CITY AND COUNTY OF BROOMFIELD
Sustainable Energy Benchmarking
&
Greenhouse Gas Accounting
2007

CITY AND COUNTY OF BROOMFIELD • COLORADO •

UNIVERSITY OF COLORADO DENVER
DOWNTOWN CAMPUS

Prepared by:
Meghan Bernard, Abel Chavez, and Dr. Anu Ramaswami, PI
The Sustainable Urban Infrastructure Program, Civil Engineering
University of Colorado Denver

With Kevin Standbridge, Alan King, and Kathy Schnoor, City and County of Broomfield

Prepared for: The City and County of Broomfield

AKNOWLODGEMENTS
We would like to thank the employees at the City and County of Broomfield and other organizations for assisting with gathering the data necessary to conduct this inventory.

City and County of Broomfield Employees:
Rich Coufal and Ken Rutt, Water and Wastewater Data
Dale Alberts, Fleet Data
Jill Johnson, Facilities and Energy Data
Tim Pate, Building Department

Other Organizations:
Les Fraley, Xcel Energy Account Representative
Ed Maycumber, United Power

For further information on the data, appendices or the report, please contact:

Dr. Anu Ramaswami
Department of Civil and Environmental Engineering
Sustainable Urban Infrastructure Program
University of Colorado Denver
Ph: 303-556-4734
Email: Anu.Ramaswami@ucdenver.edu

Kathy Schnoor
Environmental Services Superintendent
City & County of Broomfield
Ph: 303-438-6363
Email: kschnoor@broomfield.org

Executive Summary

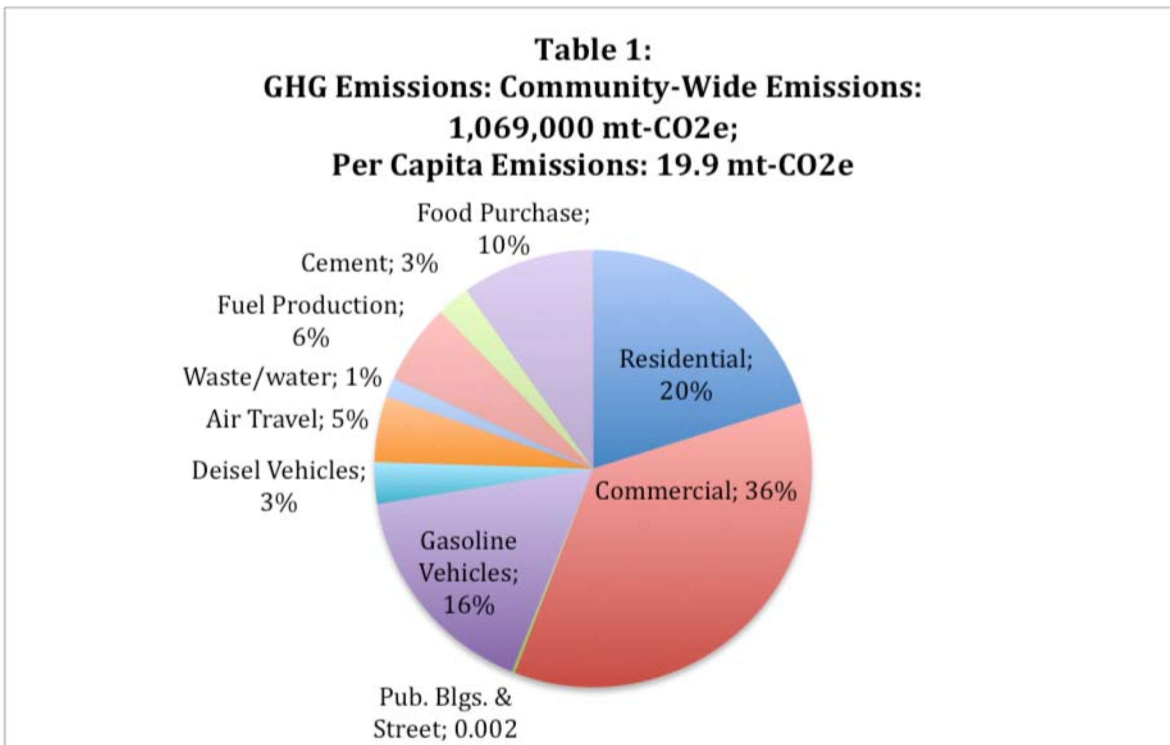
At the end of 2008 the City and County of Broomfield (CCB) partnered with the University of Colorado Denver (UCD) and the National Civic League (NCL) to begin the process of updating the Environmental Stewardship Chapter of the 2005 Comprehensive Plan. To do this, CCB formed a 30 person Sustainable Community Task Force to embark on a 14-month process to develop revised policies and action steps for what will become a Sustainability Plan. In order to inform the Task Force on the current conditions of the city's greenhouse gas emissions, the University of Colorado Denver conducted a greenhouse gas inventory for 2007, which will become the baseline inventory for the community-wide emissions. This inventory was necessary because it provides measureable data that can be tracked over time. Greenhouse gas accounting allows for the city to develop a baseline starting in 2007, establish goals into the future, and track progress along the way.

This report assesses the 2007 greenhouse gas (GHG) emissions for the City and County of Broomfield, Colorado using a hybrid demand-center life cycle assessment methodology developed by Ramaswami et al (2008). This method treats the city as a demand center and accounts for buildings electricity and natural gas, surface and air transportation, and the embodied energy of key urban materials. This report could be updated every two years to track the progress of greenhouse gas emissions in the City and County.

Greenhouse gases are emitted almost exclusively from the burning of fossil fuels, such as coal, natural gas, gasoline and diesel. Greenhouse gases are important to keep track of because they trap heat in the atmosphere, which over many years causes changes in climate worldwide. Greenhouse gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and three replacements for chlorofluorocarbons (HFCs, PFCs, SF_6). This report tracks CO_2, CH_4, and N_2O in the buildings, transportation and materials sectors for the entire community. In order to compare the different gases, they are converted into carbon dioxide equivalents (CO_2e) based on their different global warming potential. Tracking emissions is calculated with the following equation:

$$\sum[\text{Material Flow Analysis (MFA) x Emission Factor (EF)}] = \text{Total Emissions.}$$

In other words, the emissions for each sector are found by multiplying the total consumption of a GHG emitting activity (e.g. kWh for electricity, therms for natural gas, gasoline, cement, etc.) by the calculated emission factor for that particular activity (e.g. kg-CO_2e/kWh; kg-CO_2e/gallon, etc.). The greenhouse gas emissions from each sector can be summed up to find the total community-wide greenhouse gas emissions for Broomfield.



