Madison City Operations Tracking Framework: A Roadmap to Sustainability

Prepared for the City of Madison

By:
Carl Christiansen
Andy Lick
Eric O'Shaughnessy
Annie Racine
Kyle Schroeckenthaler

Workshop in Public Affairs
Spring 2015

Robert M. La Follette
School of Public Affairs
UNIVERSITY OF WISCONSIN–MADISON

For an online copy, see
www.lafollette.wisc.edu/research-public-service/workshops-in-public-affairs
publications@lafollette.wisc.edu

List of Tables

List of Figures

Foreword

This report is the result of collaboration between the La Follette School of Public Affairs at the University of Wisconsin–Madison and the City of Madison and the Sustainable Madison Committee. Our objective is to provide graduate students at La Follette the opportunity to improve their policy analysis skills while contributing to the capacity of the City to track and evaluate greenhouse gas emissions.

The La Follette School offers a two-year graduate program leading to a master's degree in public affairs. Students study policy analysis and public management, and they can choose to pursue a concentration in a policy focus area. They spend the first year and a half of the program taking courses in which they develop the expertise needed to analyze public policies. The authors of this report are all in their final semester of their degree program and are enrolled in Public Affairs 869 Workshop in Public Affairs. Although acquiring a set of policy analysis skills is important, there is no substitute for doing policy analysis as a means of learning policy analysis. Public Affairs 869 gives graduate students that opportunity.

This year the workshop students were divided into eight teams. Other teams completed projects for the Wisconsin Department of Public Instruction, the Wisconsin Department of Children and Families, the Wisconsin Legislative Council, Madison Metro, the Center for Economic Progress, and The Financial Clinic of New York City.

In the absence of an effective national strategy on climate change, local governments are trying to understand how to make a difference. But the scale of the problem may seem overwhelming, and the variety of policy options bewildering. How can a city prioritize? This report develops the City of Madison tracking framework to help policymakers face these challenges. The report includes an analysis of the emissions impact of City operations, building upon prior efforts. It also provides metrics that will allow the City to understand the progress it is making. But a fundamental problem in this policy area is how to act upon this type of information. The report develops and illustrates the benefits of evaluative criteria that will point to policy options where the City has the greatest potential influence over outcomes.

Donald Moynihan
Professor of Public Affairs
Madison, Wisconsin
May 2015

Acknowledgements

We would like to acknowledge our clients, Jeanne Hoffman and the Sustainable Madison Committee, who were valuable in helping to shape and direct this project. We valued Jeanne's experience with past inventory teams and knowledge of City sustainability initiatives incredibly. We would especially like to recognize committee members Brad Campbell, Chelsea Chandler, and Sophia Rogers, with whom we had the pleasure of working with throughout this process. These individuals met with us and helped us further develop recommendations to the committee.

We would like to acknowledge Mike Collins and Don Moynihan, the instructors for the workshop course that supported development of this report. We found Don's guidance as our advisor important in developing a clear and effective narrative for this document.

We owe our gratitude to several individuals who provided data for the 2014 City of Madison greenhouse gas inventory. We would especially like to thank Brynn Bemis, Kathy Cryan, Wayne Block, and Bill Vandenbrook from the City of Madison, Keith Beck and Michelle Goldade from the Dane County Department of Administration, and Jesse Shields from Madison Gas & Electric.

We would also like to thank J.R. Killigrew from the International Council for Local Environmental Initiatives for his support with the ClearPath greenhouse gas inventory software.

Executive Summary: A Roadmap to Sustainability

The City of Madison developed ambitious sustainability goals in the 2011 Madison Sustainability Plan. A frequent problem for community-level sustainability efforts is a lack of a comprehensive cross-time assessment mechanism to evaluate progress toward targets and to identify policies to achieve those targets (Erickson 2013). Absent a more systematic approach to evaluate progress and policies, community-level sustainability initiatives such as the Madison Sustainability Plan may remain untargeted and ineffective.

To have a realistic chance of achieving the ambitious goals set in the Sustainability Plan, the City of Madison needs a sustainability assessment mechanism and a decision-forcing framework to target policies that will generate significant gains. We recommend that the City of Madison implement a tracking framework as a roadmap to assess sustainability progress and evaluate policy alternatives.

