City of Raleigh
North Carolina

CITY OF RALEIGH

Greenhouse Gas Inventory: Municipal Operations

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SUSTAINABLE Raleigh

July 12, 2010

Executive Summary

The Raleigh City Council established the Environmental Advisory Board in 2006 to help address the Council's commitment to environmental stewardship. The City Council also endorsed the U.S. Mayor's Climate Protection Agreement in 2007, and officially established the City's Office of Sustainability in 2010 to develop programs and lead the implementation to achieve the City's goals of economic strength, environmental stewardship, and social equity. Raleigh's commitment to environmental stewardship is highlighted in the City Council mission statement (see box). The City of Raleigh is enacting its mission in practice by addressing the City's contribution to global climate change.

There is consensus within the global scientific community that the earth's climate is changing due in large part to atmospheric changes attributable to human activity. Consistent with the U.S. Mayors Agreement and in order to provide leadership within the community on this critical issue, Raleigh conducted a greenhouse gas (GHG) inventory in 2010. The purpose of the Inventory is to quantify emissions from municipal operations and form a better understanding of the City's emission sources. This inventory will be the foundation for a coordinated action plan to reduce GHG emissions, energy consumption and costs, taxpayer dollars, and improve air quality.

This inventory was conducted in accordance with The Climate Registry's *Local Government Operations Protocol* for the baseline year of Fiscal Year 2007 (FY2007). GHG emissions, measured in **metric tons of carbon dioxide equivalent ($MTCO_2E$)**, were calculated for the following sources:

- Electricity used in City buildings; street, traffic, and area lighting installations; miscellaneous uses such as irrigation, and water and wastewater pumping and treatment facilities;
- Fuels used in City buildings, vehicles, and equipment;
- Solid waste treatment at the City's yard waste processing facility and the now-closed Wilders Grove landfill;
- Wastewater treatment at the City's treatment plants;

City Council Mission Statement

We are a 21st Century City of Innovation focusing on environmental, cultural and economic sustainability.

We conserve and protect our environmental resources through best practices and cutting edge conservation and stewardship, land use, infrastructure and building technologies.

We welcome growth and diversity through policies and programs that will protect, preserve and enhance Raleigh's existing neighborhoods, natural amenities, rich history, and cultural and human resources for future generations.

We lead to develop an improved neighborhood quality of life and standard of living for all our citizens.

We work with our universities, colleges, citizens and regional partners to promote emerging technologies, create new job opportunities and cultivate local businesses and entrepreneurs.

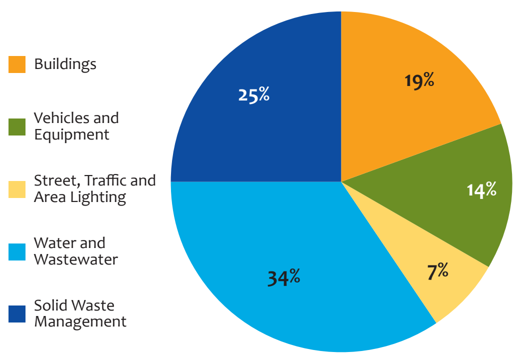
We recruit and train a 21st Century staff with the knowledge and skill sets to carry out this mission, through transparent civic engagement and providing the very best customer service to our current citizens in the most efficient and cost-effective manner.

Adopted June 2008

- Refrigeration and air-conditioning in City buildings; and
- Horses maintained by the Raleigh Police Department.

Total emissions from City Operations for FY2007 were estimated to be 151,000 MTCO2E annually. The largest source of emissions is electricity use (56 percent), followed by solid waste treatment (26 percent), and vehicle and equipment fuel use (14 percent). Emissions were also estimated for each City department, with the largest three departments being Public Utilities (35 percent), Solid Waste Services (28 percent), and Public Works (15 percent). Finally, emissions were also organized into five major sectors of City activities: buildings; vehicles and equipment; street, traffic, and area lighting; water and wastewater; and solid waste management. From this perspective, water and wastewater activities represented the largest emissions sector (34 percent), followed by solid waste management (26 percent) and buildings (19 percent), as shown in Figure 1 below.

Figure 1: Emissions from City Operations by Sector



The City's emissions profile has already been reduced through the implementation of energy efficient retrofits in City buildings and lighting, the use of biodiesel and ethanol in the City's vehicles, and investments in landfill gas collection systems at the Wilders Grove landfill. Future measures and actions will further reduce the emissions intensity of municipal operations in the City of Raleigh. This GHG emissions inventory is the first step in preparing a comprehensive climate change strategy that includes an action plan with clear goals and specific actions, partnerships that foster creative solutions to combating climate change, messaging that engages and motivates the public, and planning that integrates climate change response into existing planning efforts and the City's growing culture of sustainability.

As part of developing this inventory, the City's project leadership team has begun the process of analyzing emissions by department and activity, and outlining the elements needed for a comprehensive climate change strategic action plan. While this inventory is focused on City operations, the action plan might also incorporate community-wide strategies. This action plan would identify, evaluate, quantify, and prioritize actions for reducing GHG emissions, and devise a methodology to evaluate future actions in a manner that will allow the City of Raleigh to track progress and demonstrate the effectiveness of its investments in a transparent, accountable, and effective way. It would also identify strategies for implementing existing and potential state and local programs that address renewable energy, residential building energy efficiency, commercial and public building energy efficiency, transportation, forestry & agriculture, long-term transportation and land use planning, and education and outreach. Achieving actual overall reductions in GHG emissions will be difficult as Raleigh continues to grow in size and population. This inventory will serve as the baseline for evaluating the City's progress toward meeting its GHG and energy reduction goals.

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Climate Change

Introduction

Communities throughout the world are concerned with **greenhouse gases (GHGs)**[1] because of the effect they have on the global climate system and, consequently, both manmade and natural systems. These gases are responsible for trapping heat in Earth's lower atmosphere and, at appropriate concentrations, allow the planet to be hospitable to life. Just a slight increase in the concentrations of GHGs, such as **carbon dioxide (CO_2)**, **methane (CH_4), and nitrous oxide (N_2O)**, can disrupt the delicate balance required to sustain natural systems in their present states. **Anthropogenic emissions** over the last several hundred years have resulted in increasing concentrations of GHGs in the atmosphere. Government and business leaders have acknowledged in recent decades the importance of reducing GHG emissions (*mitigation*), as well as preparing for climate changes that are inevitable (*adaptation*). Often, a first step in mitigating GHG emissions is for a private company, local municipality, state government, or federal government to take an inventory of their own **baseline** GHG emissions produced through routine activities.

The purpose of this report is to document the methods for and results of the City of Raleigh's Government Operations greenhouse gas (GHG) inventory. This inventory is consistent with the City of Raleigh's endorsement of the U.S. Mayors Climate Protection Agreement on August 7, 2007. A multi-departmental team provided oversight throughout the project to ensure input from each of the City's largest departments. This included selecting and guiding the consultant team, providing and verifying data, selecting the protocol and base year, and reviewing results and report to ensure they will be useful to the City. This project leadership team includes:

- Fred Battle, Solid Waste Services
- Ken Best, Public Utilities – Water
- Travis Brown, Public Works – Vehicle Fleet Services
- Cindy Holmes, Office of Sustainability
- Billy Jackson, Parks & Recreation – Facilities
- Mike Kennon, Public Works – Transportation
- T.J. Lynch, Public Utilities – Wastewater
- Joyce Munro – Budget Office
- Jim Payne, Public Works – Vehicle Fleet Services
- Audrey Robinson, Information Technology – Communications
- Paula Thomas, Office of Sustainability
- Suzanne Walker, Parks & Recreation – Facilities

Fayetteville Street LED lighting

[1] Words in **bold** are defined in the Glossary at end of the report.

The report begins with a background discussion of GHGs, **climate change**, the inventory process, and inventory protocols. The methods and results are then presented for each emission source, followed by estimates[2] of City emissions by department. The report then compares the City of Raleigh's emission inventory to those of other cities for context, followed by the conclusion.

1.1 What is a Greenhouse Gas Inventory and Why is It Important?

A GHG inventory is an accounting of GHGs emitted to, or removed from, the atmosphere over a specific period (such as one year, for example). Decision-makers use inventories to track trends in emissions, to develop strategies and policies to reduce GHG emissions, and to assess progress in reducing emissions during future periods. Scientists use inventories as inputs to atmospheric and economic models. An inventory begins with a defined **baseline year**.

An inventory can help with any or all of the following tasks:

- Identifying the greatest sources of GHG emissions within a particular geographic region, department, or activity;
- Understanding emission trends;
- Quantifying the benefits of activities that reduce emissions;
- Establishing a basis for developing an action plan;
- Tracking progress in reducing emissions; and
- Setting goals and targets for future reductions.

Since it is difficult to manage what is not measured, developing an inventory is usually the first step taken by governments, companies, and individuals who want to reduce their GHG emissions. The City of Raleigh acknowledges that it cannot reduce emissions and energy costs if does not first measure them, and has therefore chosen to follow suit in developing a GHG inventory. This inventory will provide the City with a snapshot of the departments and sources generating the City's GHG emissions, enabling us to develop an informed plan for reducing GHG emissions, reducing energy consumption, and saving taxpayer dollars.

Alternative Fuel Vehicle

[2] Although all emissions estimates presented here were calculated with the best available data and methodology, there remains some uncertainty in these calculated values. Therefore, as done in the LGO Protocol and other GHG inventory efforts, this document refers to calculated emissions as "emissions estimates."

1.1.1 The Role of GHG Inventories in Reducing GHGs

In order to work toward reducing anthropogenic contributions to atmospheric GHGs, governments and private sector entities first need to inventory the GHG emissions produced by their activities or within the City's operational control. After an initial inventory is conducted and GHG reduction goals are put in to place, steps can be taken to modify activities and/or change the types of fuel or energy sources in use. For example, a city could determine, post-inventory, that the most effective route toward reducing its GHG emissions is to replace lighting or HVAC equipment throughout its buildings.

1.2 Greenhouse Gases and Climate Change

Scientific consensus indicates that GHG emissions from anthropogenic sources are contributing to changes in the Earth's climate. GHGs are always present, in varying concentrations, on the planet and actually allow life to thrive. However, life has evolved with a particular balance of GHGs in the atmosphere and there is concern that changes in the balance, which are already occurring, will have negative effects on humans and the planet's other natural systems. As concentrations of GHGs increase, more **infrared radiation** emitted from Earth's surface is trapped in the atmosphere, warming the planet's surface and atmosphere. The resulting increase in average global temperature is linked to changes in precipitation patterns, sea level rise, more severe and prolonged droughts, and increasing severity of coastal storms.

When referring to GHGs, the most abundant and influential on the planet's surface and atmospheric temperatures are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), **fluorinated hydrocarbons (PFCs and HFCs)**, and sulfur hexafluoride (SF_6). Water vapor (H_2O) is thought to account for the largest portion of the greenhouse effect, but human activity does not significantly affect the atmospheric concentration of water vapor. As a result, GHG inventory protocols do not call for the inclusion of water vapor. GHGs, in total, are typically reported in **metric tons of CO_2-equivalent ($MTCO_2E$)**, for ease of presentation and understanding. These gases are emitted from different primary sources and have varying greenhouse effects, measure by the **global warming potential** (GWP). The GWP of each gas is discussed below and summarized in Table 1.

Carbon dioxide (CO_2) is cycled, naturally, between living organisms (plants, animals, and microbes), oceans, and the atmosphere. Its primary anthropogenic source is through the combustion of **fossil fuels**, such as coal and oil, for use in generation of electricity and transportation. In the pre-Industrial era, oceans and buried plant material absorbed any excessive CO_2 from the atmosphere in order to keep the appropriate balance to sustain life. In the post-Industrial era, CO_2 that was buried in the form of fossil fuels is being released at a rate that is faster than the planet can reabsorb it. As a result, atmospheric CO_2 concentration has increased from approximately 280 parts per million (ppm) to approximately 390 ppm as of December 2009. If global emissions of CO_2 continue unabated, its atmospheric concentration could be 750 ppm by 2100. The U.S. Climate Change Science Program (CCSP) has cited a concentration of 450 ppm in 2100 as an attainable target if rigorous reductions programs are enacted.

Methane (CH_4) is primarily a product of decomposing organic material, such as livestock waste, waste landfills, and agriculture. CH_4 is also emitted during the production and combustion of coal, natural gas, and other fossil fuel products. Since pre-Industrial times, the atmospheric concentration of CH_4 has increased from approximately 0.7 ppm to 1.75 ppm. Although a smaller component in the atmosphere than CO_2, it is a much more potent GHG than CO_2, with one pound of CH_4 producing the same greenhouse effect as would 21 pounds of CO_2. The atmospheric concentration of CH_4 is projected to continue increasing.

Nitrous oxide (N_2O) is generated via the microbial processes in soils, **nitrification** and **denitrification**. Human activities associated with agriculture have increased the global atmospheric N_2O concentration at an average rate of 0.2 to 0.3 percent per year. Its concentration in the atmosphere has increased from approximately 0.2 ppm to 0.32 ppm. Again, it is minute compared to the CO_2 concentration in the atmosphere, but the greenhouse effect of one pound of N_2O is equivalent to 310 pounds of CO_2.

Hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) are the most potent of GHGs. HFCs have been generated as replacements for earlier, ozone-depleting substances, and in some manufacturing processes. PFCs are generated during many industrial processes, such as electric power transmission, aluminum smelting, and semiconductor manufacturing. Although atmospheric concentrations are low compared to CO_2, a pound of these substances has the greenhouse effect *equivalent to hundreds or thousands of pounds of* CO_2.

Table 1: Global Warming Potentials of Common Greenhouse Gases

Greenhouse Gas	GWP
Carbon Dioxide (CO_2)	1
Methane (CH_4)	21
Nitrous Oxide (N_2O)	310
Sulfur Hexafluoride (SF_6)	23,900
Hydrofluorocarbons	12-11,700
Perflourocarbons	6,500-9,200

Source: CARB, et al., 2008. All values from the IPCC Second Assessment Report.

The relative contribution of each of these gases and sources within the City of Raleigh's Operations is shown in Figure 2 below, which groups emissions based on the activity generating the emissions. The emissions by City Department are shown in Figure 3 on page 5.

Figure 2: FY2007 City of Raleigh GHG Emissions by Source and Gas

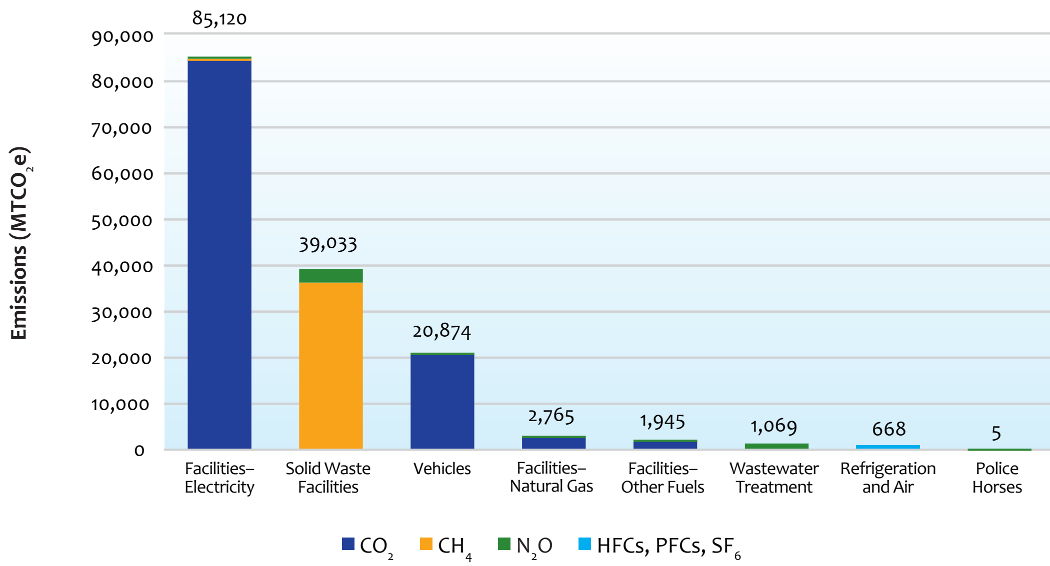
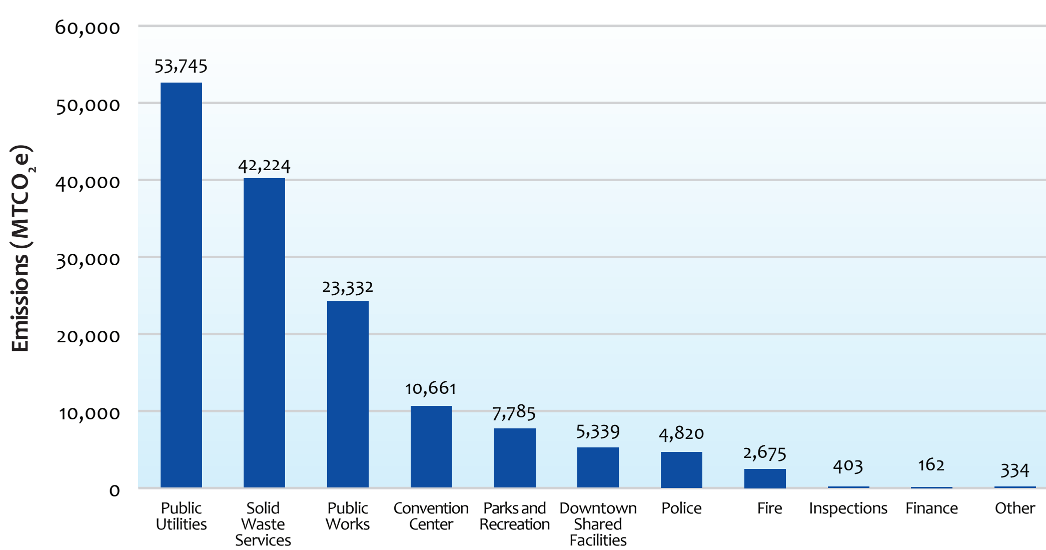


Figure 3: FY 2007 City of Raleigh GHG Emissions by Department



1.3 GHG Inventory Protocols

A key decision in preparing the GHG emission inventory for the City of Raleigh was protocol selection. Following the proper protocol helps to ensure that this inventory effort is accurate, comparable to other municipal inventories, and consistent with City, State, and Federal goals. The City of Raleigh selected the Climate Registry's *Local Government Operations (LGO) Protocol*[3] as the primary source of guidance for the City's inventory because it will enable the City to meet these goals. The Climate Registry is a nonprofit collaboration among states, provinces, territories, and Native Sovereign Nations that works to set consistent and transparent standards for calculating, verifying, and reporting GHG emissions. Its LGO Protocol is widely used and respected by municipalities throughout North America. Furthermore, the State of North Carolina is a member of the Climate Registry.