In 2007, the population of the City and County of Broomfield was estimated as 53,807 people. The activities of these 53,807 people are summed together to find the total community-wide GHG emissions and the per capita emissions. There are many activities within the community that cause greenhouse gas emissions, the majority of which are easily tracked through economic, utility, and other public data. Within the residential, commercial and industrial sectors, electricity and natural gas consumption make up about 597 thousand mt-CO_2e, or 56% of the total community-wide emissions. Emissions from transportation (gasoline, diesel, and airline modes of transportation) result in 260 thousand mt-CO_2e or 24% of total community-wide emissions. Finally, key urban materials such as food, cement, fuel production, water and waste emit 205 thousand mt-CO_2e or 20% of total community-wide emissions. The total emissions from the three sectors are 1.1 million mt-CO_2e for the entire Broomfield community. In 2007, the per capita emissions were 19.9 mt-CO_2e/capita. Table 1 shows these results split up by the main GHG emitting sectors in the community.

The City and County of Broomfield's emissions are benchmarked with Denver, CO; the State of Colorado; and national data. Since Denver, the State of Colorado, and the nation have different populations, the GHG emission must be compared on a per capita basis. The City of Denver emitted 25.3 mt-CO_2e/capita in 2007 while the State of Colorado emitted 24.5 mt-CO_2e/capita and the nation emitted 25.2 mt-CO_2e/capita in the same year. Broomfield may have fewer per capita emissions due to less commercial activity than the City of Denver and the nation. However, Broomfield's electricity consumption per household was higher than Denver's and Colorado's but lower than the nation. See Table 7 for other benchmarking numbers comparing these different locations.

Without understanding where greenhouse gas emissions are coming from within the community, a strategy to reduce them cannot be established. Reducing these emissions will require a combination of personal lifestyle changes as well as help with policies from the local government in combination with the state and national government. Recommendations for policies and action steps towards a "Sustainable Broomfield" are being developed by the Sustainable Community Task Force and will be presented to the City Council in July 2010 for approval. As the community continues to strive towards sustainability, they can use the greenhouse gas accounting report as one way to measure how future efforts are progressing.

Table of Contents

List of Tables

Abbreviations and Acronyms

CACP	Clean Air Climate Protection
CCB	City and County of Broomfield
CDPHE	Colorado Department of Public Health and the Environment
CH_4	Methane
CO_2	Carbon Dioxide
DIA	Denver International Airport
DRCOG	Denver Regional Council of Governments
EIA	Energy Information Administration
EPA	Environmental Protection Agency
GHG	Greenhouse Gases
GREET	Greenhouse Gas, Regulated Emissions, and Energy Use in Transportation model
GWh	Gigawatt hour
IGERT	Interdisciplinary Graduate Education Research Traineeship
kWh	kilowatt hour
LCI	Life Cycle Inventory
LGOP	Local Government Operations Protocol
MSW	Municipal solid waste
mt-CO_2e	metric tons of carbon dioxide equivalents
N_2O	Nitrous Oxide
NCL	National Civic League
NREL	National Renewable Energy Laboratory
P2W	Pump-to-Wheels
RMA	Rocky Mountain Airport
UCD	University of Colorado Denver
VMT	Vehicle miles travelled
WARM	WAste Reduction Model
WRI	World Resources Institute
WTP	Wells-to-Pump

1. Introduction to Sustainable Energy Planning

Sustainability is widely understood to encompass the three E's: Economics, Environment and Equity. In the context of the environment, sustainability refers to more efficient use of scarce natural resources such as water, energy and minerals. This includes reducing or avoiding emissions of toxic pollutants such as heavy metals, harmful pesticides, carcinogens, etc. Sustainability entails facilitating human activities that simultaneously promote economic development, environmental protection, and social equity in the present and into the future.

1.1 The Business Case for Sustainable Energy

There has been interest nationally, within the State of Colorado and in several Colorado cities, in developing sustainable energy plans. These plans are motivated by the projected increase in global demand for limited oil and gas resources, the increasing world-wide cost of fossil fuels, our dependence on foreign oil which impacts national energy security, and, our understanding of the global and local environmental impacts of using fossil energy. These impacts include local-scale air pollution from petroleum use in automobiles, which contributes to smog, local scale air pollution from coal-fired power plants, and global impacts of greenhouse gas emissions. The global impacts of greenhouse gas emissions are projected to have local impacts in Colorado, affecting snow pack, water supplies and agriculture. Looking toward a future with increased cost and reduced availability of fossil energy, cities are embarking on sustainable energy plans that save money through energy and resource conservation, generate jobs in the new green energy economy focused on energy efficiency and renewable energy, and promote community-wide economic development.

1.2 Sustainable Energy Planning and Greenhouse Gas Accounting

Since fossil fuels are used for almost all human activities – cooling and heating our buildings, transportation and industrial production – an accounting of GHG emissions, measured as CO_2 equivalents (CO_2e) from burning fossil fuel promotes a comprehensive understanding of fossil energy use community-wide. In addition, such greenhouse gas accounting is also useful to represent human impact on the climate.

1.3 Greenhouse Gases (GHGs)

Measured greenhouse gases (GHGs) include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and three replacements for chlorofluorocarbons (HFCs, PFCs, SF_6). The first three GHGs are dominant and account for more than 98% of GHGs emitted nationally(Environmental Protection Agency 2009). Carbon dioxide is produced primarily from burning of fossil fuels and is the largest contributor to global warming. Methane is produced largely from waste decomposition (naturally or in landfills), enteric fermentation (from cattle), and from fugitive emissions in natural gas pipelines. The latter three GHGs may be omitted unless significant industrial production of these chemicals is occurring in the region of interest. The various GHGs have different global warming potentials, or ability to trap heat in the atmosphere. In order to compare the emissions from different sources, greenhouse gases are reported together on a common standardized basis as metric tons of carbon dioxide equivalents (mt-CO_2e). Table 1 shows the top three greenhouse gases in the atmosphere and their global warming potentials. Methane has 21 times more potential to trap heat than CO_2 while N_2O has 298 times more potential to trap heat.