Sustainability assessment mechanisms are metrics-based tools to evaluate sustainability performance over time. Metrics are quantified measures used to assess environmental performance and articulate the extent to which current activities are sustainable (Singh et al. 2012). The continuous tracking of metrics allows communities to identify and analyze long-term sustainability trends (Ness et al. 2007). A tracking framework encompasses several sustainability assessment tools, and its defining feature of a tracking framework is its emphasis on detecting trends in the most relevant drivers of a community's emissions rather than the static image provided by a single greenhouse gas inventory (Chandler et al. 2012).

A **tracking framework** is a sustainability assessment tool that identifies and analyzes trends in key sources of a community's greenhouse gas emissions through the continuous analysis of tracking metrics (Chandler et al. 2012).

The City of Madison should improve the implementation of the Madison Sustainability Plan through the use of a tracking framework in four ways:

1. Formalize data collection, including bi-annual greenhouse gas inventories, to provide the inputs necessary to develop tracking metrics.
2. Track sustainability metrics to identify trends in the most significant drivers of City of Madison greenhouse gas emissions: transportation and building energy use. The City of Madison should use analyses of sustainability metrics to inform policy objectives.
3. Use a system of evaluative criteria to analyze policy alternatives to fulfill policy objectives informed by sustainability metrics.
4. Following policy implementation, the City of Madison should assess policy impacts through changes in sustainability metrics to inform policymaking.

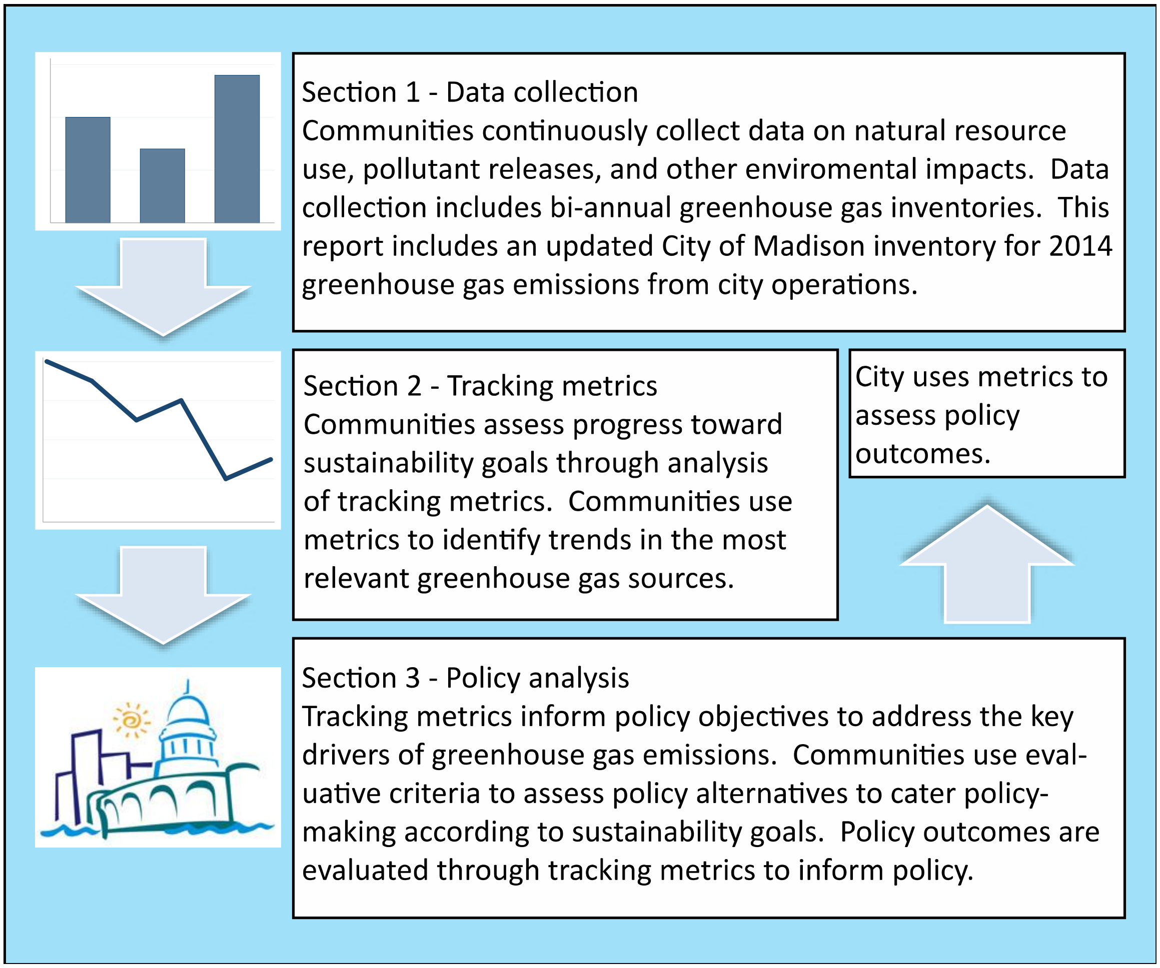
Introduction: A City of Madison Tracking Framework