Additionally, the Climate Registry's *General Reporting Protocol* was used to conduct a GHG inventory for the City of Raleigh's three wastewater treatment plants in May 2009 (Stearns and Wheler, 2009).[4] This protocol presents an identical methodology for estimating GHG emissions from wastewater treatment as the LGO Protocol. The wastewater treatment inventory conducted in May 2009 included emission estimates for facility energy consumption, vehicle fleet fuel consumption, and process emissions resulting from wastewater treatment. While these categories are present in the inventory estimates developed here, the wastewater inventory estimates for facility and vehicle fleet consumption were aggregated into the broader facility and vehicle fleet consumption categories for the City of Raleigh's inventory. Process emissions estimated in the May 2009 wastewater inventory were examined, as well, to determine potential emission factor improvements, and incorporate these emissions into the City's overall inventory. Here, multiple summaries are presented (e.g., by source, by department) to help the City put its emissions in context.

1.3.1 Local Government Operations Protocol Overview

A local government GHG emissions inventory accounts for emissions that take place over a certain period of time within the defined **boundaries** of the government organization. One of the key challenges for any local government in compiling its inventory is to appropriately define these boundaries. The LGO Protocol strongly recommends the utilization of **operational control** when defining boundaries. The stakeholders involved in the protocol development believe that operational control most accurately represents the emission sources that local government can influence. The LGO Protocol describes this approach as follows:

Cree Shimmer Wall at the Raleigh Convention Center

[3] California Air Resources Board, California Climate Action Registry, ICLEI – Local Government for Sustainability, The Climate Registry. Local *Government Operations Protocol For the Quantification and Reporting of Greenhouse Gas Emissions Inventories*, Version 1.0. September, 2008. Available online at: http://www.theclimateregistry.org/resources/protocols/local-government-operations-protocol/.

[4] This document is available on the City's website at: raleighnc.gov

Operational Control Approach: A local government has operational control over an operation if the local government has the full authority to introduce and implement its operating policies at the operation. One or more of the following conditions establishes operational control:

- Wholly owning an operation, facility, or source
- Having the full authority to introduce and implement operational and health, safety and environmental policies

In this context, the City's inventory included 100% of the GHG emissions from operations over which it has operational control. This approach was selected because it most accurately accounts for GHG emissions from the City's operations. Using the above definitions as a guideline, Table 2 below summarizes the treatment of the City's key emission sources under this protocol.

Table 2: Organizational Boundary

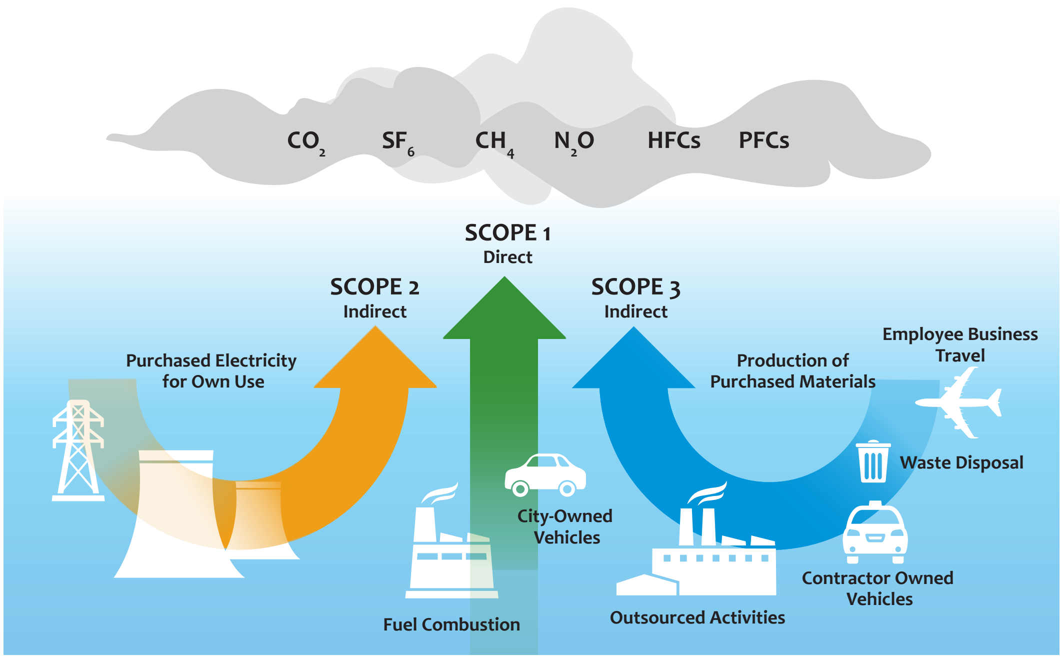
Business Activity	Included in Organizational Boundary?	Reason
Facilities	Included	The City of Raleigh exercises operational control over these premises and therefore, all facilities are included within the organizational boundary.
Vehicle and Equipment Fleet	Included	The City of Raleigh exercises operational control over these fleets and therefore, all City fleets are included within the organizational boundary. The City's Capital Area Transit (CAT) program is operated under contract, but because the City exercises control over the service provided, these vehicles are included within the organizational boundary.
Street, Traffic, and Area Lighting	Included	The City of Raleigh exercises operational control over these operations and therefore, all operations are included within the organizational boundary.
Water/Wastewater Pumping and Water/ Wastewater Treatment	Included	The City of Raleigh exercises operational control over these operations and therefore, all operations are included within the organizational boundary.
Solid Waste Management	Included	The City of Raleigh exercises operational control over these operations and therefore, all operations are included within the organizational boundary.

Emissions that are generated by the City's equipment and facilities are referred to as **direct emissions**, while emissions generated by another entity but driven by the City's activities are referred to as **indirect emissions** (such as electricity generated by a utility but consumed by the City of Raleigh).To help organize the inventory, account for **direct** and **indirect emissions** separately, and improve transparency, the LGO Protocol follows the WRI/WBCSD GHG Protocol's[5] convention (and ISO 14064) in categorizing emissions

5 World Resources Institute and World Business Council for Sustainable Development. *The Greenhouse Gas Protocol – A Corporate Accounting and Reporting Standard, Revised Edition*. March 2004.

into **Scope 1 (direct)**, **Scope 2 (indirect)**, and **Scope 3 (other indirect)**. Specifically, indirect GHG emissions (off-site emissions not directly generated by the City) associated with electricity use are included in Scope 2, whereas direct emissions associated with on-site natural gas and fuel oil use are included in Scope 1. This inventory chose to focus on those emissions over which the City exerts direct control and for which established protocols exist. Therefore, no Scope 3 emissions were included.

Figure 4: Illustration of Scope 1, Scope 2, and Scope 3 Emissions



Source WRI/WBCSD: *The GHG Protocol—A Corporate Accounting and Reporting Standard, Revised Edition* (revised to reflect Raleigh operations)

For the purpose of this GHG inventory, Scope 1 emissions were estimated based on the consumption of fuels used for heating and/or hot water in facilities owned or leased by the City for site operation purposes. In addition, emissions from fuel consumption in any vehicles and equipment leased/owned and operated by the City are included as Scope 1. Electricity consumption in the City's owned or leased buildings/facilities are included as Scope 2 indirect emissions. The Protocol considers Scope 3 sources optional, and these sources were not included in this inventory for the City of Raleigh as they are not under the City's direct control. Emissions included under each Scope are as follows:

Scope 1 (direct)

- Emissions from fuels consumed at all City facilities, e.g. natural gas
- Emissions from fuels consumed by all City fleet vehicles and equipment
- CH_4 and N_2O emissions from wastewater treatment
- CH_4 emissions from solid waste management
- HFC emissions from refrigeration and air conditioning equipment

- CH_4 and N_2O emissions from horses maintained by the Police Department

Scope 2 (indirect)

- Emissions associated with purchased electricity used at all City buildings and facilities, including office buildings, water and wastewater treatment and pumping facilities, and other City facilities.

Scope 3 (other indirect)

- No Scope 3 sources were included in this inventory. Since GHG inventory efforts are an evolving practice and guidelines change over time, future inventory efforts may elect to improve this inventory by including Scope 3 emissions such as employee commuting, work-related employee travel, and/or life-cycle emissions associated with material and service procurement.

1.4 Selection of the Baseline Period

Selection of the baseline period is a key step in any inventory process because it serves as a reference point for future comparisons. Selection of an inventory's baseline period, usually a specific calendar or fiscal year, should take into account several factors: data availability, anomalies present in the baseline caused by external factors such as weather or economic conditions, emissions reduction efforts that an entity has already undertaken in recent years, growth and changes in service area, and the context of larger state, national, or other voluntary efforts.

Electric Car

For this inventory, Fiscal Year 2007 (July 1, 2006 - June 30, 2007) was selected as the baseline year. The first key factor driving this decision is the City Council's established goal to reduce fossil fuel consumption in vehicles and equipment to 20 percent below FY2007 levels by 2011. Since FY2007 serves as the reference point for the City's goal, it is appropriate to use the same year for the baseline inventory. Second, the data available for FY2007 are sufficient for this inventory. This was not the case for other years under consideration such as 2005 (changes in the City's data systems have improved data availability since then) and 2009 (when this effort was begun, not all 2009 data were available).

However, weather can affect the suitability of a baseline year, so research was conducted to determine if weather conditions in FY2007 led to unusual energy demands for heating or cooling. "Heating degree days" (HDD) and "cooling degree days" (CDD) are measures used to gauge the relative need for heating and cooling in a given year. HDD and CDD are defined in relation to a base temperature (usually 65° F). One HDD is counted for every degree that the average daily temperature is below the base temperature, while one CDD is counted for every degree that the average daily temperature is above the base temperature.

Figure 5 and Figure 6 on page 10 show the annual HDD and CDD for the FY2001-FY2008 period, compared to the 1971-2000 average and the FY2001-FY2008 average, respectively.

Both show that the City of Raleigh experienced warmer than average temperatures during this time period. The HDD was lower than the 30-year average, indicating warmer than average winters and reduced need for space heating. The CDD was higher than the 30-year average, indicating warmer than average summers and increased need for air conditioning. In neither case was FY2007 an outlier within the time series.

Figure 5: Heating Degree Days, FY2001-FY2008

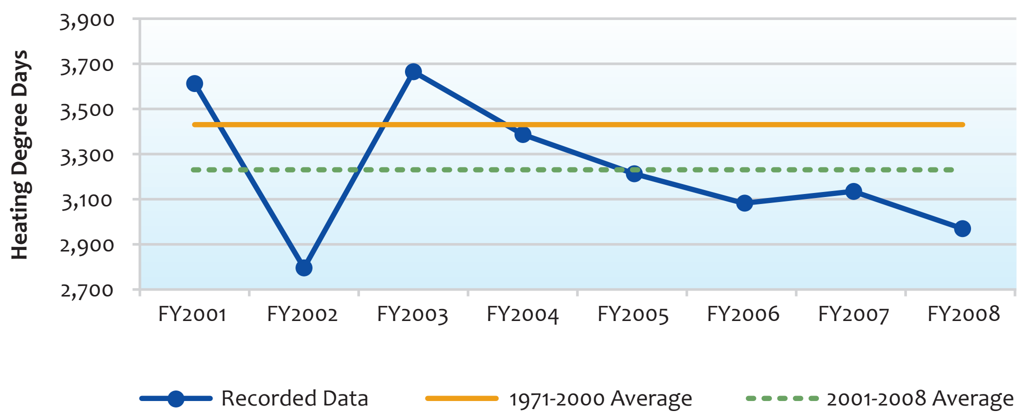
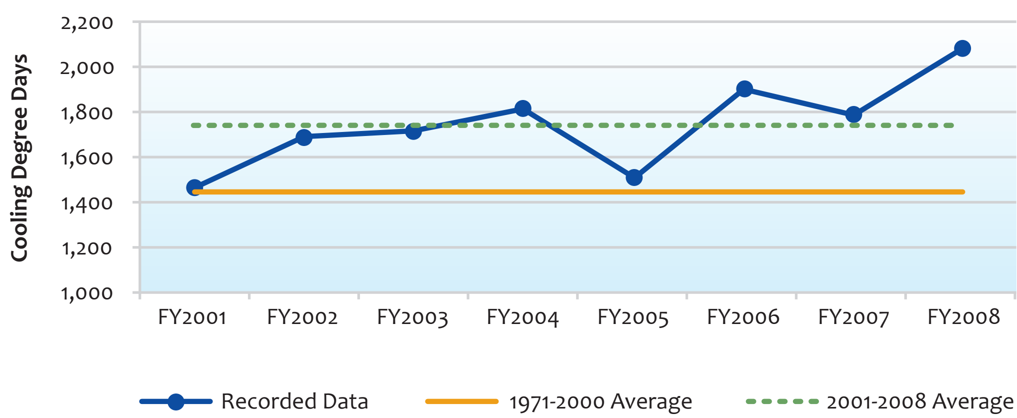


Figure 6: Cooling Degree Days, FY2001-FY2008



1.5 The Development of the City of Raleigh's Energy Efficiency and Climate Protection Strategy

The City of Raleigh is now ranked the 45th largest city in the United States, with a population of 405,791.[6] During this time of rapid growth, the City has been preparing to address Climate Protection. In 2007-2008, the City Council of the City of Raleigh took action to adopt three recommendations submitted to them by the Environmental Advisory Board (EAB). Included in the EAB recommendations was the language "Make reduction in fossil fuel usage and greenhouse gas emissions, together with energy conservation, priorities of the City government on par with the stewardship of fiscal resources and delivery of government services."

[6] According to the U.S. Census Bureau's Annual Estimates for Resident Population for Incorporated Places. See City of Raleigh website for more information.

The three specific actions taken were:

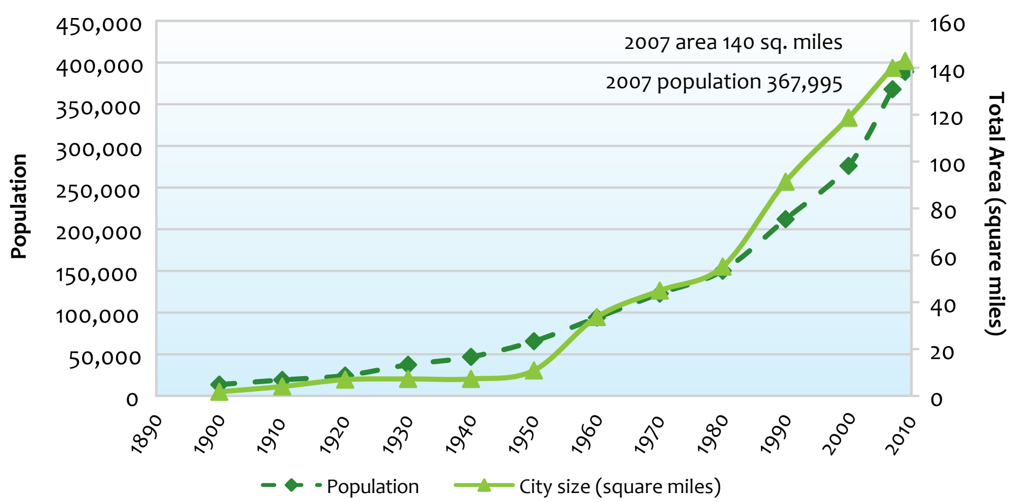
- Established a goal of 20 percent reduction in fossil fuel consumption by the City fleet from 2006 levels within 5 years. (Council Action date – April 17, 2007)
- Established energy efficient building standards requiring LEED silver certification for all new city construction and additions encompassing 10,000 gross square feet or more. (Council Action date – May 20, 2008)
- Endorsed the U. S. Mayors Climate Protection Agreement, committing to develop a Greenhouse Gas Emissions Reduction Strategy for the City. (Council Action date – August 7, 2007)

The Greenhouse Gas Emissions Inventory for Local Government Operations is the first step in preparing a comprehensive energy efficiency and climate protection strategy. The next step will be to adopt a formal GHG emissions reduction target and then to develop a specific comprehensive inter-departmental implementation work plan for achieving the reduction target. Finally, identifying and the assembling resources necessary to accomplish the goal will commence.