Table 1: Greenhouse Gases Global Warming Potentials

Greenhouse gas	Chemical Formula	Global Warming Potential
Carbon Dioxide	CO_2	1
Methane	CH_4	21
Nitrous Oxide	N_2O	298

Data Source: Intergovernmental Panel on Climate Change, Climate Change 2007: The Physical Science Basis (Cambridge, UK: Cambridge University Press, 2007), website www.ipcc.ch/

1.4 Developing a Sustainable Energy Plan

A Sustainable Energy Plan for a community includes:

1. Conducting an inventory of CO_2e emissions, to understand fossil fuel use and associated GHG emissions in basic human activity sectors;
2. Developing a matrix of actions that can be taken in each of the sectors to promote energy efficiency, conserve resources, save money and/or create business

opportunities while mitigating CO_2e emissions;

3. Choosing and prioritizing among the available action options based on local economics, culture, civic engagement and political support to develop a practical sustainable energy action plan suited for implementation;
4. Developing an implementation plan for the prioritized actions, with outcomes assessment protocols.

Some communities are also focusing on adaptation strategies, or planning to adapt to the effects of climate change, i.e. water supply variation, peak oil prices, or other anticipated future trajectories.

2. Background and Methodology

In January of 2009, Broomfield contracted with the Interdisciplinary Graduate Education Research Traineeship (IGERT) Program on Sustainable Urban Infrastructure at the University of Colorado Denver (UCD) to assist in providing technical information for the development of a sustainability plan based on the business case of advancing the three E's of sustainability. The objectives of the study were to:

- Conduct an inventory of community wide CO_2e emissions, to understand fossil fuel use and associated GHG emissions in the main activity sectors in Broomfield.
- Develop a matrix of sustainable energy actions that can be taken in each of the activity sectors to promote energy efficiency, conserve resources, save money and/or create business opportunities while mitigating CO_2e emissions.
- Create a simple, self-explanatory worksheet to assist with calculating and tracking metrics to facilitate regular inventory updates by the City and County.

In April 2009, Broomfield created a Sustainable Community Task Force to update the Environmental Stewardship section of the 2005 Comprehensive plan as a way to involve different members of the community in the process. The University of Colorado Denver assisted the Task Force as a technical advisor, presenting greenhouse gas inventory data and potential programs to reduce greenhouse gases. The result of the Task Force's work will be a draft sustainability plan for Broomfield Council's consideration. If adopted the plan will provide measurable goals for CCB now and into the future.

2.1 Background on the City and County of Broomfield

The City of Broomfield became incorporated in 1961 with approximately 6,000 residents. In 2001 Broomfield became Colorado's youngest county. The City and County of Broomfield is situated within the north metro area between Denver and Boulder along the U.S. 36/Boulder turnpike and up to the north I-25 corridor, beyond Colorado 7. As a result, Broomfield receives traffic from both Boulder and Denver areas. The City is about 20 minutes from both Denver and Boulder and 40 minutes from Denver International Airport (DIA). Broomfield has approximately 34 square miles of area surrounded by Jefferson, Weld, Boulder and Adams Counties. In 2007, Broomfield had an estimated population of 54,000 and a population projection of 83,300 people at build-out in 2034. Broomfield enjoys 130 miles of biking and walking trails with 50 parks in the area and a goal of 40% open lands by build-out. The Flatiron Crossing Mall provides an extensive shopping center for Broomfield's residents and the neighboring communities. Broomfield has two public high schools and one private high school in the area, with many elementary and middle schools in four different school districts. Broomfield is also close to the higher education centers, University of Colorado Boulder and Front Range Community College. Residents of Broomfield are proud of their community and seek to be leaders in sustainability in the Denver Metro Area.

3. GHG Inventory Method

3.1 Method and Scopes

The GHG inventory is conducted using the advanced method developed by Ramaswami et al (2008). The method uses the standardized Local Governments Operations Protocol (LGOP) to report GHG emissions from in-boundary (within jurisdictional boundary) activities (ICLEI 2008). LGOP provides a protocol for the quantification and reporting of GHG emissions for cities separated into Scopes 1, 2, and 3. Scope 1 emissions include emissions from in-boundary activities, such as on-site combustion of fuels, Scope 2 emissions are out-of-boundary emissions such as purchased electricity, and Scope 3 emissions includes other "optional" out-of-boundary activities crucial for a community (e.g.

water, food, fuels, and shelter). This inclusion of additional out-of-boundary activities (World Resource Institute Scope 3) is highly recommended by EPA's Climate Leaders Program. The inventory method for GHG accounting was first pioneered by UCD with the City of Denver, and since then it has been utilized by other cities such as Portland, OR; Seattle, WA; Arvada, CO; Austin, TX and Minneapolis, MN(Ramaswami, et al. 2008).

3.2 In-Boundary Activities

In-boundary activities include the following energy uses and are required to be reported by all jurisdictions as per LGOP and World Resources Institute (WRI) guidelines.

- BUILDINGS ENERGY USE – Use of electricity, natural gas, and steam in residential, commercial and industrial sectors in a community.
- TRANSPORT OPERATIONS ENERGY USE – Includes tailpipe emissions from operating personal and commercial vehicles associated with a community
- EMISSIONS FROM WASTE DISPOSAL – In LGOP protocol, emissions from waste disposal by residential and commercial sectors are also included in the in-boundary accounting.

Formally, the GHGs emitted directly from burning natural gas in buildings and gasoline/diesel in vehicles are termed Scope 1 emissions by World Resource Institute (WRI), while CO_2e emissions from power plants outside a jurisdiction's boundaries that produce electricity used within boundaries is termed Scope 2 emissions. Scope 1-2 plus waste emissions are included in the "in-boundary" activities and are required to be reported in a jurisdiction's GHG inventory as per LGOP.