The report presents an ongoing collaboration between the City of Madison and the University of Wisconsin–Madison to implement City sustainability initiatives. Every two years the City works with university students and faculty to collect data for greenhouse gas inventories. We build upon these inventories and the 2011 Madison Sustainability Plan (SEDC 2011), and we develop a tracking framework to better inform, analyze, and prioritize plan implementation efforts.

A tracking framework is a sustainability assessment tool that identifies and analyzes trends in key sources of a community's greenhouse gas emissions through the continuous analysis of tracking metrics. The defining feature of a tracking framework is its emphasis on detecting trends in the most relevant drivers of a community's emissions rather than the static image provided by a single greenhouse gas inventory (Chandler et al. 2012). Compared to an inventory concentrated on simple reporting, the value of a tracking framework is it capacity to serve as a decision support tool.

Figure 1 summarizes the core components of the proposed tracking framework. The three components correspond to the three sections of this paper.

Figure 1. Summary of the proposed tracking framework for sustainability assessment



Section 1 - Data collection
Communities continuously collect data on natural resource use, pollutant releases, and other enviromental impacts. Data collection includes bi-annual greenhouse gas inventories. This report includes an updated City of Madison inventory for 2014 greenhouse gas emissions from city operations.

Section 2 - Tracking metrics
Communities assess progress toward sustainability goals through analysis of tracking metrics. Communities use metrics to identify trends in the most relevant greenhouse gas sources.

City uses metrics to assess policy outcomes.

Section 3 - Policy analysis
Tracking metrics inform policy objectives to address the key drivers of greenhouse gas emissions. Communities use evaluative criteria to assess policy alternatives to cater policy-making according to sustainability goals. Policy outcomes are evaluated through tracking metrics to inform policy.

1. Data Collection: 2014 City of Madison Greenhouse Gas Inventory Results

City of Madison local government operations emitted approximately 92,000 tons of carbon dioxide equivalent in 2014, approximately a three percent reduction from the 2012 inventory.

In collaboration with the City of Madison, University of Wisconsin–Madison graduate students have completed three greenhouse gas inventories of City government operations using a variety of energy use, employee behavior, and operations data. Each inventory requires a student group to reach out to city agencies to request data and learn to use the greenhouse gas inventory software. These data have facilitated bi-annual snapshots of City greenhouse gas emissions; however, the City has not used these data to systematically assess sustainability progress and inform policies. A tracking framework formalizes continuous data collection as a method for sustainability assessment and policy analysis.

The following results of the fourth City of Madison government operations greenhouse gas inventory provide a summary of data collection. The City of Madison measures greenhouse gas emissions using a protocol developed by the International Council for Local Environmental Initiatives (ICLEI). This protocol provides standardized guidelines to assist local governments in the quantification and reporting of greenhouse gas emissions. The protocol includes three supplemental components of inventory reporting: a City of Madison government profile (Appendix A), activity data disclosure (Appendix B), and emissions factor disclosure (Appendix C). We used ICLEI ClearPath greenhouse gas inventory software to convert all City-provided data inputs to units of greenhouse gas emissions.

City of Madison government operations emitted approximately 92,000 tons of carbon dioxide equivalent in 2014.[1] We analyze inventory results by emissions scope and government activity sector in the following sections.