However, meeting these goals while the City continues to grow will present a challenge. As shown in Figure 7 below, both the population and area of Raleigh have experienced rapid growth over the past few decades. To support this growing population, the City maintains 997 miles of City and State highway system streets, more than 1,500 miles of water mains, and more than 2,300 miles of wastewater lines. The City of Raleigh also delivered to its customers an average 50.69 Million Gallons a Day (MGD) of water in FY2007, with a maximum day total of 77 MGD. The City collected and treated 44.01 MGD of wastewater on average, with a maximum daily total of 72.19 MGD. The vehicle miles driven (VMT) by city fleets were 10,961,335 for on road vehicles. The off road vehicles and equipment were operated for 50,384 hours in FY 2007. The volume of solid waste accepted for disposal by the City was 84,538 tons, the volume of recyclable material accepted for processing was 21,042 tons, and the volume of yard waste accepted for processing was 35,242 tons in FY2007.

The completion of this GHG inventory will allow the City to establish goals and determine strategies for reducing emissions.

Figure 7: Raleigh Population and Area since 1900



Source : http://www.raleighnc.gov/publications/Planning/Demographics/Past_Raleigh_Population_and_Acreage_Data_Since_1800.pdf

2 Emissions and Methodology by Source

The following section describes the methodology, data, and results for the estimation of emissions from each emission source. Each section contains a review of that source, the methodology and data used, and a discussion of the results. Key summary data and emission factors are provided. All calculations discussed below are contained in a separate Microsoft Excel spreadsheet. These sections are organized based on the source categories in the LGO Protocol.

Following the discussion of each source, a summary by City Department is provided in Section 3, giving a more useful analysis of how these sources are emitted relative to the organization of City government. For example, most of the emissions related to wastewater pumping and treatment result from the use of electricity, and these emissions are calculated under the "Electricity Use" section immediately below. Meanwhile, there is another source referred to as "Wastewater Treatment," yet emissions from this source are limited to the fugitive emissions of CH_4 and N_2O that occur through the wastewater treatment process. In Section 3, emissions from both of these sources are combined under the total for the Public Utilities department.

2.1 Scope 2: Electricity Use in Facilities, Lighting, and Water/Wastewater Pumping and Treatment (56%)

The City of Raleigh's buildings, facilities, water and wastewater pumping and treatment plants, and lighting installations consume electricity that is mostly produced through the combustion of fossil fuels. The combustion of these fuels typically yields CO_2, and to a lesser extent, N_2O and CH_4. Although these emissions are generated by power plants outside of the City's direct control, by creating demand for this electricity, the City is indirectly responsible for these emissions. Therefore, electricity consumed at City facilities is considered a Scope 2 emission source, and represents more than half of the City's emissions. Due to extensive data collected and maintained by Facilities and Operations, these estimates are supported by robust data.

2.1.1 Methodology

Emissions from electricity consumed at City facilities were calculated using the approach recommended in Section 6.2.1 of the LGO Protocol. Electricity consumption data were collected from a variety of sources. First, account-level consumption detail was collected from bill data for August 2007 through the present. Due to a change in the City's accounting system, account-level data were not available for the baseline year of FY2007, so these data were used only for estimating emissions by department, as discussed below. Progress Energy, the provider of most of the City's electricity, provided a summary of metered consumption by month for a longer period, which included the total electricity consumption in FY2007. In addition to Progress Energy, the City also has two facilities served by Duke Energy. Bill data for each of these were collected separately. Finally, the City has a large number of traffic, street, and area lights that are not individually metered. To estimate electricity consumption from these sources, the City assembled an inventory of all unmetered lights with the monthly electricity use and count for each type of light.

The monthly consumption for each light type was multiplied by the total number of lights of each type and aggregated across all categories to estimate total electricity consumption from lighting.

Electricity use was then summed across all usage categories described above. As recommended by the LGO Protocol, eGRID regional default emission factors for CO_2, CH_4, and N_2O were determined based on Raleigh's subregion, as shown in Table 3 below.

Table 3: eGRID Subregion Emission Rates

eGRID Subregion Acronym	eGRID Subregion Name Associated with eGRID Subregion Acronym	eGRID Subregion Annual CO_2 Output Emission Rate (lb/MWh)	eGRID Subregion Annual CH_4 Output Emission Rate (lb/GWh)	eGRID Subregion Annual N_2O Output Emission Rate (lb/GWh)
SRVC	SERC Virginia/Carolina	1,134.88	23.77	19.79

These emission rates are based on the mix of fuels used to generate electricity consumed by the City, which is located in the SERG Virginia/Carolina eGRID region (SRVC). As shown in Table 4 below, coal—the most CO_2-intensive fuel—accounts for the largest portion of generation in the SRVC region (50.5 percent), while nuclear power, which does not result in GHG emissions, is the second most common fuel with 38.7 percent. In 2005, the latest year for which data are available, the average CO_2 emission rate for the SRVC region was 1,135 lbs CO_2/MWh. The average emissions rate for methane was 23.8 lbs CH_4/GWh and the average emissions rate for nitrous oxide was 19.8 lbs N_2O/GWh (U.S. EPA, 2009d).

Table 4: SRVC Regional Electricity Generation Resource Mix, 2005 (latest available year)

Fuel	Percent of Generation
Coal	50.46%
Nuclear	38.74%
Gas	4.95%
Biomass/wood	1.93%
Hydro	1.93%
Oil	1.69%
Other fossil combustion & unknown	0.29%
Solar	0%
Wind	0%

Note: Totals may not sum due to independent rounding. Source: U.S. EPA, 2009d

Using Equation 1, indirect emissions were calculated for electricity consumed by each facility category for CO_2, CH_4, and N_2O by multiplying the eGRID emission factors by the electricity used. Emissions totals for CH_4 and N_2O were then converted to metric tons of CO_2 equivalent by multiplying emissions by the global warming potential (GWP) of CH_4 (21) and N_2O (310), respectively.

Equation 1: CO_2 Emissions from Stationary Combustion
CO_2: Annual CO_2 emissions (metric tons) = Electricity use (MWh) × Emission factor (lbs CO_2 per MWh) ÷ 2,204.62 (lbs/metric tons) **CH_4:** Annual CO_2 emissions (metric tons) = Electricity use (MWh) × Emission factor (lbs CH_4 per MWh) ÷ 2,204.62 (lbs/metric tons) **N_2O:** Annual CO_2 emissions (metric tons) = Electricity use (MWh) × Emission factor (lbs N_2O per MWh) ÷ 2,204.62 (lbs/metric tons)

2.1.2 Emissions Estimate

In FY2007, Scope 2 emissions from electricity use in the City of Raleigh were approximately 85,000 metric tons CO_2-equivalent. The City's accounts with Progress Energy represented the bulk of all emissions, with metered electricity accounting for about 87 percent and unmetered lighting accounting for 13 percent of all electricity use. The individual breakdown by City department is discussed below in Section 3. The results are summarized below in Table 5.

Table 5: Indirect Emissions from Electricity Use FY2007 (Metric Tons CO_2 Equivalent)

	Emissions $MTCO_2E$				MWh	Million BTU
Data Source	**CO_2**	**CH_4**	**N_2O**	**Total**		
Progress Energy	73,491	32	397	73,920	142,764	487,253
Duke Energy	381	0	2	383	740	2,525
Unmetered Street, Traffic, and Area Lighting	10,754	5	58	10,817	20,891	71,301
Total	**84,625**	**37**	**457**	**85,120**	**164,395**	**561,079**

Note: Totals may not sum due to independent rounding.

2.2 Scope 1: Solid Waste & Composting Facilities (26%)

Greenhouse gases—including methane (CH_4) and nitrous oxide (N_2O)—are emitted by landfills and composting facilities. In particular, CH_4 is generated by the **anaerobic decomposition**[7] of waste in landfills, while both CH_4 and N_2O are emitted by composting facilities. This section provides an overview of landfill waste and composting GHG emissions in the City of Raleigh associated with its landfills and composting facilities. According to the Local Government Operations (LGO) Protocol, direct emissions from the operational control of solid waste facilities within the City of Raleigh, including waste-related emissions from its landfills and compost facilities, are considered Scope 1 emissions (LGO 2008).

[7] A process where microorganisms break down biodegradable material in the absence of oxygen.

The LGO Protocol provides guidance on estimating the fugitive CH_4 emissions released from solid waste facilities, namely landfills that accept (or accepted) organic waste. For these facilities, only CH_4 from landfills will be estimated since direct CO_2 emissions from landfills are considered biogenic and not included in GHG Inventories. [8]

The LGO Protocol does not include standardized methodologies to estimate fugitive emissions from composting. The LGO Protocol urges local governments to assess the potential for emissions from composting and utilize the best methodology available. This inventory utilized methodology used in the U.S. Inventory of Greenhouse Gas Emissions (EPA 2009), which is based on the 2006 IPCC Guidelines (IPCC 2006). As a result, both CH_4 and N_2O emissions are estimated for composting facilities.

2.2.1 Methodology

Methane Collection System at Wilder's Grove Landfill

This section presents the methodology for estimating emissions from landfills and composting facilities under the City of Raleigh's operational control. Detailed activity data were collected from the Solid Waste Services Department.

2.2.1.1 Landfills

The Wilders Grove landfill, within the City of Raleigh's operational boundaries, opened in 1972 and closed in 1997.[9] Since 1989, the Wilders Grove landfill has been collecting landfill gas (LFG) for use in energy recovery and flaring systems as required under U.S. EPA's New Source Performance Standards (NSPS). Through investments made to improve the landfill gas collection system, the City has further reduced emissions of landfill methane. In FY2007, a reported 1,036 million standard cubic feet (scf) of LFG were delivered to Ajinomoto Aminoscience LLC (AAS) to generate electricity while 12 million scf of LFG were flared (City of Raleigh 2009a).[10] The amount of LFG collected is not included in the total waste emissions estimate; however the LFG collected is integral in calculating fugitive emissions from the Wilders Grove landfill.

According to the LGO Protocol's "Methodology Decision Tree for CH_4 Emissions from Landfills", the Wilders Grove fugitive landfill CH_4 emissions can be derived using the data

[8] Section 4.5 of LGO Protocol states that "Biogenic emissions also occur from sources other than combustion, such as the aerobic decomposition of organic matter. These non-combustion biogenic emissions should not be included in your GHG inventory"

[9] Although the City of Raleigh has been delivering waste to North Wake and South Wake landfills as well, these landfills are not under the operational control of the City of Raleigh and therefore are not included in this Scope 1 emissions estimate.

[10] The use of LFG to generate electricity results in indirect GHG emission reductions by offsetting fossil fuel demand for electricity generation. These benefits were outside of scope of this inventory per the LGO Protocol, and were not quantified here.

on actual LFG collected. [11] Fugitive CH_4 emissions were calculated using Equation 2 (Equation 9.1 of the LGO Protocol).

Equation 2: Landfills with Comprehensive LFG Collection Systems
CH_4 emitted (metric tons CO_2e) = LFG collected x CH_4% x {(1 - DE) + [((1 – CE) / CE) x (1 – OX)]} x unit conversion x GWP

Using this equation, the landfill characteristics that were assumed are provided in Table 6 below.

Table 6: Terms Used in Equation 2

Term	Description	Value
LFG collected	Annual LFG collected by the collection system (MMSCF)	Primary data from Wilders Grove landfill input
CH_4%	Fraction of CH_4 in LFG	Primary data from Wilders Grove
DE	CH_4 Destruction Efficiency, based on the type of combustion/flare system.	99%
CE	Collection Efficiency	85%
OX	Oxidation Factor	10%
Unit conversion	Applies when converting million standard cubic feet of methane into metric tons of methane (volume units to mass units)	19.125
GWP	Global warming potential to convert methane into metric tons of CO_2 equivalents (CO_2e).	21

Sources: EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2008, Chapter 8, 8-4 (April 2009). 2 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 3, 3.15, 3.19 (2006).

The LGO Protocol recommends using a default collection efficiency value of 75 percent. However, this value is based on the average range of collection efficiencies of 60-85 percent as reported by the U.S. EPA (U.S. EPA, 1998). Based on City investments made to the landfill gas collection including a synthetic cap covering about 70 percent of the landfill, a consistent record of low measurements of surface methane emissions, and low methane measurements at the perimeter trench system, the Wilders Grove landfill gas collection system is assumed to be operating with greater than average collection efficiency. Therefore, the high end of the collection efficiency range was assumed for this analysis.

2.2.1.2 Compost Facilities

The City of Raleigh has one compost facility within its operational boundaries that accepts municipal yard waste. The City of Raleigh's Yard Waste Recycling Center has been

[11] The LGO Protocol states, "Fugitive CH_4 emissions from a landfill with an active and comprehensive LFG collection system can be derived using the data on actual LFG collected and applying a standard collection efficiency."

in operation since 2000. In FY2007, the Yard Waste Center accepted and processed just over 35,000 short tons of yard waste (City of Raleigh 2009b).

The CH_4 and N_2O emissions from compost facilities are dependent on a variety of factors including type and amount of waste, temperature, moisture content, and level of aeration during the composting process (EPA 2009). As previously noted, the LGO Protocol does not include standardized methodologies to estimate fugitive emissions from composting. Therefore, the approach used in the *U.S. Inventory of Greenhouse Gas Emissions* was applied (EPA 2009). This approach is based on a Tier 1 methodology[12] and emission factors in the 2006 IPCC Guidelines as shown below in Table 7 (IPCC 2006).

Table 7: Default CH_4 and N_2O emission factors for composting

	CH_4 Emission Factors (g CH_4/kg waste treated)		N_2O Emission Factors (g N_2O/kg waste treated)	
Type of Biological Treatment	dry weight basis	wet weight basis	dry weight basis	wet weight basis
Composting	10 (0.08–20)	4 (0.03–8)	0.6 (0.2–1.6)	0.3 (0.06–0.6)

Sources: Arnold, M.(2005) Personal communication; Beck-Friis (2002); Detzel et al. (2003); Petersen et al. 1998; Hellebrand 1998;

Hogg, D. (2002); Vesterinen (1996).

Assumptions on the waste treated: 25-50% DOC in dry matter, 2% N in dry matter, moisture content 60%. The emission factors for dry waste are estimated from those for wet waste assuming moisture content of 60% in wet waste.

The following equations were applied to estimate CH_4 and N_2O emissions from composting:

Equation 3: CH_4 Emissions from compost facilities
CH_4 emitted (metric tons CO_2e) = Mass yard waste collected x EF x unit conversion x GWP

Equation 4: N_2O Emissions from compost facilities
N_2O emitted (metric tons CO_2e) = Mass yard waste collected x EF x unit conversion x GWP

Using these equations, the composting characteristics that were assumed are provided in Table 8 below.

[12] A Tier 1 approach applies a simplistic methodology using default emission factors. The basic equation for a Tier 1 approach is: GHG emissions = activity data x default emission factor.

Table 8: Terms Used in Equation 3 and Equation 4

Term	Description	Value
Mass yard waste collected	Annual yard waste collected by the collection system	Primary data from Yard Waste Center
EF	IPCC emission factor for CH_4 and N_2O based on wet weight	4g CH_4/kg waste treated 0.3g N_2O/kg waste treated
Unit conversion	Conversion from grams to metric tons	1,000,000
GWP	Global warming potential. Methane and nitrous oxide into metric tons of CO_2 equivalents (CO_2e).	21 for CH_4 310 for N_2O

Sources: EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2008, Chapter 8, 8-4 (April 2009). IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 4 (2006).

2.2.2 Emissions Estimate

In FY2007, emissions from solid waste management in the City of Raleigh were approximately 39,000 metric tons CO_2-equivalent. CH_4 emissions from Wilders Grove Landfill constituted the majority of emissions from solid waste management while CH_4 and N_2O emissions from compost facilities accounted for the remainder. Table 9 below summarizes FY2007 GHG emissions from landfill and composting activities in the City of Raleigh.