3.3 Out-of-Boundary Activities

Out-of-boundary activities designated by the WRI as Scope 3 are optional, but are highly recommended by the EPA, as they can lead to win-win strategies for GHG mitigation. Although a city may report a larger GHG footprint by including Scope 3 emissions, there may also be easier, more cost-effective actions that can be taken to reduce these Scope 3 emissions. The following out-of-boundary activities, when added to in-boundary activities, yield a more holistic account of a community's CO_2e footprint:

- EMBODIED ENERGY OF CRITICAL URBAN MATERIALS: This includes energy use and associated GHG emissions from producing key urban materials such as water, transport fuels, food, and shelter (cement for concrete), necessary to support life in cities.
- AIRLINE TRAVEL: Energy use for airline travel is important as it appears in national and statewide GHG inventories and in personal calculators. At the city-scale, these appear as out-of-boundary emissions, particularly when the airport is outside city boundaries (as in the case of Broomfield).

3.4 Energy Use Sectors and Data

To better communicate a community's overall energy use and GHG emissions, classifying end-use of energy in three different sectors is more useful. In this report, we consistently report energy use and GHG emissions in the following three sectors:

- **Buildings Sector –** Energy use (electricity and natural gas) in residential and commercial buildings and industrial facilities.
- **Transport Sector –** Energy (gasoline and diesel) used to operate personal vehicles, commercial trucks and airplanes, termed Pump-to-Wheels (P2W) energy use.
- **Materials Sector –** Energy use and associated GHG emission from producing critical urban materials (food, transport fuels, water, cement) and waste disposal.

For energy (or materials use) in each sector, the following data were gathered:

- **Annual Materials of Energy Consumption Data**: Total kWh of electricity consumed annually, total water consumed annually, total natural gas use, etc. The annual Material/Energy Flow Analysis tells us how much is consumed as a community. By benchmarking these consumption data on per person, per household or other metric, the efficiency of the community can be determined.
- **GHG Emission Factors:** GHG emission factors represents how much CO_2e is emitted per unit of the product consumed. For example, kg-CO_2e emitted per unit kWh of electricity consumed.

Total emissions are computed as the product of how much is consumed and the GHG emissions per unit of the product consumed. The CO_2e emissions for each sector can be summed to find the total community-wide emissions. In the next section, consumption data and emission factors for all three sectors are reported and an overall community-wide GHG inventory and footprint is developed.

4. Community-Wide Energy and GHG Analysis

4.1 Reporting year

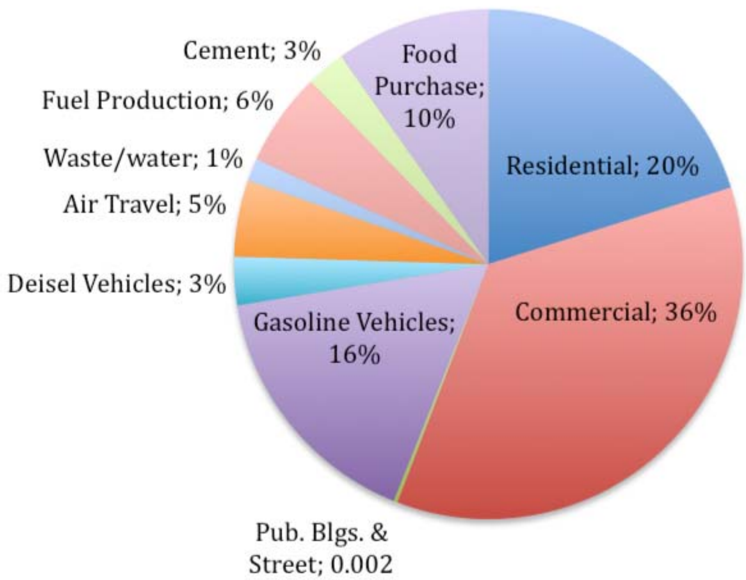
This section reports energy (or materials) consumption data and associated GHG emission factors for the year 2007, for the three main sectors:

- Buildings
- Transport (tailpipe emissions)
- Materials and Waste

This baseline inventory can be referenced to measure Broomfield's progress in the coming years. For each sector, raw consumption data are presented, the data are normalized and compared with benchmarking metrics, and emission factors are quantified. The total GHG emissions from each sector are consolidated and reported as an overall community-wide summary in Table 2. GHG emissions are reported in terms of metric tons (mt) of carbon-dioxide equivalent, shown as mt-CO_2e.

The total community-wide greenhouse gas emissions for Broomfield amounted to 1,069 thousand mt-CO_2e and 19.9 mt-CO_2e/capita. Figure 1 shows the GHG emissions from each source. The following sections explain the calculations, and assumptions for each sector.

Figure 1:
GHG Emissions: Community-Wide Emissions: 1,069,000 mt-CO2e; Per Capita Emissions: 19.9 mt-CO2e



4.2 Buildings Sector

4.2.1 Buildings Energy Consumption and Energy Use Intensity

The buildings sector energy use reports electricity and natural gas consumed in residential, commercial, and industrial facilities. Data were obtained from the two electricity providers Xcel Energy (electricity and natural gas) and United Power (electricity only) for the year 2007. Based on the number of households and the square footage of commercial spaces in Broomfield (data obtained from the Broomfield Land Use Accounting Summary), energy use intensity can be computed in terms of electricity and natural gas use per home, and kBTU used per commercial square foot. Calculated energy intensity for buildings in Broomfield can be benchmarked with energy intensity metrics reported by the Energy Information Administration (EIA) in the Rocky Mountain region and national data. The Rocky Mountain region reports an average of 104 kBTU/sf/yr in commercial buildings while national data reports an average of 90 kBTU/sf/yr (See Table 7). Broomfield used an average of 190 kBTU/sf/year in 2007.