---

[1] Tons of carbon dioxide equivalent (tCO_2e) is the sum of all greenhouse gases in terms of the global warming potential in terms of carbon dioxide. For more information see Appendix C.

1.1 Emissions by Scope and Sector

Emission scopes are measures of the operational control that local governments exercise over emission sources. The ICLEI protocol defines three scopes. Reporting of all scope 1 and 2 emissions are required by the protocol, while reporting of a variety of scope 3 emissions sources are optional.

Scope 1: Greenhouse gas emissions directly emitted from City-owned property, vehicles, and equipment capital. Scope 1 emission sources include:

- Vehicle fleet: gasoline and diesel use
- Transit fleet: gasoline and diesel use
- Solid waste facilities: fugitive methane emissions from landfills
- Refrigerant losses from buildings and facilities

Scope 2: Indirect greenhouse gas emissions from the use of purchased or acquired energy. Scope 2 emission sources include:

- Buildings and other facilities: electricity, natural gas, and steam use; emissions from refrigerant losses
- Streetlights and traffic signals: electricity and natural gas use
- Water delivery facilities: electricity and natural gas use

Scope 3: All other indirect greenhouse gas emissions not included in Scope 2. The scope 3 emission sources which Madison elects to report include:

- Employee commute: gasoline and diesel use
- Employee waste: emissions from landfilled waste

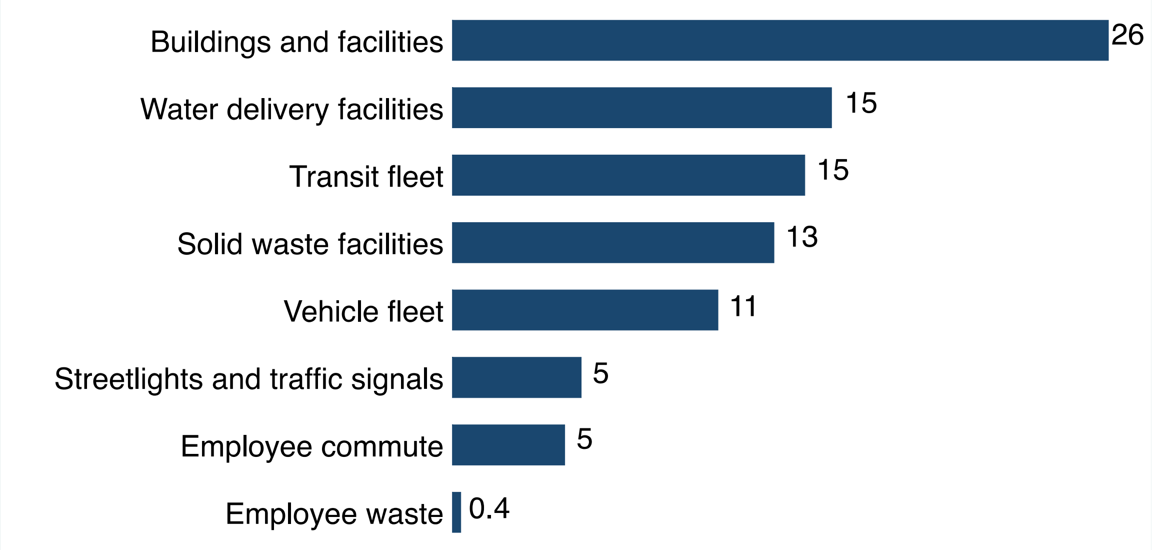
Table 1 reports emissions by scope. Figure 2 reports emissions by sector.

Table 1. 2014 City of Madison greenhouse gas emissions by scope, in tons of carbon dioxide equivalent

Scope 1	Scope 2	Scope 3
46,000	41,000	5,000

Source: Authors' calculations using ClearPath

Figure 2. 2014 City of Madison greenhouse gas emissions by government activity sector in tons of carbon dioxide equivalents (1,000 tons of carbon dioxide equivalent)