Table 9: Emissions from Solid Waste Management in FY2007 (Metric Tons CO_2 Equivalent)

Source	Gas	Emissions ($MTCO_2E$)
Landfills		
	CH_4	33,377
Composting		
	CH_4	2,684
	N_2O	2,972
Composting Subtotal		5,656
Total Landfills and Composting		**39,033**

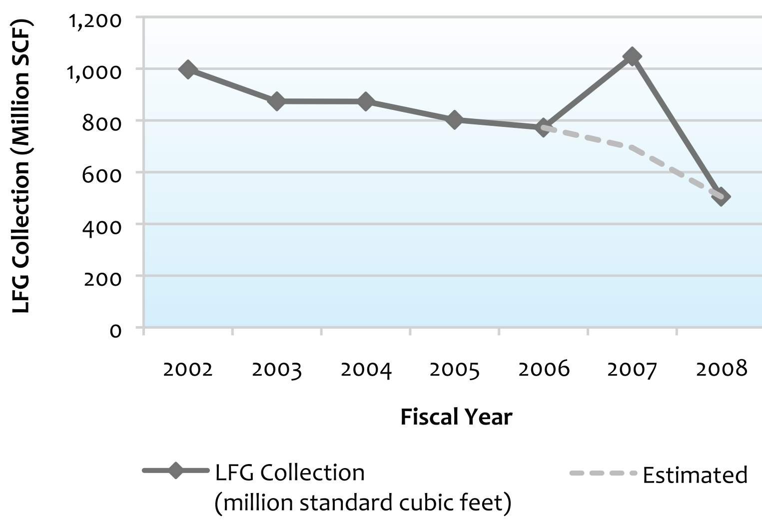
Note: Totals may not sum due to independent rounding.

2.2.2.1 Landfills

Generally, there has been a decreasing trend of fugitive CH_4 emissions from the City's Wilders Grove landfill since 2001. From 2002 to 2008, CH_4 emissions from Wilders Grove decreased by nearly 60 percent. The only exception to the decrease in emissions occured in FY2007 (CY2006), which included a sharp increase in the reported amount of LFG collected. The LFG collection at Wilders Grove directly influences the 2007 calculated fugitive CH_4 emissions.

This increase followed the completion of improvements to the landfill gas collection system over the past several years, including an expansion of the synthetic cap covering the landfill and improvements to individual wells. This increase may be a result of improved collection efficiency, though it may also be caused by an error in monitoring gauges or a change in operating procedures (City of Raleigh 2010). Figure 8 displays the LFG collected at Wilders Grove landfill for FY 2002 through 2008 (including the LFG that was flared and the LFG used to produce energy), as well as an estimated amount of LFG collected for 2007 based on the 2002-2008 trend. If 2007 collections were in line with the observed trend rather than the observed value, landfill emissions would be approximately 13,000 $MTCO_2E$ lower than estimated here. Ultimately, this inventory used the actual recorded values in order to maintain consistency with data reported to the State of North Carolina.

Figure 8: Landfill Gas collection at Wilders Grove landfill (million scf)



2.2.2.2 Compost Facilities

Total emissions from composting facilities in the City of Raleigh fluctuate over time due to the varying amounts of yard waste processed each year. In 2007, the City of Raleigh yard waste center processed approximately 35,000 short tons of yard waste (compared with a 10 year maximum of almost 50,000 short tons in 2003). In 2007, the yard waste compost facility emitted 2,684 metric tons CO_2 Eq. of CH_4 and 2,972 metric tons CO_2 Eq. of N_2O. As mentioned in the Methodology section, the emissions factors used in these calculations were the average values of emissions ranges reported in the IPCC Guidelines (IPCC 2006). However, the waste composition greatly affects the potential emissions from composting operations, as indicated by the large range of emission factors provided in the IPCC Guidelines. As the state of the science behind estimating potential emissions from compost facilities improves, the ability to more accurately assess emissions will also improve. Recognizing the inherent uncertainty in estimating emissions from composting, the total emissions from composting is only a small percentage (3.7 percent) of the total City emissions.

2.3 Scope 1: Vehicle and Equipment Fleets (14%)

The City of Raleigh uses both highway and non-highway vehicles and equipment in several municipal departments to deliver city services, including the Fire Department, Police Department, Parks and Recreation, Public Utilities, Public Works, Solid Waste Services, Capital Area Transit (CAT)[13], and others. The combustion of fossil fuels in mobile sources emits CO_2, CH_4 and N_2O. Emissions from City-owned vehicles and equipment were calculated for each fuel used and vehicle and equipment type. The City's fleet uses gasoline, diesel, biodiesel (B5 and B20), off-road diesel, compressed natural gas (CNG), and ethanol (E85). With approximately 2,000 vehicles and pieces of equipment, the City uses a wide array of vehicles and equipment, including passenger cars, light trucks, heavy-duty vehicles, motorcycles, agricultural and landscaping equipment, construction equipment, and utility equipment. Generators that are managed by the City's Vehicle Fleet Services Division are included in this section. Those generators that are managed by individual facilities are included in the Stationary Combustion section below. This methodology used to estimate emissions in this sector and the results are discussed below.

2.3.1 Methodology

Hybrid Downtown Circulator

Due to the extensive databases maintained by the City's Vehicle Fleet Services (VFS) Division, data used to calculate mobile combustion emissions are available for the years 2000 through 2008, both for fiscal and calendar years. As with the rest of the inventory, FY2007 was used as the baseline for this calculation. For vehicles and equipment in the City's fleet for a given year, the following data are available: equipment description, meter type (mileage, hour, or none); usage (miles or hours); quantity of fuel consumed (gallons); total cost (dollars); fuel consumption rate (miles per gallon or hours per gallon); fuel cost per mile (dollars per mile); and fuel type. The vehicle and equipment description includes the make, model name, and model year. These data, in conjunction with total volumes at the City's fueling facilities, were used to estimate emissions from Vehicle Fleet Services-managed vehicles and equipment.

Two groups of vehicles were not included in the Vehicle Fleet Services Division databases: CAT and the Fire Department. The data provided for the CAT buses and other vehicles were structured much in the same way as the VFS data, with fuel type, equipment description, vehicle mileage, quantity of fuel consumed, total cost, and vehicle model year. In June 2007, CAT buses began using biodiesel (B5) instead of conventional diesel fuel. While the actual fuel consumption of B5 in June 2007 was not available, the

[13] CAT is operated by a contractor, but the vehicles are City-owned and the Raleigh Transit Authority sets CAT's fares, routes, and policies. Since the City maintains effective operational control over CAT, emissions for CAT were included under Scope 1.

total fuel consumption of conventional diesel (July 2006-May 2007) and B5 (June 2007) was available. Therefore, it was assumed that one-twelfth of the recorded diesel fuel consumption for CAT buses in FY2007 was B5, while the remainder was conventional diesel. The data for the Fire Department included total fuel consumption by fuel type, but vehicle mileage was not available. In order to estimate CH_4 and N_2O emissions using the methodology discussed below, mileage for Fire Department vehicles was estimated using an assumed mileage of 12.96 miles per gallon for diesel vehicles and 10.13 miles per gallon for gasoline vehicles. These correspond to Class 2 heavy-duty diesel vehicles and Class 2 heavy-duty gasoline vehicles in the EPA's MOBILE6 model. Although this represents a simplification of the Fire Department's vehicle fleet, these assumptions affect only the non-CO_2 emissions, which account for less than 1 percent of emissions from vehicles.

The City's vehicle fleet includes both highway and non-highway vehicles. The LGO Protocol identifies six highway vehicle types in LGO Protocol Table G.10: gasoline passenger cars, gasoline light trucks, gasoline heavy-duty vehicles, diesel passenger cars, diesel light trucks, and diesel heavy-duty vehicles. The LGO Protocol also provides emission factors for several types of non-highway vehicles in LGO Protocol Table G.12. Based on the descriptions available for the City's fleet vehicles and equipment, it was determined that the non-highway portion of the fleet includes only Agricultural, Construction, and Utility equipment and vehicles. Using these vehicle and equipment descriptions, each vehicle in the City's fleet was assigned one of the seven vehicle types and five fuel types.

Emissions from the City's fleet of vehicles and equipment were then calculated using the approaches recommended in Chapter 7 of the LGO Protocol. To calculate CO_2 emissions from highway vehicles, the approach recommended in Section 7.1.1.1 was used. First, the vehicles in the City's fleet for each year were organized by vehicle type, fuel type, and model year. The City fueling facility totals were used to calculate CO_2 emissions from VFS vehicles because the total records for the City's fueling facilities were assumed to be more accurate than the individual records for each vehicle. The emissions were calculated for vehicles following Equation 5. The factors for these fuels are shown in Table 10.

Equation 5: CO_2 Emissions from Mobile Combustion
Annual CO_2 emissions (metric tons) = Fuel Consumed in gallons × Emission factor (kg CO_2 per gallon of fuel) × Conversion factor (kg to metric tons)

Table 10: Factors for Calculation CO_2 Emissions from Gasoline and Diesel Fuel Combustion

Fuel	Emission Factor (kg CO_2/gallon or kg CO_2/gasoline gallon equivalent for CNG)
Unblended Fuels	
Biodiesel (B100)	9.46
CNG	6.84
Diesel	10.15
Ethanol (E100)	5.56
Gasoline	8.81
Blended Fuels	
Biodiesel (B5)	10.12
Biodiesel (B20)	10.01
Ethanol (E85)	6.05

Notes:

(1) CNG gasoline gallon equivalent is based on 126.67 standard cubic feet of natural gas at 0.054 kg CO_2 per standard cubic foot.

(2) The City uses B5, a blend of 5 percent biodiesel and 95 percent conventional diesel; B20, a blend of 20 percent biodiesel and 80 percent conventional diesel; and E85, a blend of 85 percent ethanol and 15 percent gasoline.

Source: LGO, 2008.

With biodiesel and ethanol, the emission factor was estimate based on the content of the B5, B20, and E85 fuel blends. Because biodiesel (B100) and ethanol (E100) are biofuels, CO_2 emissions from the biofuel portions of B5, B20, and E85 are considered biogenic, and in accordance with the LGO Protocol, biogenic emissions are not included in the City's total emissions. CO_2 emissions from these fuels were therefore estimated yet omitted from the emissions total while non-CO_2 emissions from these fuels were included in the totals. As a result, the City is reducing its net GHG emissions by using biofuels. However, it should be noted that the boundaries of this inventory do not include fuel life-cycle emissions for any fuels. The extraction, processing, and transportation of biofuels and fossil fuels result in GHG emissions that can affect their net life-cycle emissions. If, for example, biofuels used by the City have greater life-cycle emissions than the equivalent fossil fuels, then the net GHG savings may be smaller than calculated here. In discussing this issue, the LGO Protocol advises that local governments consider the upstream emissions from the specific source of biofuels when making decisions about which fuels to use. The total fuel consumption by the City's vehicle and equipment fleets in FY2007 is presented in Table 11 below.

Table 11: Vehicle and Equipment Fuel Consumption in FY2007, By Fuel

Fuel	Unit	Consumption
Gasoline	Gallons	835,346
Diesel	Gallons	882,315
Biodiesel (B5)	Gallons	58,826
Biodiesel (B20)	Gallons	386,153
Off-Road Diesel	Gallons	68,017
Ethanol (E85)	Gallons	1,468
CNG	Gasoline gallon equivalent	3,919

To calculate CH_4 and N_2O emissions from highway vehicles, the approach in Section 7.1.3.1 of the LGO Protocol was used. For on-road vehicles, emissions are based on the fuel type, vehicle type, model year, and mileage traveled. With off-road vehicles and equipment, emissions are based on the fuel type, vehicle/equipment type, and amount of fuel consumed. Emissions for both vehicles and equipment were estimated using Equation 6 and Equation 7 below. Emissions totals for each of these gases were then converted to metric tons of CO_2 equivalent by multiplying emissions by the global warming potential (GWP) of CH_4 (21) and N_2O (310), respectively.

The emission factors for on-road gasoline and diesel vehicles are presented in Table 1 of the Appendix. The emission factors for non-road vehicles and alternative fuel vehicles, which do not vary by model year, are presented below in Table 12.

Equation 6: CH_4 Emissions from Mobile Combustion
For on-road vehicles: Annual emissions (metric tons CH_4) = Annual distance (miles) × Emission factor (g CH_4/mile) × Conversion factor (g to metric tons)
For off-road vehicles and equipment: Annual emissions (metric tons CH_4) = Fuel usage (gallons) × Emission factor (g CH_4/gallon) × Conversion factor (g to metric tons)

Equation 7: N_2O Emissions from Mobile Combustion
For on-road vehicles: Annual emissions (metric tons N_2O) = Annual distance (miles) × Emission factor (g N_2O /mile) × Conversion factor (g to metric tons)
For off-road vehicles and equipment: Annual emissions (metric tons N_2O) = Fuel usage (gallons) × Emission factor (g N_2O /gallon) × Conversion factor (g to metric tons)

Table 12: CH_4 and N_2O Emission Factors for Alternative Fuel Vehicles and Off-Road Equipment

Vehicle Type / Fuel Type	N_2O (g/mi)	CH_4 (g/mi)
Light Duty Vehicles		
CNG	0.05	0.737
Ethanol	0.067	0.055
Vehicle Type / Fuel Type	**N_2O (g / gallon fuel)**	**CH_4 (g / gallon fuel)**
Agricultural Equipment		
Gasoline	0.22	1.26
Diesel Fuel	0.26	1.44
Construction		
Gasoline	0.22	0.5
Diesel Fuel	0.26	0.58
Other Utility		
Gasoline	0.22	0.5
Diesel Fuel	0.26	0.58

2.3.2 Emissions Estimate

In FY2007, emissions from vehicles and equipment in the City of Raleigh were approximately 21,000 metric tons CO_2-equivalent. Diesel vehicles—including CAT buses, fire trucks, and a wide range of equipment used by the Public Works and Public Utilities departments—accounted for about 50 percent of net emissions from this sector. All gasoline vehicles accounted for about 35 percent of emissions, with all other fuels accounting for the remaining emissions. The use of B5, B20, and E85 reduced the City's net emissions by 765 metric tons, or about 3.5 percent of gross emissions from vehicles. Table 13 below summarizes FY2007 GHG emissions from the City of Raleigh's vehicle and equipment fleets.

Table 13: Gross and Net Emissions from Vehicles and Equipment FY2007 (Metric Tons CO_2 Equivalent)

	Emissions $MTCO_2E$			
Fuel Type	**CO_2**	**CH_4**	**N_2O**	**Total**
Gasoline	7,359	5	73	7,437
Diesel	9,646	3	16	9,665
Biodiesel (B5)*	595			595
Biodiesel (B20)*	3,866			3,866
CNG	27	1	1	30
Ethanol (E85)*	9	0	7	17
Gross Total	**21,502**	**10**	**98**	**21,610**
Biogenic CO_2	**(765)**			**(765)**
Net Total	**20,737**	**10**	**98**	**20,845**

* Indicates that emission estimates for these fuels include biogenic CO_2 emissions. Emissions from the biogenic portion of these fuels (those produced by living organisms) were included in the gross total but excluded from the net total. The treatment of biogenic fuels is discussed in Section 2.3.1 above.

Note: Totals may not sum due to independent rounding.

2.4 Scope 1: Stationary Combustion at Buildings & Facilities (3%)

Stationary combustion refers to the on-site combustion of fuels to produce electricity, heat, or motive power (e.g., water pumps) using equipment in a fixed location (CARB 2008). This section refers only to the use of fuels and not to the use of electricity. Depending on the nature of a given facility, it could produce emissions from either stationary combustion, electricity use, or both. For example, a typical City facility may use natural gas for heat and electricity for lighting. Stationary combustion is a Scope 1 emission source because its emissions are generated on-site (directly), while electricity use is a Scope 2 source because its emissions are generated off-site (indirectly). This section covers emissions from stationary combustion, while emissions from electricity use are included in Section 2.1 above. These two categories are divided because emissions from stationary combustion are under the direct control of the City of Raleigh, while emissions from electricity use are indirect—the actual emissions take place at the facilities used to generate the electricity. This section includes the use of fuels in generators that are managed by individual facilities. Generators that are managed by the Vehicle Fleet Services Division were included in the previous section.

2.4.1 Methodology

Emissions from stationary combustion of natural gas at City facilities were calculated using approach recommended in Section 6.1.1 of the LGO Protocol. Monthly metered natural gas consumption data were provided by the City of Raleigh in units of therms for each facility that consumed natural gas. Additional data on gasoline, diesel fuel, and propane used at a limited number of facilities were also collected.

Consumption of each fuel was summed for the FY2007 base year and converted from the measured units (therms in the case of natural gas, gallons for all other fuels) tomillion BTU (MMBTU). Once the amount of energy in terms of MMBTU was determined, this value was multiplied by the CO_2 emission factor. Finally, emissions were converted into metric tons of CO_2. The equations used for these calculations, which vary based on the fuel, are shown in Equation 8 below. The factors used are shown in Table 14 below.

Equation 8: CO_2 Emissions from Stationary Combustion

Natural Gas: Annual CO_2 emissions (metric tons) = Fuel Consumed in therms × Heat Content (MMBTU/therm) × Emission factor (kg CO_2 per MMBTU) × Conversion factor (kg to metric tons)

Other fuels: Annual CO_2 emissions (metric tons) = Fuel Consumed in gallons × 1 Barrel/42 Gallons × Fuel Heat Content (MMTBU/Barrel) × Emission factor (kg C per MMBTU) × Fuel Combustion Efficiency × Conversion factor (kg to metric tons) x 44/12 (Ratio of molecular weight of CO_2 to C)

Table 14: CO_2 Emission Factors for Stationary Combustion

Fuel	Heat Content (MMBTU/therm)	Emission Factor (kg CO_2/MMBTU)
Natural Gas	0.1	53.06
Fuel	**Heat Content (MMBTU/barrel)**	**Emission Factor (kg CO_2/MMBTU)**
Diesel	5.825	73.15
Gasoline	5.218	70.88
Propane	3.849	63.16

Source: LGO Protocol, Table G.1

The recommended approach in Section 6.1.1 of the LGO Protocol was used to estimate CH_4 and N_2O emissions from stationary combustion. Emissions for each fuel were estimated by multiplying fuel consumption in MMBTU by the fuel-specific emission factor and converting to metric tons of gas. The equations used for estimating CH_4 and N_2O are shown below in Equation 9 and Equation 10. Emissions totals for each of these gases were then converted to metric tons of CO_2 equivalent by multiplying emissions by the global warming potential (GWP) of CH_4 (21) and N_2O (310), respectively. The factors used in these calculations are shown in Table 15 below. As suggested by the LGO Protocol, the commercial/institutional emission factors for CH_4 and N_2O were used.