4.2.2 Emission Factors for Electricity & Natural Gas

The GHG emission factor for electricity and natural gas use was provided by Xcel energy as 0.75 kg-CO_2e/kWh and United Power's emission factor was calculated from their grid mix (76% bituminous coal, 9% natural gas, 15% renewable energy) as 0.82 kg-CO_2e/kWh. Xcel Energy is the only company that provides pipelined natural gas to Broomfield and they report an emissions factor of 5.4 kg-CO_2e/therm. These emission factors are in line with those reported by the Environmental Protection Agency (EPA) and EIA (Environmental Protection Agency 2009). The total consumption of electricity or natural gas is multiplied by the emissions factor to yield the total GHG emissions in mt-CO_2e. See Table 2 for a summary of buildings energy in Broomfield.

Table 2: Summary of energy use and GHG emissions from residential buildings and industrial and commercial facilities in Broomfield (numbers may not add due to rounding)

A. Residential Energy	**2007**
Total Number of People	53,807
Total Number of Households	19,889
Total Number of Customers	21,492
Total Grid Electricity Used including Windsource (GWh)	190
Total grid Electricity used from Windsource (GWh)	3.8
Number of premises buying electricity from Windsource	776
Electricity/household/month (kWh/hh/mo)	736
Total Natural Gas Used (million therms) (Xcel Energy)	14
Natural Gas/household/month (therms/hh/mo)	66
Total Residential GHG emissions (thousand mtCO_2e)	**215**
Total Residential per capita GHG emissions (mtCO_2e per person)	**4**
B. Commercial-Industrial Energy	
Total Number of Customers	3,467
Total Commercial-Industrial Area (million sf)	4.89
Total Electricity Used including Windsource (GWh)	440
Total Electricity Used from Windsource (GWh)	0.26
Number of premises buying electricity from Windsource	11
Total Natural Gas (million therms) (Xcel Energy)	9
Total energy use per square foot (kBtu/sf)	190
Total commercial–industrial GHG emissions (thousand mtCO_2e)	**382**
C. Total Buildings and Facilities GHG Emissions (thousand mton CO2e)	**597**

Data Source: Energy data from Xcel Energy and United Power. GWh = Giga Watt-hours of electricity = 1 million kWh;(1 kWh = 3.412 kBtu; 1 therm = 100 kBtu).

4.3 Transportation Sector

The transportation energy use in Broomfield includes two main modes of transport:

1. **Personal and Commercial Motor Vehicles:** Cars and trucks, modeled for the entire Denver Regional Council of Governments (DRCOG) region, were separated to assign the miles of personal and commercial traffic attributable to Broomfield[1].
2. **Airline Transport:** Energy use associated with jet fuel and fleet operations at the Denver International Airport (DIA) in 2007 attributable to Broomfield.

Summary of the miles traveled, fuel consumed and GHG emissions for both modes of transport are presented in Table 3.

4.3.1 Surface Travel Miles and Travel Intensity

Annual vehicle miles traveled (VMT) for Broomfield were computed by the demand-method (Ramaswami, et al. 2008) from the DRCOG 2007 model run. Consistent with modeling the city as a demand center for travel, only those trips that either originated or ended in Broomfield were included, amounting to an average of 1,188,656 daily surface VMT in 2007[2] and 407 million annual VMT. Pass-through trips in the Broomfield area, including those on major interstates (Highway 36 and E-470) were not included in Broomfield's inventory, as they do not relate to Broomfield-based activities. Fuel use (gasoline and diesel) was computed by allocating the annual VMT to an average State of Colorado Vehicle mix as reported by the Colorado Department of Public Health and the Environment (CDPHE); 95% gasoline-powered cars and 5% diesel-fueled vehicles, with average fuel economies as reported in ICLEI CACP program. Fuel consumption was computed by dividing the total annual VMT by the average fuel economy (ICLEI 2003).

The VMT intensity is the total annual VMT allocated to Broomfield per resident of Broomfield. VMT intensity was determined by dividing Broomfield's annual VMT by the 2007 population.[3] Normalizing the total annual VMT results for personal and commercial

---

[1] Mass Transit RTD bus trips were included in the personal and commercial motor vehicle sector.
[2] Average daily surface VMT is based on average weekday travel. Annual VMT was determined by multiplying the daily surface VMT by 342 in order to normalize the data for yearly travel that includes weekends and holidays.
[3] City of Broomfield's Planning Department.

vehicles per Broomfield resident allowed the data to be compared with Denver and national transportation data. National data for 2006 yielded 23.4 VMT/person/day, and 23.0 VMT/person/day for Denver, both in the range of the 22.1 VMT/person/day obtained for Broomfield, demonstrating that the daily VMT/person in Broomfield are comparable with travel behaviors observed regionally and nationally.[4]

4.3.2 Airline trips

Energy use associated with jet fuel and fleet operations at DIA in 2007 was allocated to Broomfield using the DRCOG regional transportation model. From this model, Broomfield's trip ratio to DIA was determined to be 0.0124 or 1.24%. In 2007, 423 million gallons of jet fuel were consumed at DIA, of which, 1.24%, or 5.2 million gallons was attributable to Broomfield. In order to benchmark the DIA trip ratio, the proportion of Broomfield residents to the entire DRCOG region was determined to be 2.2%, indicating relative congruence.

Although the Rocky Mountain Airport (RMA) is just outside of Broomfield's jurisdictional boundary, energy use associated with RMA's operations were not included in this inventory because small regional airports have not been included in prior assessments and would make results difficult to compare.

4.3.3 Emission Factors for Diesel, Gasoline and Jet Fuel

Diesel, gasoline, and jet fuel emissions factors were obtained from ICLEI calculations. The following emissions factors were used to calculate total transportation emissions: 9.1 kg-CO_2/gallon for gasoline fuel, 10.2 kg-CO_2/gallon for diesel fuel, and 9.9 kg-CO_2/gallon for jet fuel (Carbon Registry, 2008). The emissions factors for transportation fuels were multiplied by the total fuel consumption for gasoline, diesel and jet fuel. Broomfield emitted 256 thousand mt-CO_2e from transportation. Details are provided in Table 3 below.

[4] Per person normalization distributes total miles equally across total population. This method does not correlate exactly with vehicle miles traveled per vehicle.