Source: Authors' calculations from City data using ClearPath

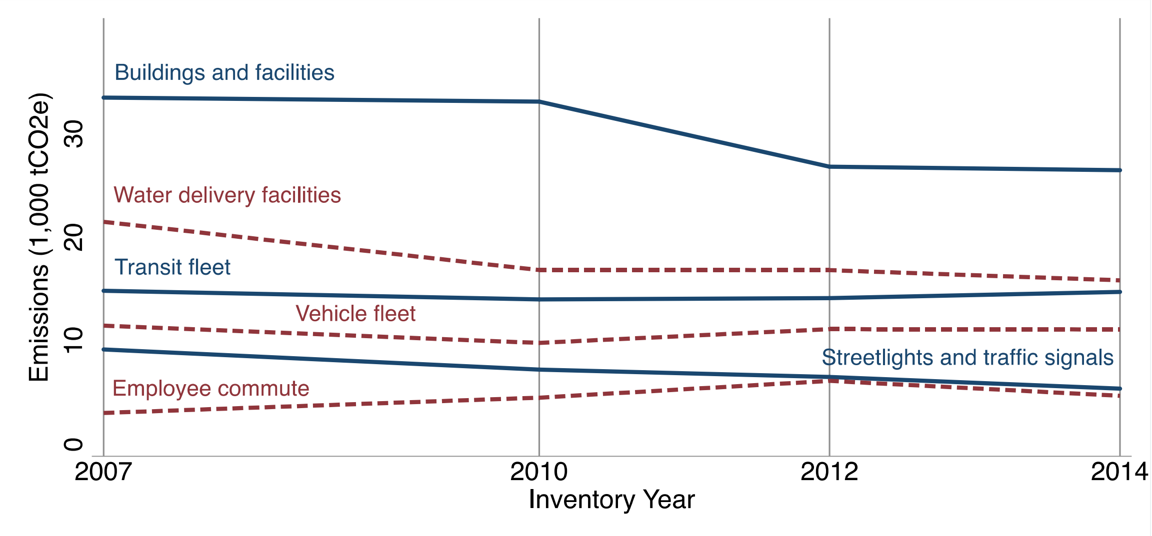
Consistent with previous inventories, Figure 2 shows that electricity, natural gas, and steam use at buildings and facilities together constituted the single largest sector source of City of Madison greenhouse gas emissions—about 29 percent of the City of Madison's 2014 greenhouse gas emissions. Transportation-related emissions from City of Madison vehicle fleet, transit fleet, and employee commuting accounted for about 33 percent of 2014 greenhouse gas emissions. See Appendix B for a detailed summary of greenhouse gas emissions by sector and sub-sector.

1.2 City of Madison Greenhouse Gas Trends (2007-2014)

City of Madison greenhouse gas emissions have declined in every government activity sector except employee commuting since 2007, with the most significant reductions occurring in the buildings and facilities sector.

Figure 3 compares 2014 inventory emissions data for the largest sector contributors with the 2007, 2010, and 2012 inventories. Figure 2 does not include a trend for emissions from solid waste facilities due to data inconsistencies in City of Madison inventories.

Figure 3. City of Madison emissions over time by sector



Source: Chung et al. 2013; Bray-Hoagland et al. 2011; Dart et al. 2010; and authors' calculations from 2014 data using ClearPath

The privatization of the Overture Center accounts for the significant decrease in emissions from City-owned buildings and facilities between 2010 and 2012. The Overture Center accounted for approximately 25 percent of emissions from City of Madison buildings and facilities before 2012 (Bray-Hoagland et al. 2011). The reduction in employee commute is partially associated with data inconsistencies. The 2012 inventory estimated employee commute figures based on a City of Madison employee population of 3,676 individuals, rather than the 2,756 full-time employees budgeted in 2012. Our employee commute estimate is based on 2,784 budgeted full-time employees in 2014.

Although the 2014 inventory shows an approximate 3 percent reduction from 2012 greenhouse gas emissions, the interpretation of this result is limited due to data inconsistency and variability. Measurement inconsistencies, such as the employee commute figure, translate to inconsistent results. Significant emissions variability from year to year stems from renovations, operational changes, and climatic conditions. Data inconsistencies and variability are motivations for the formalization of data compilation in a tracking framework.

Table 2 provides a more specific summary of the 2014 inventory results by sector.