Raleigh Skyline

Equation 9: CH_4 Emissions from Stationary Combustion
Annual emissions (metric tons CH_4) = Fuel consumption (MMBTU) × Emission factor (g CH_4/MMBTU) × Conversion factor (g to metric tons)

Equation 10: N_2O Emissions from Stationary Combustion
Annual emissions (metric tons N_2O) = Fuel consumption (MMBTU) × Emission factor (g N_2O /MMBTU) × Conversion factor (g to metric tons)

Table 15: CH_4 and N_2O Emission Factors for Stationary Combustion

Fuel	CH_4 Emission Factor (g CH_4 / Million BTU)	N_2O Emission Factor (g N_2O / Million BTU)
Natural Gas	5	0.1
Diesel	11	0.6
Gasoline	11	0.6
Propane	11	0.6

2.4.2 Emissions Estimate

In FY2007, emissions from stationary combustion in the City of Raleigh were approximately 4,700 metric tons CO_2-equivalent. With nearly 60 percent of emissions in this category, natural gas usage accounted for the bulk of emissions. Diesel fuel, which was most commonly used for emergency generator and water pumping stations, accounted for nearly all of the remaining 40 percent. The results are summarized below in Table 16.

Table 16: Emissions from Stationary Combustion FY2007 (Metric Tons CO_2 Equivalent)

	Emissions $MTCO_2E$			
Fuel Type	**CO_2**	**CH_4**	**N_2O**	**Total**
Natural Gas	2,758	5	2	2,765
Diesel fuel	1,918	6	5	1,929
Gasoline	1	0	0	1
Propane	15	0	0	15
Total	**4,692**	**12**	**7**	**4,710**

Note: Totals may not sum due to independent rounding.

2.5 Scope 1: Wastewater Treatment (1%)

Wastewater treatment plants (WWTP) treat wastewater through filtering and microbial decomposition processes in order to prepare the resulting effluent for release into aquatic environments. The treatment removes soluble organic matter, suspended solids, pathogenic organisms and chemical contaminants from the wastewater stream. This collection of materials is known as the "biosolids" and can be further digested either anaerobically or aerobically. The remaining wastewater stream, or effluent, also undergoes additional processing driven by microbial digestion of the soluble organic contaminants in the effluent. The specific mix of processes used to treat wastewater at a centralized treatment plant varies from location to location, but may involve lagooning, anaerobic or aerobic digestion, and other options (EPA 2009).

LEED Silver Training Center at the Neuse River Wastewater Treatment Plant

The process of treating wastewater by the City of Raleigh generates nitrous oxide (N_2O) emissions.[14] The majority of emissions related to wastewater treatment result from the use of electricity. However, those emissions are considered to be Scope 2 and were included in Section 2.1 above. This section refers only to fugitive

[14] Since the wastewater treatment facilities do not include anaerobic treatment lagoons, septic systems or any form of anaerobic digestion, it can be assumed that methane (CH_4) is not produced.

emissions from the treatment processes that were directly emitted by the wastewater treatment plants. A more complete representation of the GHG emissions from wastewater treatment is provided in the summary by City Department in Section 3 below.

The City of Raleigh currently has three wastewater treatment plants within operational control: Little Creek, Neuse River and Smith Creek.[15] All three treatment plants in the City of Raleigh employ advanced wastewater treatment technology, relying on nitrification/denitrification technology and the aerobic digestion of biosolids (Stearns & Wheler 2009). The three plants emit nitrous oxide (N_2O) during the nitrification/denitrification treatment process and the effluent discharge into streams and rivers. The majority of emissions from these facilities result from electricity or fuel use. These emissions are included in the sources above, and also included in the departmental summary below under Public Utilities.

2.5.1 Methodology

Emissions were calculated according to the wastewater treatment facilities methodology outlined in the LGO Protocol (LGOP 2008). While wastewater treatment plants also emit GHGs from electricity consumption and fuel combusted during the use of treatment equipment, this section only estimates emissions from wastewater treatment processes. The GHG emissions resulting from fuel and electricity use in wastewater treatment facilities are included in Scope 1 emissions from building and facility fuel use, and Scope 2 emissions from building, facility, and lighting electricity use, respectively.

GHG emissions can result from a variety of wastewater treatment processes and emissions depend on the technology and processes used at a particular site. The LGO Protocol provides both site specific and default equations to calculate these emissions. Since site specific data were available for the three wastewater treatment plants, the site specific equations from the LGO Protocol were used to calculate emissions.

CH_4 emissions are a result of treatment processes occurring in anaerobic conditions. These processes types include septic systems, poorly-managed aerobic systems, anaerobic treatment lagoons and anaerobic digestions where the captured biogas is not completely combusted (LGOP 2008). Since none of the treatment plants operated by the City of Raleigh rely on these treatment process types (Stearns & Wheler 2009), CH_4 emissions are assumed to be zero. However, in the future, if treatment lagoons, anaerobic digesters or other anaerobic technologies become a part of the treatment system, CH_4 emissions will need to be calculated using the relevant methodologies outlined in the LGO Protocol.

N_2O emissions are a result of wastewater processing with or without nitrification/denitrification and during effluent discharge to aquatic environments. Since all three centralized wastewater treatment plants only use the nitrification/denitrification method (Stearns &

[15] Both Neuse River and Little Creek facilities receive industrial as well as municipal wastewater, and the Smith Creek facility only receives municipal wastewater (Stearns & Wheler 2009a).

Wheler, 2009), Equation 11 was used to calculate N_2O process emissions (Equation 10.7 in the LGO Protocol).

Equation 11: N_2O Process Emissions from wastewater treatment plants with nitrification/denitrification
Annual N_2O emissions (metric tons) = Ptotal x EFnit/denit x 10-6

Using this equation, the wastewater characteristics used for these calculations are shown in Table 17 below.

Table 17: Terms Used in Equation 11

Term	Description	Value
P_{total}	Municipal population served by wastewater treatment facility	Varies by location
$EF_{nit/denit}$	Emissions factor for nitrification/denitrification processes	7 kg N/person/day
Grams to Metric Tons	Conversion from grams to metric tons	10-6 grams/metric ton

This equation multiplies population by an emissions factor specific to the nitrification/denitrification technology (i.e., 7 kg N/person/day). The main activity data driving these results is therefore the municipal population served by the treatment plant. Both Little Creek and Neuse River receive industrial wastewater in addition to municipal wastewater (Stearns & Wheler, 2009a). According to the LGO Protocol, the population should be adjusted upwards in order to account for industrial wastewater processed by the treatment plant. The protocol recommends that the population adjustment be made by dividing the nitrogen discharged by industry to the municipal treatment system by 0.026 kg N/person/day. With daily industrial nitrogen discharges of 22 kg and 513 kg to the Little Creek and Neuse River treatment plants, respectively, the Little Creek plant processes industrial wastewater equivalent to an estimated 840 people, while the Neuse River plant processes industrial wastewater equivalent to an estimated 19,700 people.

The second source of N_2O emissions is effluent discharge of wastewater to aquatic environments. The City of Raleigh provided data on the total nitrogen discharged by each treatment plant per day (kg N/day). As a result, the LGO Protocol site specific methodology was employed to calculate emissions from this source using Equation 12 (Equation 10.9 in the LGO Protocol).

Equation 12: Process N_2O Emissions from effluent discharge
Annual N_2O emissions (metric tons) = NLoad x EFeffluent x 365.25 x 10-3 (metric ton/kg)

Using this equation, the wastewater characteristics used for these calculations are shown in Table 18 below.

Table 18: Terms Used in Equation 12

Term	Description	Value
N_{Load}	Measured average total Nitrogen discharged (Kg N/day)	Varies by location
$EF_{effluent}$	Emissions factor	0.005 Kg N_2O-N/Kg sewage-N produced
Conversion Factor	Number of Days in a Year	365.25 days/year
Kilograms to metric tonnes	Conversion from kilograms to metric tonnes	10-3 metric ton/kg

This equation multiplies the average total N discharged per day by an emission factor of 0.005 N_2O-N released per kg of sewage N. The main activity data driving these results is therefore total N discharged. Since the N discharged at each facility is a measured and site-specific value, this calculation automatically includes the input of industrial wastewater sources.

2.5.2 Emissions Estimate

In FY 2007, total N_2O emissions from wastewater treatment were 1,114 $MTCO_2E$. Emissions from Neuse River were 1,032 $MTCO_2E$, emissions from Little Creek and Smith Creek were 19 $MTCO_2E$ and 62 $MTCO_2E$, respectively. Table 19 shows the emissions from each of the three wastewater treatment plants operated by the City of Raleigh in FY 2007. Wastewater emissions represent 0.6% of total emissions from the City of Raleigh's Government Operations.

Table 19: N_2O Process and Effluent Discharge Emissions (Metric Tons CO_2 Equivalent) in FY 2007

Wastewater Treatment Plant	Process Emissions (N_2O) (Nitrification/denitrification)	Emissions from Effluent Discharge (N_2O)	Total N_2O Emissions ($MTCO_2E$)
Little Creek	14	5	19
Neuse River	867	165	1,032
Smith Creek	52	10	62
Total	**934**	**180**	**1,114**

Note: Totals may not sum due to independent rounding.

2.6 Scope 1: Refrigeration & Air-Conditioning (<0.5%)

Because of ongoing efforts to reduce the use of **ozone-depleting substances** in the City's facilities, some refrigeration and air-conditioning equipment use hydrofluorocarbons (HFCs) as alternatives. These HFCs act as powerful GHGs. Buildings and facilities within the City of Raleigh contain several different types of refrigeration and air-conditioning equipment including window air-conditioners, chillers, and refrigerators, some of which use HFCs. Refrigerant leaks during the installation, use, and disposal of these systems produce fugitive emissions of HFCs. **Fugitive emissions** from refrigerants were estimated for domestic refrigeration, stand-alone commercial applications, industrial refrigeration, chillers, and air-conditioning. According to the Local Government Operations (LGO) Protocol, fugitive emissions of HFCs from on-site refrigerants used for refrigeration and air-conditioning are categorized as a Scope 1 source of emissions (CARB et al. 2008).

Fugitive refrigerant emissions for the City of Raleigh were estimated to be 668 $MTCO_2E$ in FY2007. Eighty-seven percent of emissions, or 581 $MTCO_2E$, are attributable to chillers, used for climate control and comfort cooling of government buildings. Residential or commercial sized air-conditioning units and heat pumps are the second largest contributor of total fugitive refrigerant emissions, accounting for 10 percent, or 63 $MTCO_2E$.

2.6.1 Methodology

This study used the alternate methodology described in section 6.6.2.2 "Estimation Based on Equipment Inventory and Refrigerant Use" of the LGO Protocol to estimate fugitive refrigerant emissions (CARB et al. 2008). Detailed data were not available to apply the recommended mass balance approach; therefore a simplified mass balance approach was implemented instead. This simplified methodology follows three steps:

1. Determine the types and quantities of refrigerants used;
2. Estimate annual emissions of each type of HFC; and
3. Convert to units of CO_2E and determine total HFC emissions.

2.6.1.1 Step 1: Determine the types and quantities of refrigerants used

An equipment inventory of the refrigeration and air-conditioning equipment found in City of Raleigh government buildings informed the types and quantities of refrigerants used in this analysis. The equipment types are listed in Table 20. Where the refrigerant type and/or quantity were not provided by the survey, model numbers were used to obtain equipment-specific data. Where model numbers were not provided, assumptions regarding refrigerant type and quantity were made based on the type of equipment reported.

Table 20: Equipment Characterization

Type of Equipment	Description
Refrigeration	
Domestic Refrigeration	Domestic refrigerator/freezers, etc.*
Stand-alone Commercial Applications	Food and beverage, open and glass-door display cases; ice makers; vending machines, etc.
Industrial Refrigeration including Food Processing and Cold Storage	Walk-in coolers, etc.
Air-conditioning	
Chillers	Positive displacement chillers, centrifugal chillers, etc.
Residential and Commercial A/C including Heat Pumps	Water and air condensing units, window units, unitary air-conditioning, heat pumps, etc.

*Water/drinking fountains and water coolers are included under domestic refrigeration because they are assumed to have low leak rates.

It is important to note that not all City refrigeration and air conditioning equipment was included. Many pieces of equipment still in operation use ozone-depleting substances (ODS) such as chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs).[16] The emissions from ODS were not estimated here. Depletion of the ozone layer (while harmful for other non-climate reasons) actually has a cooling effect on the climate that counteracts the direct warming effects from emissions of ODS. While the IPCC (2007) estimates the direct global warming potential (GWP) of these gases to account for their warming capabilities, it does not estimate the net GWP because of the greater uncertainty associated with the cooling effects of depleting the ozone layer. As a result, neither the IPCC guidelines nor the LGO Protocol require emission estimates of ODS. In practice, most new or recently retrofitted buildings will use HFCs, leading to GHG emissions. For this reason, newer and retrofitted buildings are included here, while older buildings that still utilize CFCs and HCFCs (Freon) were not included here.

Additionally, data from equipment in the City's Fire Department facilities were not readily available. In order to estimate emissions from these facilities, field visits were conducted at six of the City's 27 fire stations in order to estimate emissions from these facilities. The number and types of equipment at these sample stations were used to estimate the equipment in service at the remaining stations. Although this slightly increases the uncertainty associated with this calculation, it is unlikely to significantly affect the City's emissions total—this source accounts for less than ½ of one percent of the City's emissions, while dozens of much larger facilities were fully accounted for.

2.6.1.2 Step 2: Estimate annual emissions of each type of HFC

Once the types and quantities of refrigerants were identified for each piece of equipment identified in Step 1, the equipment was categorized into the five refrigeration and air-conditioning equipment types in Table 20. The **emission factors** (EF) corresponding to

[16] The most common ODS used as refrigerants by the City of Raleigh are R-11, R-12, and R-22.

each equipment type (Table 21) were then applied using Equation 13 for each refrigerant and equipment type to estimate HFC emissions.

Table 21: Default emission factors for refrigeration and air-conditioning equipment by equipment type (CARB et al. 2008)

Type of Equipment	Installation EF (% charge) k	Operating EF (% charge/yr) x	Refrigerant Remaining at Disposal (% charge) y	Recovery efficiency (% remaining) Z
Refrigeration				
Domestic Refrigeration	1%	0.5%	80%	70%
Stand-alone Commercial Applications	3%	15%	80%	70%
Industrial Refrigeration including Food Processing and Cold Storage	3%	23%	100%	90%
Air-conditioning				
Chillers	1%	15%	100%	95%
Residential and Commercial A/C including Heat Pumps	1%	10%	80%	80%

Equation 13: Estimating HFC emissions by refrigerant type
Total Emissions = $[(Cn \times k) + (C \times x \times T) + (Cd \times y \times (1 - z))] \div 1$
Total Emissions = $[(Cn \times k) + (C \times x \times T) + (Cd \times y \times (1 - z))] \div 1$

The variables used in Equation 13 are shown below in Table 22.

Table 22: Terms Used in Equation 13

Term	Description
Total Emissions	**Emissions of refrigerant r in year a, metric tons**
C_n	Quantity of refrigerant r charged in new equipment, kg[1]
C	Total full charge of the equipment, kg
T	Time equipment was in use, years
C_d	Total full charge of equipment being disposed, kg[2]
k	Installation emission factor, % charge[1]
x	Operating emission factor, % charge/year
y	Refrigerant remaining at disposal, % charge[2]
z	Recovery efficiency, % remaining

1 Omitted if no equipment was installed during year a or the installed equipment was pre-charged by manufacturer.

2 Omitted if no equipment was disposed of during year a.

2.6.1.3 Step 3: Convert to units of CO_2E and determine total HFC emissions

The HFC emissions (in metric tons) calculated in Step 2 were then converted to $MTCO_2E$ by multiplying the emissions for refrigerant type by the corresponding global warming potential (GWP), and then summed to estimate total annual fugitive emissions from all refrigerants using Equation 14. The GWPs used in the estimates by refrigerant type are presented in Table 23

Equation 14: Converting to $MTCO_2E$ by refrigerant type
Total Emissions ($MTCO_2E$) = Total Emissions (Metric Tons of HFC) × GWPrefrigerant
Total Emissions ($MTCO_2E$) = Total Emissions (Metric Tons of HFC) × GWPrefrigerant

The equipment inventory identified several pieces of equipment that were labeled as containing either R-404A or R-507. To estimate emissions from these pieces of equipment, the average GWP for the two refrigerants (i.e., 3,280) was used to estimate emissions in $MTCO_2E$. While fugitive HFC emissions from refrigerants may not be a large source of GHG emissions, the high GWP associated with the refrigerants (as shown in Table 23) can translate into significant emissions.