Table 3: Transport distances, fuel use and GHG emissions by modes of transport in Broomfield

A. Personal & Commercial Motor Vehicles	2007
Annual Vehicle Miles Traveled (million VMT) (CDOT travel data)	407
VMT/person/day*	22.1
Annual Fuel Use	
Gasoline (million gallons)	19
Diesel (million gallons)	3
Total GHG Emissions from Personal and Commercial Motor Vehicle Transport (thousand mtCO_2e)	**208**
B. Airline Travel (282,448 trips allocated to Broomfield in 2007)	
Annual Fuel Use	
Jet Fuel (thousand gallons) (Bureau of Transportation)	5
Total GHG Emissions from Airline Travel Allocated to Broomfield (thousand mtCO_2e)	**52**
C. Total GHG Emissions from Transportation Sector (thousand mtCO_2e)	**260**

A. Data Source: VMT for personal-commercial vehicles obtained from DRCOG transportation model with Broomfield as demand center. Vehicle loading and fuel economy data from CDPHE to calculate PMT and fuel use.
B. Data Source: Fuel data for Airport operations provided by DIA for 2000 and 2005.
*Miles traveled are normalized to Broomfield's entire population, including children, and therefore do not reflect actual average travel distances per driver or air traveler.

4.4 Materials and Waste Sector

The materials sector comprises several sources of GHG emissions including cement, water and wastewater, fuel production, food production, and municipal solid waste (MSW).

4.4.1 Sources for Annual Consumption of Key Materials

Consumption of transportation fuels was determined from travel demand computations as summarized in Table 3 and used to determine the emissions for producing the fuel. The consumption of food was tracked in terms of money spent on food expenditures as reported in the Consumer Expenditure Surveys for residents in the Denver-Aurora Metropolitan Area. Cement use per person was also obtained for the Denver region from Consumer Expenditure Surveys for the Denver-Boulder Metropolitan Statistical Area. Water and wastewater flow data were obtained from the City and County of Broomfield with 34 billion gallons treated annually. Broomfield also purchases water from Denver, and the energy to clean Broomfield's portion of the water was included in this section of the inventory. Municipal solid waste volumes were estimated from the Colorado State average since Broomfield has over 15 trash haulers and does not own a landfill within City and County limits, making it difficult to track waste flows.

4.4.2 Emission Factors for Well-to-Pump

The GHG emissions factors for producing transport fuels were obtained from GREET Well-To-Pump analysis (Argonne National Laboratory 2007) as 2.5 kg-CO_2e/gallon for gasoline and 2.0 kg-CO_2e/gallon for both diesel and jet fuel. Broomfield emitted 44 thousand mt-CO_2e from gasoline fuel production, 7 thousand mt-CO_2e from diesel fuel production and 12 thousand mt-CO_2e from jet fuel production in 2007.

4.4.3 Denver Water and Wastewater Emissions

Broomfield purchases water from Denver Water and the Big Thompson Project and reuses a portion of this water for irrigation of local public parks and golf courses. The City of Broomfield treated a total of 34 billion gallons of water in 2007. The emissions from powering and pumping water from the Big Thompson Project to Broomfield's water treatment plant have been included in the citywide electricity data. However, Broomfield purchases approximately 40 percent of its water from Denver Water, which in 2007 amounted to 1.4 billion gallons of water. Under the expanded inventory-footprint methodology (Ramaswami, et al. 2008), the electricity consumed by Denver Water during the process of treating Broomfield's portion of water should be allocated to Broomfield. In 2007, Denver Water treated 69 billion gallons of water (Denver Water 2007). The water purchased by Broomfield equates to 2% of Denver Water's total production. Therefore, 2% of the emissions released by Denver Water should be allocated to Broomfield. In 2007, Denver Water's water treatment plant purchased 8 million kWh of electricity, (not including the electricity produced from hydro-power). Using an emission factor of 0.75-kg-CO_2e/kWh (from Xcel), Denver Water emitted 6,433 mt-CO_2e. Allocating 2 percent to Broomfield, results in 128 mt-CO_2e released in 2007.

According to LGOP, there are fugitive emissions (methane gas) associated with municipal wastewater treatment plants. It can be assumed that a percentage of the methane gas produced by a wastewater treatment plant's anaerobic digester process escapes from incomplete combustion. Using LGOP's default-value (ICLEI 2008) of 1 cubic foot of digester gas per person/per year and the equation below, Broomfield's wastewater treatment plant releases 59 mt-CO_2e annually. Fugitive methane emissions are calculated using the following formula (ICLEI 2008): Annual Methane Emissions = P x Digester Gas x F CH4 x ρ(CH4) x (1 – DE) x 0.0283 x 365.25 x 10-6 (see Table 4 for full equation description).

Table 4: Annual Methane Emissions from Wastewater Treatment Plant

Variable	Description	Value
P	Population served by the WWTP with anaerobic digesters user input	53,807
Digester Gas	Cubic feet of digester gas produced per person per day [ft^3/person/day]	1.0
F CH4	Fraction of CH_4 in biogas	0.65
ρ(CH4)	density of methane [g/m^3]	662
DE	CH_4 Destruction Efficiency	.99
0.0283	conversion from ft^3 to m^3 [m^3/ft^3]	0.0283
365.25	conversion factor [day/year] 365.25	365.25
10-6	conversion from g to metric ton [metric ton/g]	10-6
25	Global Warming Potential	**59 mt-CO2e**

In addition to methane, wastewater treatment plants release a small amount of nitrous oxide, the third greenhouse gas measured in this report. Approximately 7 grams of N_2O is released per person per year (ICLEI 2008). Using the global warming potential of 298 for nitrous oxide and a population of 53,807, Broomfield emitted 112 mt-CO_2e in 2007 from nitrification/denitrification. Finally, wastewater treatment plants emit a N_2O emission from the effluent discharge, which can be calculated using Equation 10.9 in the LGO protocol (ICLEI 2008). The N_2O emissions from effluent discharge were 2.82 mt-CO_2e.

