clean energy including the Low Carbon Energy Supply Strategy, the Net Zero New Construction Requirement for Municipal Buildings, and the Market Based Incentives Pilot for Multifamily Buildings.

This inventory and forecast provides the City valuable insight into the level of emissions generated community-wide as well as an understanding of the path the City is on to reduce emissions in the future. The 2012 community-wide inventory can also be a resource for developing new policies and programs that may be needed to reach the future targets. The City is committed to meeting future goals for emissions reductions, and will continue to track, manage, and monitor progress so that the 2050 reduction goals are achieved.