Table 23: Global warming potentials for refrigerants (CARB et al. 2008)

Refrigerant	GWP
R-134a	1,300
R-404A	3,260
R-410A	1,725
R-507	3,300
R-500	37

2.6.2 Emissions Estimate

Total HFC emissions from fugitive refrigerants by equipment type and refrigerant type for the City of Raleigh are presented in Table 24. Figure 9 and Figure 10 provide the percent contribution of emissions by refrigerant type and equipment type, respectively. The chillers in Raleigh's Convention Center contributed the most HFC emissions, with 84% of total chiller emissions or 73% of total HFC emissions,[17] followed by the chiller at the Progress Energy Center which contributes 9% of total chiller emissions or 8% of total HFC emissions. After these major facilities, smaller residential- and commercial-scale air conditioning equipment accounted for most of the remaining emissions. As mentioned above, these emissions were dominated by new or recently-retrofitted buildings that utilize HFCs instead of CFCs or HCFCs.

[17] This emissions inventory covers FY2007, though no Convention Center was in operation during this time. The previous convention center was demolished in February 2006, while the new Convention Center did not open until September 2008. In order to present a representative baseline year, the new Raleigh Convention Center was included as if it were in operation during FY2007.

Table 24: HFC emissions by equipment and refrigerant type

Equipment Type	Refrigerant	Emissions ($MTCO_2E$)
Refrigeration		**21.9**
Domestic Refrigeration	HFC-134a	0.2
	R-500	+
Stand-alone Commercial Applications	R-404A	16.3
	HFC-134a	2.0
Industrial Refrigeration and Cold Storage	R-404A	5.5
Air-conditioning		**616.4**
Chillers	HFC-134a	580.8
Residential and Commercial AC/HP	R-410A	44.5
	R-404A	11.3
	R-404A/507A	7.2
	R-134a	0.2
Total		**668.2**

+ Less than 0.5$MTCO_2E$
Note: Totals may not sum due to independent rounding.

Figure 9: HFC Emissions by Gas

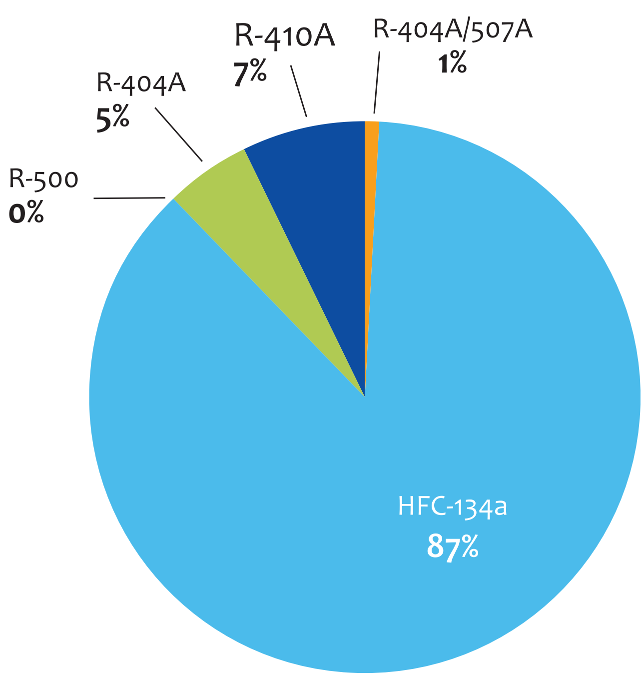
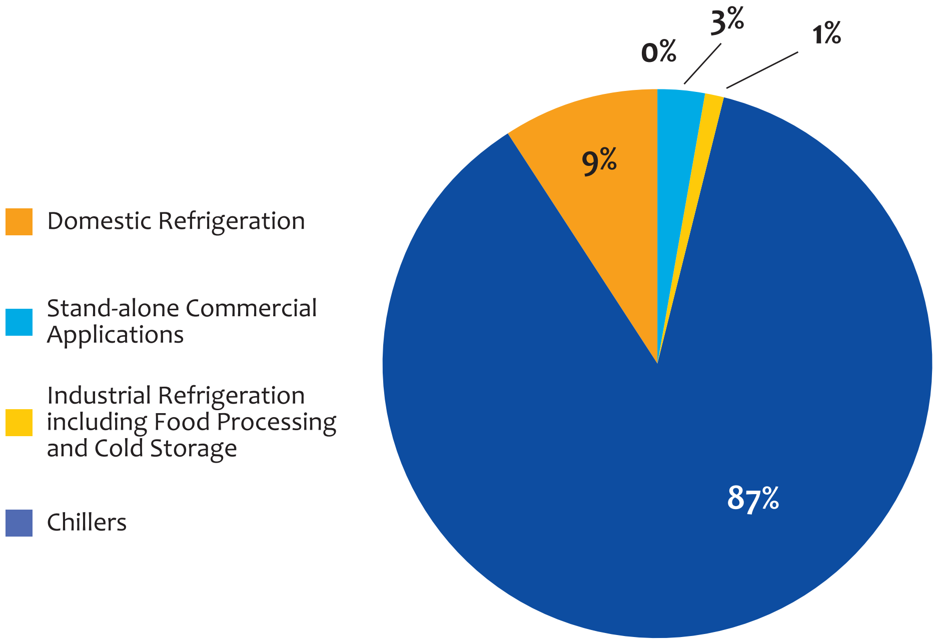


Figure 10: HFC Emissions by Equipment Type



2.7 Scope 1: Livestock (<0.5%)

Horses emit methane (CH_4) as part of a natural digestive process that occurs in animals. During digestion, microbes resident in an animal's digestive system ferment food consumed by the animal. This microbial fermentation process, referred to as **enteric fermentation**, produces CH_4 as a by-product, which can be exhaled or eructated by the animal (EPA 2008). In addition to enteric fermentation emissions, the management of livestock manure can produce CH_4 emissions as the manure is anaerobically decomposed.

Raleigh's Mounted Police

The City of Raleigh owns five horses that are used for mounted police work.[18] The horses are owned and housed by the City of Raleigh, and as a result fall under Scope 1 of the LGO Protocol.

2.7.1 Methodology

A methodology to estimate enteric fermentation and manure management emissions from livestock is not included in the LGO Protocol. Emissions from horses were estimated using methodology based on the U.S. Greenhouse Gas Inventory and the Intergovernmental Panel on Climate Change (IPCC) Guidelines (EPA 2008 and IPCC 2006). Two sources of emissions were considered: CH_4 from enteric fermentation and CH_4 from manure management.

[18] The City owned five horses during data collection and inventory; at time of this report, the City owns four horses.

2.7.1.1 Enteric Fermentation

Enteric fermentation was calculated using an emission factor of 18 kg CH_4/head, originally from the 2006 IPCC Guidelines (IPCC 2006). The emission factor was multiplied by the number of horses (five) to calculate the total emissions in kg of CH_4. Totals in kg of CH_4 were then converted to metric tons CO_2 eq. using methane's global warming potential of 21 and known molecular weight ratios, using Equation 15.

Equation 15: CH_4 Emissions from Enteric Fermentation
Enteric Fermentation Emissions in metric tons CO_2 eq. =   Number of Animals × Emission Factor in kg CH_4/head × GWP of CH_4 ÷ 1000 kg/metric ton

Using this equation, the following livestock characteristics were assumed:

Table 25: Terms Used in Equation 15

Term	Description	Value
Number of Animals	Number of Horses	5
Emission Factor	CH_4 Emission Factor	18 kg CH_4/head
GWP	Global warming potential to convert methane into metric tons of CO_2 equivalents (CO_2e).	21

2.7.1.2 Manure Management

Manure management CH_4 emissions were calculated using a typical animal mass (TAM) of 450 kg multiplied by a volatile solids (VS) excretion rate of 0.010 kg VS/kg animal mass and a maximum potential emissions rate of 0.33 m3CH_4/kg VS. Totals in kg of CH_4 were then converted to metric tons CO_2 eq. using methane's global warming potential of 21 and known molecular weight ratios, using Equation 16.

Equation 16: CH_4 Emissions from Manure Management
Manure Management CH_4 Emissions = Number of Animals × TAM × Volatile Solids in kg VS/kg animal mass/day × 365 days/year × Maximum Potential Emissions in m3 CH_4/ kg VS × Weighted MCF × 0.662 kg CH_4/m3 CH_4 × GWP of CH_4 ÷ 1000 kg/metric ton

Using this equation, the following livestock characteristics were assumed:

Table 26: Terms Used in Equation 16

Term	Description	Value
Number of Animals	Number of Horses	5
TAM	Typical Animal Mass	450 kg
VS	Volatile Solids	0.010 kg VS/kg animal mass
Maximum Potential Emissions	Rate of Maximum Potential Emissions	0.33 m3CH_4/kg VS
Weighted MCF	Weighted Methane Conversion Factor	0.013
GWP	Global warming potential to convert methane into metric tons of CO_2 equivalents (CO_2e).	21

2.7.2 Emissions Estimate

In FY 2007, livestock used by the City of Raleigh's police department emitted 4.8 metric tons CO_2 eq. as shown in Table 27. Emissions from enteric fermentation contributed 40%, and manure management contributed the remaining 60% to total livestock emissions. Overall, emissions from livestock are a small source, and contributed 0.003% to total emissions from the City of Raleigh.

Table 27: Emissions from Livestock Enteric Fermentation and Manure Management ($MTCO_2E$)

Source	Gas	Emissions ($MTCO_2E$)
Enteric Fermentation		
	CH_4	1.9
Manure Management		
	CH_4	0.5
	N_2O	2.4
Manure Management Subtotal		2.9
Total Livestock Emissions		**4.8**

Note: Totals may not sum due to independent rounding.

2.8 Summary of Results by Source

The estimates from each inventory source are aggregated in Table 28 below. Indirect emissions from electricity accounted for 56 percent of the City's emissions, while emissions from solid waste facilities (Scope 1) were the second largest source with 26 percent of the City's emissions. Energy consumption (both Scope 1 and Scope 2) in buildings, facilities, vehicles and equipment combined to account for 73 percent of the City's emissions (facility electricity 56%, facility natural gas 2%, facility other fuels 1%, vehicles and equipment 14%). .

Table 28: FY2007 GHG Emissions by Gas and by Source

		Emissions ($MTCO_2e$)					
Scope	**Source**	**CO_2**	**CH_4**	**N_2O**	**HFCs, PFCs, SF_6**	**Total**	**% of Total**
2	Facilities - Indirect (Electricity)	84,625	37	457		85,120	56%
1	Solid Waste Facilities		36,061	2,972		39,033	26%
1	Vehicles and Equipment	20,737	10	98		20,845	14%
1	Facilities - Natural Gas	2,758	5	2		2,765	2%
1	Facilities - Other Fuels	1,934	6	5		1,945	1%
1	Wastewater Treatment			1,114		1,114	1%
1	Refrigeration and Air Conditioning				668	668	0%
1	Police Horses		2	2		5	0%
Total		**110,054**	**36,122**	**4,650**	**668**	**151,494**	

Note: Totals may not sum due to independent rounding.

Emissions by Department

3 Emissions by Department

The sections above describe the methods and data used for estimating emissions from individual emission sources, as defined by the LGO Protocol and other inventory standards. This approach is useful in determining how the City generates its emissions, but it does not tell us which City departments or activities are causing these emissions. To answer that question, this inventory also tracked emissions within each source by City department. This section describes how department-level estimates were made and presents the results.

3.1 Departments Included

Due to the large number of City departments, the sharing of many facilities between departments, and natural gas and electricity account that are not all clearly described, City departments were grouped together in the list presented below. Also, to distinguish the significant role played by street, traffic, and area lighting, lighting was listed as a "sub-department" where possible. Emissions from most departments include facility fuel and electricity use, vehicle and equipment fuel use, and emissions from refrigeration and air conditioning equipment. Some additional sources were assigned to a single department. These include landfill methane (Solid Waste Services), fugitive emissions from wastewater treatment (Public Utilities), and police horses (Police). The departments included are as follows:

- **Administrative Services**
- **City Manager**
- **Community Development**
- **Community Services**
- **Convention and Conference Center**
- **Emergency Communications Center**
- **Finance**
- **Fire**
- **Information Technology**
- **Inspections**
- **Parks and Recreation**. Emissions for this department were subdivided, where possible, into two categories *park/area lighting and other parks and recreation.* The Parks and Recreation Department includes the Facilities and Operations Division, which is responsible for maintaining buildings across most City departments. For this department-level summary, emissions were allocated to the departments using those buildings.
- **Planning**

- **Police**
- **Public Affairs**
- **Public Utilities**
- **Public Works**. Emissions for this department were organized into three sub-categories where possible: *street/traffic lighting, transit (CAT), and other public works*. The Public Works Department includes the Vehicle Fleet Services Division, which is responsible for maintaining vehicles for most City departments. For this department-level summary, emissions were allocated to the departments using those vehicles.
- **Solid Waste Services**
- **Shared Facilities**. Because several key facilities—such as the Municipal Building, One Exchange Plaza, and 310 West Martin Street—are shared by multiple departments, a separate category was established.
- **Other**. A number of recently closed or new electricity and natural gas accounts with limited consumption were considered "other" because of limited information in the utility records.

3.2 Methodology for Assigning Emissions to Each Department

3.2.1 Facility Fuel Use, Natural Gas

Natural gas usage was reported for individual City accounts at buildings owned and leased by the City. Each account number was associated with an address and a facility description. In most cases, the facility descriptions were sufficient for assigning consumptions to one of the City departments (e.g., "Fire Station #11" was assigned to the Fire Department, "Pullen Aquatic Center" was assigned to Parks and Recreation, and "Street Maintenance" was assigned to Public Works). In other cases, no department was listed or the description was not specific enough to attribute. For these, the address was compared to the electricity data (see below), researched online, and/or compared to nearby facilities. If the facility was known to be occupied by more than one City department, it was classified as a shared facility.

3.2.2 Facility Fuel Use, Other Fuel

Other fuel use was reported for a handful of facilities. Virtually all reported fuel use was for Public Utilities, due to the large number of generators and pumps used by that department. A small amount of fuel use was also reported for the Convention Center, which was counted under that department.

3.2.3 Facility Electricity Use

Electricity use by department was analyzed similarly to natural gas, with two key differences. First, the actual emissions estimated were based on total reported usage at buildings owned or leased by the City for FY2007 rather than facility-level data because detailed bill data were not available for the selected base year. To estimate department-level emissions in FY2007, department-level consumption for FY2008 was determined based on available data and then used to disaggregate FY2007 consumption proportionally. Second, while the bulk of the data came from metered Progress Energy accounts, the electricity data also include data reported from other sources. In these cases, electricity purchases from Duke Power for the Mt. Herman Pumping Station and the Wake Forest Water Plant were assigned to Public Utilities and non-metered electricity from street and traffic lighting were assigned to Lighting.

All of the reported electricity accounts were assigned to departments based on the same method as natural gas. The account information included a facility description that often made categorization simple (e.g. "Water Booster Pump Station" was assigned to Public Utilities, "Police District #22" was assigned to Police, and "Auto Service Center #3" was assigned to Public Works). There were a large number of accounts that were ambiguous or provided no information (description was blank or said "NEW" or "INACTIVE"). If consumption was zero for new or inactive accounts, then it was ignored. Otherwise, the address was compared to the natural gas data, researched online, and/or compared to nearby facilities. If identifying information was still not available, it was counted under "Other." If the facility was known to be occupied by more than one City department, it was classified as a shared facility.

For facilities clearly marked as lighting, area lights and lights at recreational facilities were assigned to Parks and Recreation, while all traffic and street lighting were counted under Public Works. While both were included in the totals for these departments, individual line items were included for these two uses.

3.2.4 Vehicles and Equipment

Vehicle and equipment fuel consumption data came from three sources: Fleet Services, the Fire Department, and Capital Area Transit (CAT). All data reported by the Fire Department and CAT were assigned to those two departments. For vehicles and equipment managed by Vehicle Fleet Services, the database output provide a detailed department description that listed both the department and division. Vehicles were aggregated into departments based on these descriptions. Because total CO_2 emissions from Vehicle Fleet Services-managed vehicles were based on the pump totals, the individual vehicle consumption totals by department were used to apportion total fuel consumption to the individual departments.

3.2.5 Refrigeration and Air Conditioning

Data from refrigeration and air conditioning equipment was reported separately by the Facilities and Operation Division, the Public Utilities Department, the Progress Energy Center, and the Convention Center. Data was also collected for the Fire Department via field visits. Like the natural gas and electricity data, equipment data for each building were assigned to the appropriate department. If the building's department was not self-evident, the department was determined using the facilities listed in the natural gas and electricity data and/or web research.

3.2.6 Other Sources

Emissions from solid waste facilities were assigned to Solid Waste Services; process emissions from wastewater treatment were assigned to Public Utilities; and horses were assigned to Police.