4.4.4 Cement in Urban Concrete

Cement is included in GHG inventories because in order for a city to function, it imports large amounts of cement for new construction, remodels, etc. Producing cement emits about 1-mt-CO_2e for every 1 mt-cement produced. When cement is made, the reaction with the limestone produces carbon dioxide, which causes the emissions factor to approach one-to-one when factoring in transportation of the material. Cement can comprise about 3% of a city's total GHG emissions and so is considered for this inventory. The flow of cement was determined based upon financial data collected from the 2002 United States Census Data[5] for the Denver-Aurora area. Data for any product that is sold within the U.S. can be found on the Economic Census and can be used to calculate consumption within different Metropolitan Statistical Areas(U.S. Census Bureau 2005). The per capita cement use for Broomfield is determined by multiplying the total expenditure of cement products in the Denver-Aurora area by the cost of cement per kilogram ($/2.32kg). Allocating the kilograms of cement to the Broomfield population by taking the proportion of the total Denver-Aurora population results in cement consumed in Broomfield in 2007. The emissions factor for cement is about 1 mt-CO_2e/mt-cement(National Renewable Energy Laboratory 2008). In 2007, Broomfield emitted 26,000 mtCO_2e from cement.

4.4.5 Food Consumption

Food is another product that is usually not produced within city limits and is brought in from thousands of miles away. The embodied energy from food and food packaging was determined from "food consumed at home" for the Broomfield area. From the 2007 Census information published in the Consumer Expenditure Survey[6], food expenditures were determined on a per-household and per-person basis. Total citywide expenditure is determined from the population of Broomfield. Average Broomfield food expenditures are $3,452 per household per year or $1,276 per person per year, and the total estimate for Broomfield is $69 million (all figures are in 1997-$ in order to use the Carnegie-Mellon Economic Input-Output model). The emission factor for food is 1.5 kg-CO_2e/1997-$, the total GHG emissions from food production in Broomfield in 2007 were 105,000 mt-CO_2e (Carnegie-Mellon 2009).

4.4.6 Annual Municipal Waste and Recycling

Broomfield does not have a centralized solid waste collection service, so households

[5] Cement http://www.census.gov/econ/census02/data/metro1/M1974031.HTM#N327. NAICS code 3273.
[6] http://www.bls.gov/data

individually contact private haulers (sixteen of which are permitted to operate within the city limits). Due to the decentralized solid waste collection system, accurately identifying the amount of solid waste flowing through Broomfield is difficult. Additionally, Broomfield does not have a landfill in the City and County boundaries, making it more difficult to track these data. Hence, the waste generated in the residential sector was estimated based on the state average from CDPHE of 6.3 lb/person/day(Colorado Department of Public Health and Environment 2008). The State of Colorado produced 8.4 million tons of solid waste in 2007. The Broomfield population is 1% of the total State of Colorado population. To find Broomfield's estimated municipal solid waste, 1% of the state's total waste was allocated to Broomfield, which was about 93,000 short tons or 85,000 metric tons in 2007.

The City of Broomfield has a Recycling Transfer station where residents can drop-off recyclable materials. Broomfield's Public Works Department tracks annual tonnage of mixed recyclables collected at the Recycling Center. In 2007, the Recycled Center collected 1,622 short tons of mixed recyclables.

The EPA has developed a Waste Reduction Model (WARM) to aid municipalities and other organizations in calculating the emissions associated with solid waste and recycling. The emissions from solid waste are a result of the anaerobic breakdown of biodegradable material such as food waste, grass clippings, and paper. When such items are disposed of in landfills, methane emissions are produced. Based on the EPA's WARM Model, 93,381 short tons of solid waste disposed of in a landfill that manages the methane through flaring produces 15,000 mt-CO_2e and recycling 1,706 short tons of mixed recyclables reduces emissions by 4,920 mt-CO_2e. The total emissions from waste disposal community-wide are 10,000 mt-CO_2e.

4.4.7 Total Urban Materials Emissions

Total emissions from fuel production, Denver water, wastewater, cement, food production, and municipal solid waste and recycling are shown in Table 5.

Table 5: GHG emissions from manufacture of key urban materials in Broomfield

	2007	
Material	Annual Material Flow	GHG Emissions, thousand mtCO2e
Fuel Production (WTP for all fuels)		
Gasoline (million gallons)	19.2	44
Diesel (million gallons)	3.2	7
Jet fuel (million gallons)	5.2	12
Water (million gallons)		
Purchased from Denver Water (million gallons)	1370	0.13
Fugitive Methane Emissions (mt-methane)	2.4	0.06
Fugitive Nitrous Oxide Emissions (mt-N_2O)	0.38	0.11
Cement in Urban Concrete (thousand mt)	26.4	26
Food & Packaging ($ million)	$70	105
Municipal Solid Waste (thousand mt /year)	26	15
Recycling per person-day (lb/person/day)	NA	-5
Total GHG Emissions for Producing Key Urban Materials		205

4.5 Community-Wide and Per Capita GHG Emissions Footprint

Table 6 presents a comprehensive tally of GHG emissions from the buildings, transportation, and material sectors. The table includes materials flows, tracking metrics (in parenthesis after each consumption figure), and emissions factors as well as the total GHG emissions. The total community-wide emissions for the City and County of Broomfield in 2007 were 1.1 million mt-CO_2e. The per-capita emissions (population of 53,806) were 19.9 mt-CO_2e/person.

Table 6: Comprehensive Scope 1-2-3 GHG Emissions for Broomfield, 2007[7]