Table 2. 2014 City of Madison greenhouse gas inventory details by sector (continues on next page)

	Carbon dioxide (tons)	Nitrous oxide (pounds)	Methane (pounds)	Carbon dioxide equivalent (tons)	Energy (millions of British thermal units)
Buildings and facilities	**26,342**	**661**	**1,817**	**26,462**	**204,572**
Electricity	18,507	632	558	18,607	78,422
Natural gas	6,391	24	1,205	6,410	109,348
Steam	1,444	5	54	1,445	16,802
R-410a	0	0	0	0.8	0
Streetlights and traffic signals	**5,349**	**195**	**774**	**5,388**	**22,709**
Electricity	5,346	183	161	5,375	22,653
Natural gas	3	12	613	13	56
Water delivery facilities	**15,758**	**524**	**551**	**15,842**	**72,931**
Electricity	15,279	522	461	15,363	64,748
Natural gas	478	2	90	480	8,183
Solid waste facilities	**0**	**0**	**950,192**	**13,439**	-
Demetral landfill	0	0	92,594	1,054	-
Greentree landfill	0	0	154,324	4,307	-
Mineral Point landfill	0	0	110,231	1,271	-
Olin landfill	0	0	180,779	2,070	-
Sycamore landfill	0	0	412,264	4,738	-
Vehicle fleet	**11,077**	**104**	**283**	**11,097**	**138,169**
Diesel	6,356	33	33	6,361	77,959
Gasoline	3,572	52	157	3,582	46,109
Off-road diesel	1,144	19	92	1,149	14,029
Off-road gasoline	5.5	0.3	0.6	5.5	72

	Carbon dioxide (tons)	Nitrous oxide (pounds)	Methane (pounds)	Carbon dioxide equivalent (tons)	Energy (millions of British thermal units)
Transit fleet	**14,716**	**69**	**68**	**14,727**	**180,610**
Diesel main line	14,214	67	63	14,225	174,411
Para-transit	400	1.2	0.8	400	4,908
Support vehicles					
Diesel	34	0.1	0.1	34	424
Gasoline	67	1.1	4.8	67	867
Employee commute	**4,596**	**143**	**483**	**4,623**	**67,893**
Employee waste	-	-	**28,661**	**351**	-
Total	**77,837**	**1,697**	**982,829**	**91,931**	**679,231**

Source: Authors' calculations using ClearPath

2. Metrics in a Tracking Framework

A basic challenge in improving sustainability tracking is to find appropriate quantifiable metrics to assess a community's human and environmental wellbeing (Fiksel, Eason, and Frederickson 2012). This section proposes eight metrics to measure City of Madison carbon and energy goals. We then analyze three metrics with data from the 2014 City of Madison greenhouse gas inventory.

2.1 Carbon and Energy Metrics for Madison

We identified tracking metrics catered to the Madison Sustainability Plan according to guidance from research (Harger and Meyer 1996). We used the following criteria to propose metrics:

- **Simplicity:** Tracking metrics should be easy to interpret.
- **Measurability:** Tracking metrics should be easy to collect.
- **Sensitivity:** Tracking metrics should be sensitive enough to reflect changes in environmental performance, especially to detect the impacts of sustainability policies.

We recommend that the City of Madison use these criteria to develop tracking metrics for the remaining parts of the Madison Sustainability Plan.

Table 3 provides recommended metrics to track the Madison Sustainability Plan carbon and energy goals. Some metrics are applicable to more than one carbon and energy goal. We grouped goals accordingly:

- **Transportation:** Influence reductions in transportation related carbon impacts (Goals 1 and 5).
- **Buildings:** Systematically upgrade existing buildings and improve new buildings to reduce energy consumption (Goals 2, 3 and 5).
- **Public engagement:** Engage and communicate with the public regarding sustainability initiatives (Goals 4 and 6).

The substantive data required for these proposed metrics are already available to the City, but they are not being used to their full advantage. We recommend the City begin systematic and ongoing collection and assessment of these metrics to determine policy objectives and assess sustainability progress.