3.3 Results

The results of the department-level analysis are presented in Table 29 below. As shown, Public Utilities account for about 35 percent of the City's emissions. This is largely due to electricity consumption at the Neuse River Wastewater Treatment Plant and the E.M. Johnson Water Plant. Although these plants account for nearly one half of the City's electricity consumption, it should be noted that the City of Raleigh Public Utilities Department also has the DE Benton Water Treatment Plant, the Smith Creek Waste Water Treatment Plant, the Little Creek Wastewater Treatment Plant, and over 150 remote facilities for distributing water and collecting wastewater throughout a service area that are also accounted for in this inventory. The City of Raleigh Public Utilities Department's service area far exceeds the jurisdiction of other City services by providing water and/or wastewater services to the Towns of Garner, Wake Forest, Rolesville, Knightdale, Wendell, Zebulon, Apex, and some of Clayton in Johnston County.

Solid Waste Services is the next largest contributor from an emissions perspective with 28 percent of the City's emissions, though this is largely due to landfill methane at the City's now-closed Wilders Grove Landfill.

The Public Works Department has the third largest departmental emissions contribution, with about 15 percent of the City's total emissions, due largely to street and traffic lighting. Figure 11 presents the total emissions for the largest ten departments, while Figure 12 provides the relative share of the largest departments.

Figure 11: GHG Emissions by Department

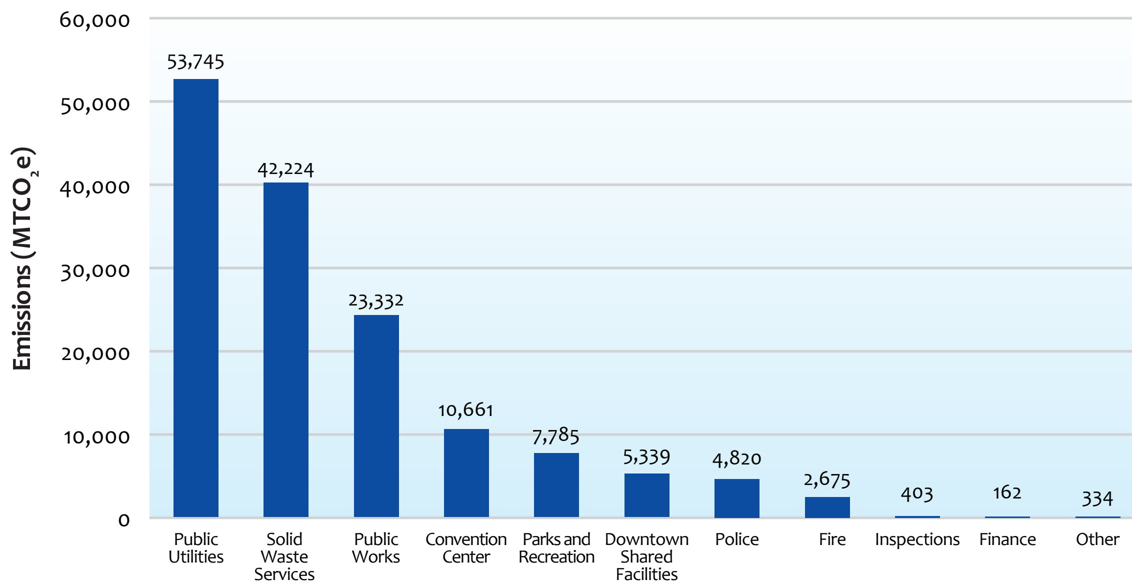


Figure 12: Share of Emissions by Department

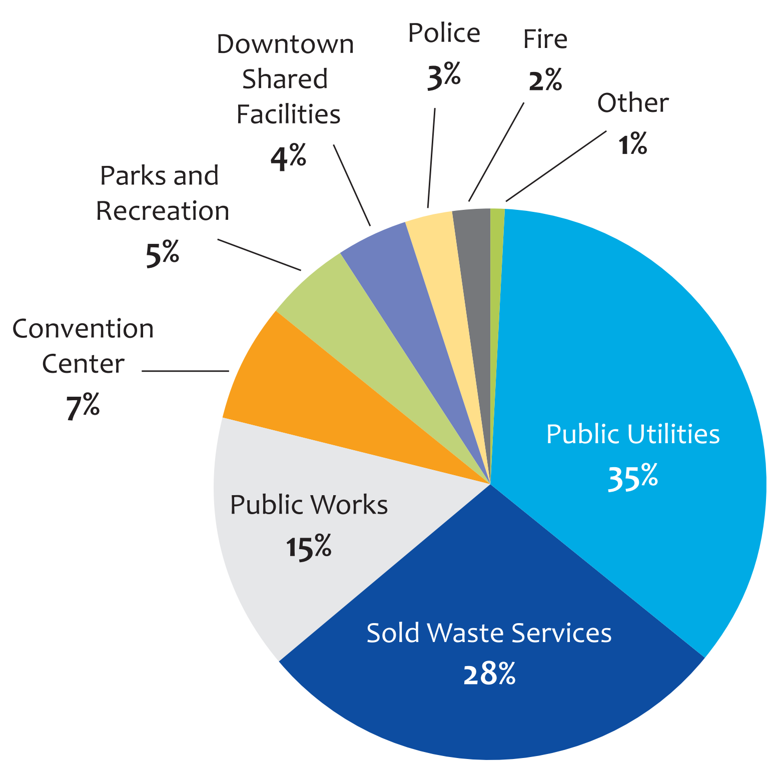


Table 29: FY2007 GHG Emissions by Department and Source ($MTCO_2E$)

	Facilities–Indirect (Electricity)	Facilities–Natural Gas	Facilities–Other Fuels	Vehicles and Equipment	Solid Waste Facilities	Wastewater Treatment	Refrigeration and Air Conditioning	Police Horses	Total	% of Total
Administrative Services	–	–	–	2			–		2	0.0%
City Manager	–	–	–	0			–		0	0.0%
Community Development	–	–	–	7			–		7	0.0%
Community Services	5	–	–	4			–		9	0.0%
Convention and Conference Center	9,349	713	8	13			577		10,661	7.0%
Emergency Communications Center	–	–	–	8			–		8	0.0%
Finance	–	–	–	162			–		162	0.1%
Fire	1,152	332	–	1,190			2		2,675	1.8%
Information Technology	–	–	–	5			–		5	0.0%
Inspections	–	–	–	403			–		403	0.3%
Parks and Recreation Total	**5,813**	**975**	**–**	**960**			**36**		**7,785**	**5.1%**
Other Parks & Recreation	*5,486*	–	–	–			–		*5,486*	*3.6%*
Park & Area Lighting	*328*	–	–	–			–		*328*	*0.2%*
Planning	–	–	–	2			–		2	0.0%
Police	1,061	72	–	3,668			15	5	4,820	3.2%
Public Affairs	–	–	–	0			–		0	0.0%
Public Utilities	48,233	185	1,937	2,311		1,114	10		53,789	35.5%
Public Works Total	**13,864**	**392**	**–**	**9,046**			**0**		**23,302**	**15.4%**
Other Public Works	*3,040*	–	–	*1,819*			–		*4,860*	*3.2%*
Street & Traffic Lighting	*10,823*	–	–	–			–		*10,823*	*7.1%*
Transit	–	–	–	*7,227*			–		*7,227*	*4.8%*
Solid Waste Services	111	16	–	3,064	39,033		–		42,224	27.9%
Shared Facilities	5,231	80	–	–			28		5,339	3.5%
Other	301	–	–	–			–		301	0.2%
Total	**85,120**	**2,765**	**1,945**	**20,845**	**39,033**	**1,114**	**668**	**5**	**151,494**	

Note: Totals may not sum due to independent rounding. Shaded lines and numbers in italics are included in the Parks and Recreation and Public Works subtotals above each of the shaded lines.

4 GHG Emissions in Perspective

GHG inventory estimates for local government operations can differ among cities, as final emissions estimates are dependent on a number of decisions and procedural steps. When developing a GHG inventory, decisions may include determining:

- Organizational and operational boundaries,
- Scope (sources and GHGs to include/exclude)
- Baseline year, and
- Quantification approach.

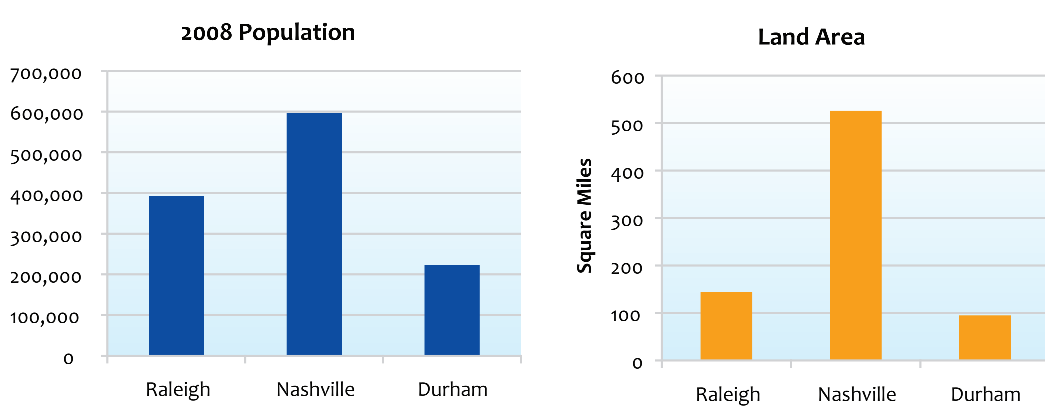
Keeping these decisions in mind, it is insightful to compare GHG emission totals for the City of Raleigh to emissions estimates for other cities to explore differences. Many of the sources included in the City of Raleigh's GHG inventory are common among government operations for nearly all U.S. cities including emergency vehicles, streetlights, city buildings and facilities, and maintenance fleets. Other sources, such as landfills and wastewater treatment plants, are only present in some cities and are therefore reflected in the GHG estimates.

4.1 Comparison to Other Local Government GHG Inventories

The following section compares Raleigh's GHG emissions for government operations to those of two other cities, Nashville, TN, and Durham, NC, in order to provide insight into similarities and differences in emissions estimates. These two cities are similar in size to Raleigh, based on city-proper population, and are located in similar climates.

Raleigh, with a population of 392,600 in 2008, is about 35 percent smaller than Nashville, with a 2008 population of 596,000; and is 76 percent larger than Durham, with a 2008 population of 223,000 (see Figure 13). Nashville is significantly larger in land area than Raleigh, at 526 sq. mi versus at 144 sq. mi, respectively. Durham is the smallest of the three, at 94.9 sq. mi.

Figure 13: Comparison of city populations (left) and land area (right).



The comparisons between municipal inventories should not be viewed as completely analogous assessments, since these inventories differ from Raleigh's with respect to scope, baseline year, and boundaries.

4.1.1 Comparing Results for the City of Raleigh

In order to provide a clear comparison between Raleigh's GHG emissions and those of Nashville and Durham, the results of the Raleigh emissions analysis have been organized into five categories paralleling the organization of the Nashville and Durham data. This breakdown is slightly different than the analysis by source or by department discussed above. In this case, emissions were organized into five key sectors: buildings, vehicles and equipment, streetlights, water and wastewater, and solid waste.

The buildings sector includes all facility electricity, natural gas, other fuel use, and refrigeration and air conditioning for Raleigh's municipal buildings, except for the Public Utilities Department and all street, traffic, and area lighting managed by Parks and Recreation or by Public Works. The vehicles and equipment sector includes all fleet vehicles and equipment, CAT transit buses, and Fire Department vehicles. The streetlights sector includes all street, traffic, and area lighting managed by either Parks and Recreation or Public Works. The water/wastewater sector includes all facility fuel and refrigeration/AC emissions for treatment and conveyance by the Public Utilities Department, as well as fugitive emissions from wastewater treatment. This is equivalent to all of the Public Utilities Department's emissions with the exception of emissions from Public Utilities vehicles. Finally, the solid waste sector consists of emissions from landfill and compost facilities.

Emissions based on this method of organization are presented in Table 30.

Table 30: FY2007 Emissions for the City of Raleigh, organized for comparison

Sector	Emissions ($MTCO_2E$)	Percent
Buildings and Facilities	28,982	19%
Vehicles and Equipment	20,879	14%
Streetlights	11,151	7%
Water/Wastewater	51,434	34%
Solid Waste	39,033	26%
Total	151,479	

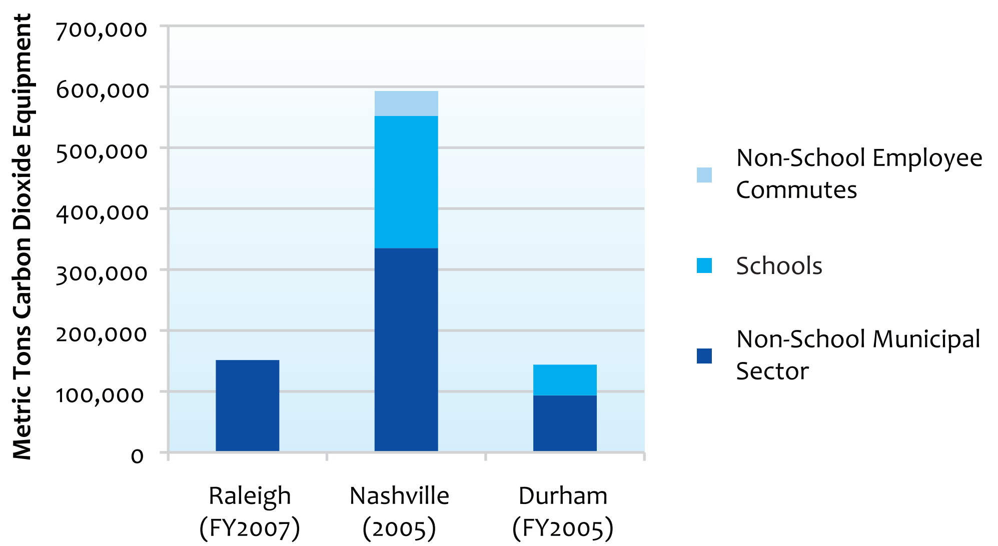
Note: Totals may not sum due to independent rounding.

4.1.2 Nashville, TN

Nashville first began developing its inventory upon the establishment of the Mayor's Green Ribbon Committee in 2008; the inventory was designed to serve as a baseline for future climate mitigation efforts. The municipal government's inventory covers the Metropolitan Government of Nashville and Davidson County, but does not include other municipal governments operating within Davidson County. The inventory encompasses buildings, vehicle fleets, employee commutes, on-road operations at airport facilities, water operations, sewage operations, streetlights, and solid waste generated by the municipal governments. The school system's buildings and school bus fleet are included in these sources as well. Traffic signals are not covered, while sulfur hexafluoride from circuit breakers under City control are included.

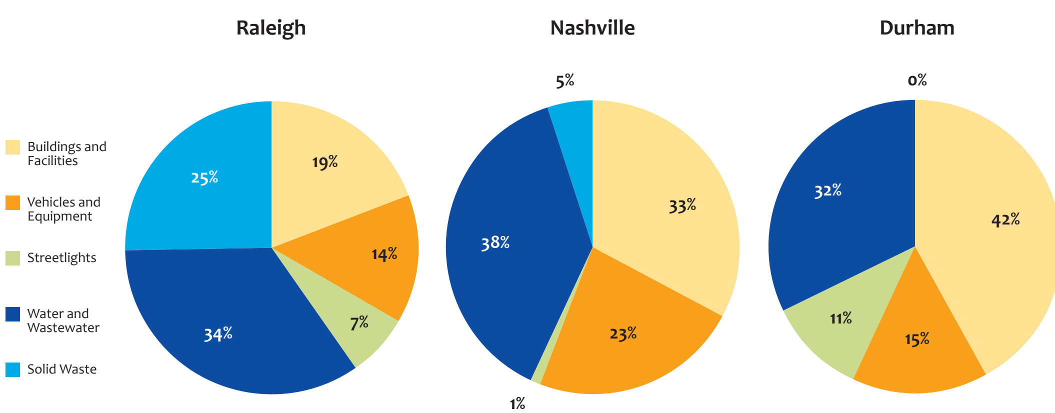
Nashville's municipal government inventory is for the baseline year, 2005. Emissions for 2005 totaled 589,141 $MTCO_2e$, including schools and employee commutes. Emissions without schools and employee commutes totaled 335,229 $MTCO_2e$. The total emissions for the Nashville government are compared to those of Raleigh, as well as Durham, in Figure 14.

Figure 14: Total municipal emissions



GHG emissions, by source for Raleigh, Nashville, and Durham are compared in Figure 15.

Figure 15: Comparison of emissions sources



In Nashville, buildings are the largest source of GHG emissions, accounting for 43.5 percent of municipal government totals. Water and sewage operations—pumping and treatment—comprise the second largest source, at 21.5 percent. Employee commutes represent 15.3 percent of emissions, and vehicle fleets represent 15.2 percent. Solid waste generated by the City resulted in 4.1 percent of municipal GHG emissions, followed by streetlights and circuit breakers at 0.5 percent. It is important to note that, while Raleigh includes all emissions from solid waste facilities, Nashville's inventory encompasses only the impacts of solid waste generated by the City and County government.