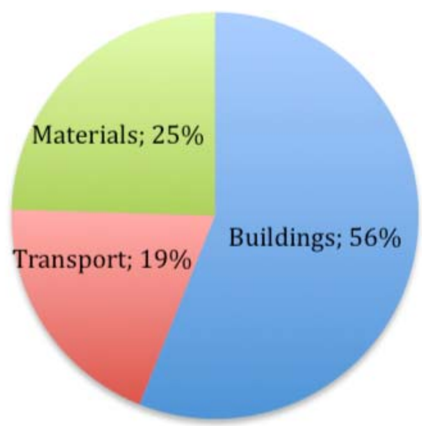
	Sector/use	Community-wide annual urban material/energy flows, MFA		GHG emission factor (EF)		Total GHG emitted = MFA x EF thousand mt-CO_2e
Scopes 1 & 2 plus waste	Buildings Electricity Use	633 GWh		0.75	0.82	473
		(736 kWh/hh/mo)		Xcel	United Power	
				kg CO_2e/kWh		
	Buildings Natural Gas	23 million therms (Xcel)		5.4 kg-CO_2e/therm (Xcel)		124
		(66 therms/hh/mo)				
	Surface Vehicle Miles Traveled, VMT	407	million VMT	9.3 kg-CO_2e/gal, Gasoline PTW		208
		Average Fuel Econ. = 20.1 mpg (gasoline), 6.3 mpg (diesel) (CDPHE)		10.2 kg-CO_2e/gal, Diesel PTW		
	Municipal Solid Waste	93,381	short tons/yr	0.16 mt-CO_2e/short ton		15
	Recycling (Center)	1,706	short tons/yr	-2.87 mt-CO_2e/short ton		-5
Scope 3	Airline Travel PTW	5	million gallons jet fuel	9.9 kg-CO_2e/gal Jet fuel PTW		52
	Fuel Production (WTP)	5	Jet Fuel (million gallons)	2.3 kg-CO_2e/gal, Jet fuel WTP		12
		3	Diesel (million gallons)	2.3 kg-CO_2e/gal, Diesel WTP		7
		19	Gasoline (million gallons)	2.3 kg-CO_2e/gal, Gasoline WTP		44
	Cement Use	26,377	mt cement	1 mt-CO_2e per tonne cement		26
	Food Purchases	$70	million (1997-$)	1.5 kg-CO_2e/$ (1997 $)		105
	Water	1370	million gallon	Use ICLEI Protocol (can vary depending on facility)		0.3
Total Community Wide Emissions:					**1,043**	**thousand mt-CO2e**
Community wide per capita emissions:					**19.9**	**mt-CO2e per capita**

Table 6 demonstrates the simple method of multiplying the material flow by the emission factor of carbon dioxide equivalence per unit of production. By summing the emissions in each sector the total community wide greenhouse gas emissions can be determined. The

[7] Table is adapted from Ramaswami et al, ES&T, 2008.

per capita emissions were found by dividing by the 2007 Broomfield population. Finding the per capita emissions is beneficial to compare the city's emissions across cities, states, and nations. The sum of Scopes 1, 2, and 3 yield a GHG footprint, while Scopes 1 and 2 only yield a boundary-limited inventory. In the case of Broomfield, Scope 3 emissions accounted for a quarter of the total emissions as seen in Figure 2. Including Scope 3 emissions allows for more innovative policies and solutions to reduce greenhouse gas emissions.

Figure 2: GHG Emissions By Sector



4.6 Benchmarking with Surrounding Communities

While determining the total emissions in a community may be important for tracking reduction progress, it is important to benchmark several descriptions of consumption to compare with other cities, states, and nations. Broomfield was benchmarked next to U.S. National, Colorado State, and Denver, CO in several consumption averages. Using this same methodology, Broomfield can be compared to any city around the world.

Table 7: Benchmarks comparing Broomfield, CO and Denver, CO

Description of Benchmark	U.S. National	CO State	Denver, CO (2007)	Broomfield, CO (2007)	Units of Measurement
Average Residential Electricity Use	888	674	528	736	kWh/hh/mo
Average Residential Natural Gas Use	58	47	65	66	therms/hh/mo
Average Commercial/Industrial Buildings Energy Use	90	104	179	190	kBTU/ft^2/yr
Vehicle Miles Travelled	27	24.5	25	22	VMT/person/day
Water/wastewater	100	154	168	178	gallons/person/day
Municipal Solid Waste	4.62	6.3	6.85	6.3	lb/person/day
GHG Emissions	25.2	24.5	25.3	19.9	mt-CO_2e/person/yr

5. Summary

This Greenhouse Gas Report is meant as a baseline inventory of the emissions in the City and County of Broomfield for 2007. The technical data in the report was also used to provide the Sustainable Task Force with background information on the current conditions of the emissions in Broomfield. The Task Force used some of this information, along with proposed climate action policies developed by the University of Colorado Denver Sustainable Urban Infrastructure program to propose policies and action steps for the city council to adopt in a Sustainability Plan. As the City and County of Broomfield continues to pursue a direction towards a sustainable community, the city can continually update the greenhouse gas accounting report to track the progress the community has made in reducing their greenhouse gas emissions.

References

Argonne National Laboratory. *The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model.* Vers. 2.7. 2007. http://www.transportation.anl.gov/modeling_simulations/GREET/index.html (accessed December 2009).

Brundtland, Gro. *Our Common Future: The World Commission on Enviornment and Development.* Oxford: Oxford University Press, 1987.

Carnegie-Mellon. *Input-Output Life Cycle Assessment (EIO-LCA) tool.* 2009. http://www.eiolca.net (accessed October 2009).

Colorado Department of Public Health and Environment. *Hazardous Materials and Waste Management Division Solid Waste Report.* 2008. http://www.cdphe.state.co.us/HM/swreportswreport.htm (accessed 12 2009).

Denver Water. "Comprehensive Annual Financial Report." Denver, 2007.

Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007." Washington D.C., 2009.
—. *Technology Transfer Network Clearinghouse for Inventories & Emissions Factors.* 2009. http://www.epa.gov/ttn/chief/efpac/index.html (accessed December 2009).

EPA. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006." 2008.

ICLEI. *Clean Air and Climate Protection Software (CACPS).* 2003. http://www.icleiusa.org/action-center/tools/cacp-software (accessed December 2009).

ICLEI. "Local Government Operations Protocol." 2008, 99.
National Renewable Energy Laboratory. *U.S. Life-Cycle Inventory Database.* August 26, 2008. http://www.nrel.gov/lci/database/default.asp (accessed December 2009).

Ramaswami, Anu, Tim Hillman, Bruce Janson, Mark Reiner, and Gregg Thomas. "A Demand-Centered, Hybrid Life-Cycle Methodology for City-Scale Greenhouse Gas Inventories." *Environmental Science and Technology* 42, no. 17 (2008): 6455-6461.

U.S. Census Bureau. *2002 Economic Census.* October 12, 2005. http://www.census.gov/econ/census02/data/metro1/M1974031.HTM (accessed December 2009).