The Metropolitan Government of Nashville and Davidson County had 11,146 employees in 2005, translating to per-employee emissions of 52.9 $MTCO_2e$, or 44.8 $MTCO_2e$ per employee when employee commutes are excluded. With approximately 3,000 employees, the City of Raleigh emits an estimated 50.5 $MTCO_2e$ per employee.

4.1.3 Durham, NC

Durham developed its first inventory in 1999 upon joining the Cities for Climate Protection. In 2005, the City decided to update the inventory, as part of its efforts to develop a climate action plan. The municipal government inventory covers the operations of the City of Durham and Durham County. It includes buildings, vehicle fleets, streetlights, traffic signals, park lights, water operations, wastewater operations, waste generated by municipal government, and school buildings and fleets. Schools are included as a separate sector, and hence their emissions are not included under the municipal buildings or fleet sectors.

The inventory is for Fiscal Year 2005. Municipal government operations, including schools, have total emissions of 143,979 $MTCO_2e$. Excluding schools, the total is 93,586 $MTCO_2e$.

The school system comprises 35 percent of the City's total municipal operations' emissions. If schools are excluded, the largest source of Durham's municipal emissions is municipal buildings, generating 42 percent of emissions. Water and sewage operations follow at 32.3 percent. Vehicle fleets represent 15.4 percent, and lighting (streetlights, traffic signals, and park lights) represents 11 percent. The emissions from municipal solid waste are negligible. Similar to Nashville's inventory, the solid waste sector includes only the impacts of solid waste generated by City government.

As of 2010, the City and County government employs 2,200 people. This translates to emissions of 65.4 $MTCO_2e$ per employee. With approximately 3,000 employees, the City of Raleigh emits an estimated 50.5 $MTCO_2e$ per employee.

A summary comparing the three Cities is shown in Table 31 below.

Table 31: Comparison of Emissions Totals and Per Employee Emissions

	Raleigh	Nashville	Durham
Total Emissions ($MTCO_2e$)	151,494	499,123	143,979
Employees	3,000	11,146	2,200
$MTCO_2e$/employee	50.5	44.8	65.4

Note: In order to facilitate comparison, emissions from employee commutes are not included in the emission total for Nashville.

5 Conclusion

The City of Raleigh is enacting its mission in practice by addressing the City's contribution to global climate change. Raleigh's commitment to environmental stewardship has been highlighted in the City Council mission statement, endorsement of the U.S. Mayor's Climate Protection Agreement, and establishment of the Environmental Advisory Board and the Office of Sustainability. This GHG Inventory has quantified the City's emissions from municipal operations and helped develop a better understanding of the City's emission sources. It can serve as a foundation for a coordinated action plan to reduce GHG emissions, energy consumption and costs, save taxpayer dollars, and improve air quality.

Total emissions from City Operations for FY2007 were estimated to be 151,000 MTCO2E annually. The largest source of emissions is electricity use (56 percent), followed by solid waste treatment (26 percent), and vehicle and equipment fuel use (14 percent). Emissions were also estimated for each City department, with the largest three departments being Public Utilities (35 percent), Solid Waste Services (28 percent), and Public Works (15 percent), as shown in Figure 16. Emissions were also organized into five major sectors of City activities: buildings; vehicles and equipment; street, traffic, and area lighting; water and wastewater; and solid waste management. From this perspective, water and wastewater activities represented the largest emissions sector (34 percent), followed by solid waste management (26 percent) and buildings (19 percent), as shown in Figure 17.

Figure 16: GHG Emissions by Department

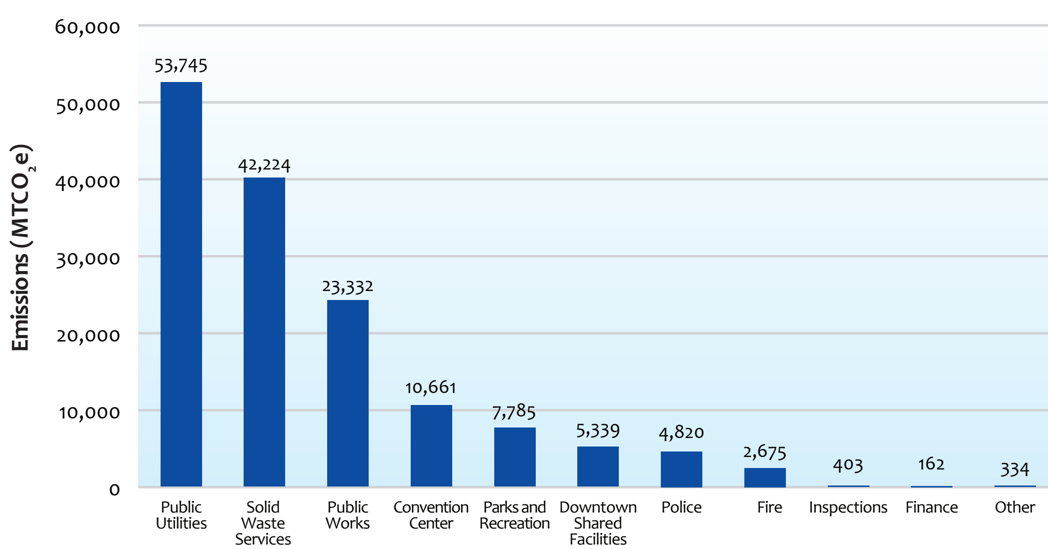
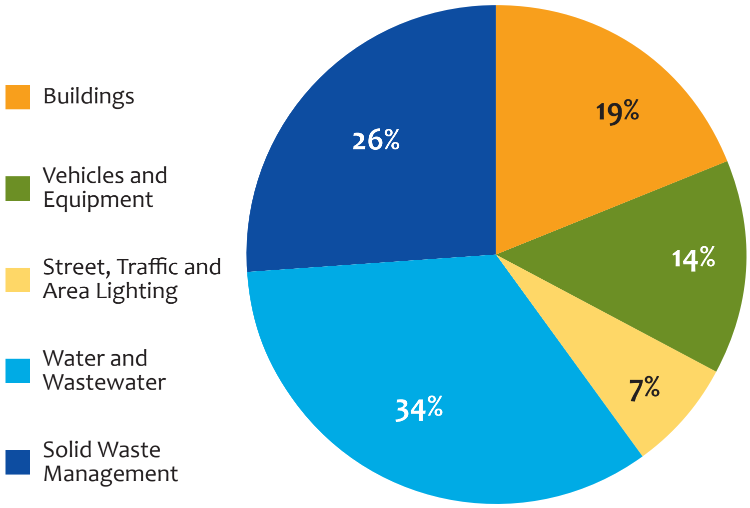


Figure 17: Emissions from City Operations by Sector



It is worth noting that many of the larger emissions sources are relatively hard to address. Electricity consumption at the Neuse River Wastewater Treatment Plant and the E.M. Johnson Water Plant accounts for nearly one half of the City's electricity consumption, with an additional 3 smaller plants and over 150 remote facilities for distributing water and collecting wastewater throughout an extended service area. While energy efficiency and alternatives can help reduce the energy used to move water and wastewater, the best long-term approach may be more sustainable development patterns – which will require regional strategies with public and private sector partners. Similarly, the second largest emissions contributor, Solid Waste, is largely due to landfill methane at the City's now-closed Wilders Grove Landfill. Long-term regional strategies to reduce solid waste, separate and manage compostables, increase recycling, and implement sustainable purchasing will help address this emissions source over time.

Action towards reducing the City's emissions profile has already been initiated, through the implementation of energy efficient retrofits in City buildings and lighting, requiring LEED silver standards for larger, new City buildings, the use of biodiesel, ethanol, and other alternative fuels in the City's vehicles, purchase of hybrid vehicles, investment in landfill gas collection systems at the Wilders Grove landfill, and solar power installations. Future measures and actions will further reduce the emissions intensity of municipal operations in the City of Raleigh.

Solar Power installation at EM Johnson Water Treatment Plant

This GHG emissions inventory is the first step in preparing a comprehensive climate change strategy that includes:

- **A Climate Action Plan** with clear goals and specific actions
- **Partnerships** that foster creative solutions to combating climate change
- **Messaging** that engages and motivates the public and partners
- **Planning** that integrates climate change response into ongoing sustainable community planning efforts and the City's growing culture of sustainability

As part of developing this inventory, the City's project leadership team has begun the process of analyzing emissions by department and activity, and outlining the elements needed for a comprehensive climate change strategic action plan. While this inventory is focused on City operations, the action plan might also incorporate community-wide strategies. This action plan would identify, evaluate, quantify, and prioritize actions for reducing GHG emissions, and devise a methodology to evaluate future actions in a manner that will allow the City of Raleigh to track progress and demonstrate the effectiveness of its investments in a transparent, accountable, and effective way.

The action plan would also identify strategies for implementing existing and potential state and local programs that address renewable energy, residential building energy efficiency, commercial and public building energy efficiency, transportation, forestry & agriculture, long-term transportation and land use planning, and education and outreach. Achieving actual overall reductions in GHG emissions will be difficult as Raleigh continues to grow in size and population. This inventory will serve as the baseline for evaluating the City's progress toward meeting its GHG and energy reduction goals. It will be used as the basis for a work session with the City's project leadership team to identify and prioritize potential next steps.

6 Glossary

Aerobic Decomposition is the decomposition of organic matter in the presence of oxygen.

Anaerobic Decomposition is the decomposition of organic matter in an environment lacking oxygen.[19]

Anthropogenic Emissions are emissions generate by human activities.

A **baseline** is a measurement, calculation, or time used as a basis for comparison.

Baseline Year is the first full year of energy use and emissions data. The baseline analysis is undertaken in order to provide a comparison for later years.

Biogenic emissions or fuels are produced by the biological processes of living organisms. Note that this term refers only to recently produced (i.e. non-fossil) material of biological origin.

Boundaries define what activities are included in a GHG inventory. The boundaries of this inventory include those activities over which the City of Raleigh has operational control.

Carbon Dioxide (CO_2) is a greenhouse gas that is produced by a number of natural and human activities. It is always present in the atmosphere and helps the earth retain some of its heat.

Climate Change is the observed and projected changes in the Earth's climate system. There are a number of complex factors involved in that catalysts for such changes, but a portion of the changes are likely to be caused by the increasing concentrations of greenhouse gases in the atmosphere, which prevent heat from escaping the Earth's surface.

Denitrification is the process by which microorganisms remove nitrogen from its fixed form in the soil and release it into the atmosphere in the form of nitrous oxide (N_2O).[20]

Direct Emissions are the emissions generated on-site (as opposed to electricity delivered through a grid system), such as from the combustion of fossil fuels.

Effluent is the treated or untreated wastewater that flows out of a source.[21]

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19 http://www.chem.purdue.edu/gchelp/gloss/anaerobicd.html

20 http://www.rtcc.org/2007/html/glossary.html

21 http://wordnetweb.princeton.edu/perl/webwn?s=effluent

Emissions Factor (EF) is the "value for scaling emissions to activity data in terms of a standard rate of emissions per unit of activity (e.g., grams of carbon dioxide emitted per barrel of fossil fuel consumed)."[22]

Enteric Fermentation is the process through which digestive processes in animals (such as livestock) generate greenhouse gases, such as methane.

Fluorinated Hydrocarbons are greenhouse gases that, while released in much smaller quantities than other greenhouse gases (such as CO_2 or CH_4), have a much greater impact on the atmosphere, molecule for molecule. Examples include HCFCs, HFCs, and PFCs.

Fossil Fuel is any fuel derived from the pre-historic burial of organic matter. Examples include natural gas (methane or CH_4) and petroleum products (gasoline, diesel, kerosene, propane, and others). Combustion of petroleum products releases greenhouse gases into the atmosphere.

Fugitive Emissions are emissions of gases that escape from pressurized equipment, such as fuel transportation pipelines.

Global Warming Potential (GWP) is "an index, based upon radiative properties of well-mixed greenhouse gases, measuring the radiative forcing of a unit mass of a given well-mixed greenhouse gas in the present-day atmosphere integrated over a chosen time horizon, relative to that of carbon dioxide. The GWP represents the combined effect of the differing times these gases remain in the atmosphere and their relative effectiveness in absorbing outgoing thermal infrared radiation."[23]

Greenhouse Gas (GHG) is any gas that acts to trap heat in the lower atmosphere by preventing outgoing infrared radiation from leaving the Earth's surface.

Indirect Emissions are emissions that can be allocated in an inventory to an entity, but that are generate offsite. An example is electricity that is not generated directly at a facility. A facility uses electricity on-site, but the fuels used to generate the electricity are combusted off-site, perhaps at a regional power plant.

Infrared Radiation, in this context, is the energy re-emitted by Earth's surface and atmosphere after they have absorbed ultraviolet (UV) radiation from the Sun.

Methane (CH_4) is a greenhouse gas with a Global Warming Potential (GWP) that is 21 times that of CO_2. It is produced through anaerobic decomposition of waste, enteric fermentation, production of natural gas and petroleum products, and other industrial processes.[24]

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[22] http://epa.gov/climatechange/glossary.html

[23] http://www.ipcc.ch/publications_and_data/ar4/wg1/en/annex1sglossary-e-o.html

[24] http://epa.gov/climatechange/glossary.html

Metric tons of carbon dioxide equivalent ($MTCO_2E$) is the standard unit for measuring emissions of greenhouse gases.

Nitrification is the biological process in which ammonia is converted to nitrate (NO_3).

Nitrous Oxide (N_2O) is a greenhouse has with a GWP of 310 times that of CO_2. Major sources include soil cultivation, petroleum combustion, and biomass burning, among other processes.[25]

Operational Control. A local government has operational control over an operation if it has the full authority to introduce and implement its operating procedures.

Ozone Depleting Substance (ODS) is a group of manmade compounds that are known to deplete the Earth's stratospheric ozone. Included in this group are CFCs, bromofluorcarbons, methyl chloroform, HCFCs, and carbon tetrachloride. [26]

A **protocol** is a set of common standards for measuring and reporting GHG emissions.

Scope 1 Emissions are all direct GHG emissions.

Scope 2 Emissions are indirect GHG emissions from the consumption of purchased electricity, heat, or steam.

Scope 3 Emissions are other indirect emissions, such as the extraction and production of purchased materials and fuels, transport-related activities in vehicles not owned or controlled by the reporting entity, outsourced activities, etc. This inventory does not include any Scope 3 emissions.

Stationary combustion refers to the on-site combustion of fuels to produce electricity, heat, or motive power using equipment in a fixed location.

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[25] http://epa.gov/climatechange/glossary.html

[26] http://epa.gov/climatechange/glossary.html

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Appendix

Vehicle Emission Factors for Non-CO_2 Gases

Table 32. Default CH_4 and N_2O Emission Factors for Highway Vehicles by Model Year

Vehicle Type and Year	N_2O (g/mi)	CH_4 (g/mi)
Gasoline Passenger Cars		
Model Years 1984-1993	0.0647	0.0704
Model Year 1994	0.056	0.0531
Model Year 1995	0.0473	0.0358
Model Year 1996	0.0426	0.0272
Model Year 1997	0.0422	0.0268
Model Year 1998	0.0393	0.0249
Model Year 1999	0.0337	0.0216
Model Year 2000	0.0273	0.0178
Model Year 2001	0.0158	0.011
Model Year 2002	0.0153	0.0107
Model Year 2003	0.0135	0.0114
Model Year 2004	0.0083	0.0145
Model Year 2005	0.0079	0.0147
Gasoline Light Trucks (Vans, Pickup Trucks, SUVs)		
Model Years 1987-1993	0.1035	0.0813
Model Year 1994	0.0982	0.0646
Model Year 1995	0.0908	0.0517
Model Year 1996	0.0871	0.0452
Model Year 1997	0.0871	0.0452
Model Year 1998	0.0728	0.0391
Model Year 1999	0.0564	0.0321
Model Year 2000	0.0621	0.0346
Model Year 2001	0.0164	0.0151
Model Year 2002	0.0228	0.0178
Model Year 2003	0.0114	0.0155
Model Year 2004	0.0132	0.0152
Model Year 2005	0.0101	0.0157

Vehicle Type and Year	N_2O (g/mi)	CH_4 (g/mi)
Gasoline Heavy-Duty Vehicles		
Model Years 1985-1986	0.0515	0.409
Model Year 1987	0.0849	0.3675
Model Years 1988-1989	0.0933	0.3492
Model Years 1990-1995	0.1142	0.3246
Model Year 1996	0.168	0.1278
Model Year 1997	0.1726	0.0924
Model Year 1998	0.1693	0.0641
Model Year 1999	0.1435	0.0578
Model Year 2000	0.1092	0.0493
Model Year 2001	0.1235	0.0528
Model Year 2002	0.1307	0.0546
Model Year 2003	0.124	0.0533
Model Year 2004	0.0285	0.0341
Model Year 2005	0.0177	0.0326
Diesel Passenger Cars		
Model Years 1960-1982	0.0012	0.0006
Model Years 1983-2004	0.001	0.0005
Diesel Light Trucks		
Model Years 1960-1982	0.0017	0.0011
Model Years 1983-1995	0.0014	0.0009
Model Years 1996-2004	0.0015	0.001
Diesel Heavy-Duty Vehicles		
All Model Years	0.0048	0.0051

Source: LGO Protocol, Table G.10