Table 3. Proposed metrics for City of Madison carbon and energy goals

VMT=vehicle miles traveled; MMBTU=million British thermal units; GGE=gallon of gasoline equivalents; kWh=kilowatt-hour

Goal area	Metric	Metric description
Transportation	Commuter Mode Share	**Employee commuting patterns:** The share of employees commuting via each mode tracks the City's efforts in reducing Scope 3 emissions. Is based on employee surveys.
	Use Share by Engine Type	**Fleet composition:** Vehicle use rather than the number of vehicles is a better measure of progress in improving fleet composition. The city tracks diesel and gasoline vehicles by hours logged or miles traveled. Additional engine types include hybrids, biofuels, propane, compressed natural gas, electric, fuel cell, etc.
	Total Fuel Purchases By Type	**Fuel mix:** Can convert to GGE for comparability. Ratios (ex. GGE_{Clean}/GGE_{Total}) could be calculated. Requires accurate accounting of alternative energy use.
Buildings	Energy Use Per Square Foot	**Building energy efficiency:** Building electricity, natural gas, and steam use should be combined and normalized for area to remove effects of changing building stock size.
	Benchmarked Buildings	**Building energy use best practices:** The City benchmarks buildings with the U.S. Environmental Protection Agency's Portfolio Manager that allows the city to compare facilities with peers. As the number of facilities benchmarked by the City of Madison and other local governments expands, other metrics using the ENERGYSTAR Score calculated by Portfolio Manager could be useful.
	Clean Share of Electricity	**Green power for electricity:** The Wisconsin State Energy Office considers clean electricity generation to include wind, biomass, biogas, hydroelectric, solar electric, and solar thermal. The City of Madison should accurately meter energy generated from clean sources to calculate the ratio $kWh_{clean\ electricity}/kWh_{total\ electricity}$.
	Clean Share of Heating Energy	**Green power for heating:** Examples of clean building heating include solar water heating, biofuels, and geothermal heat pumps. These clean energy sources should be tracked and compared to fossil fuel use using a ratio such as $mmBTU_{clean}/mmBTU_{total}$.
Public engagement	Visitors to City Sustainability Web Resources	**Madison sustainability public engagement:** The Information Technology department collects this information. The City should curate a central location for engagement.

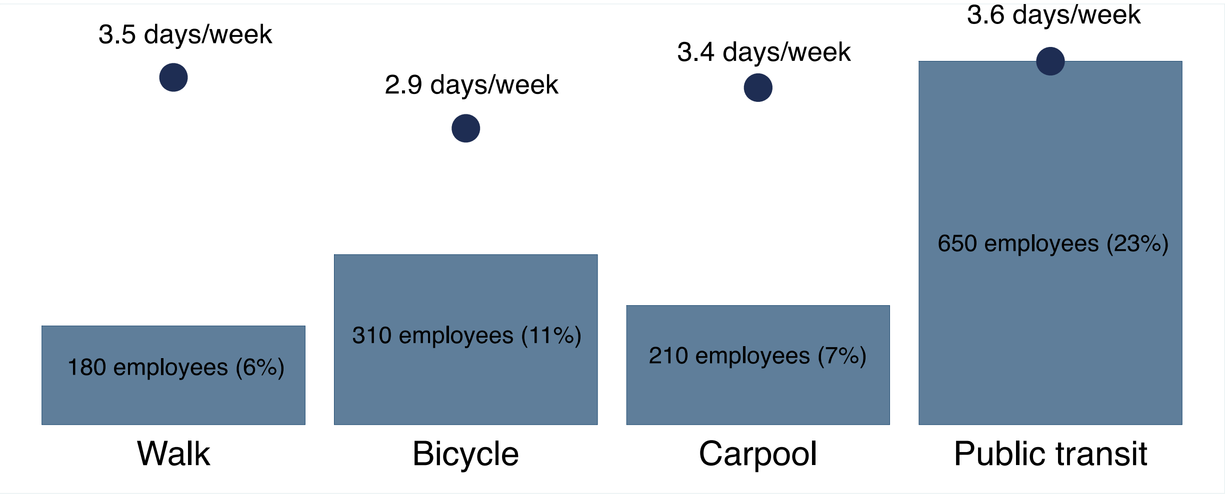
2.2 Metric Analysis of Alternative Employee Commuting Patterns

Main result: Approximately 48 percent of City of Madison employees use an alternative mode of transportation (not a personal motor vehicle) at least once per week. About 10 percent of employees use public transit every day.

The results of the employee commute surveys associated with the City of Madison inventory can inform decision-making on greenhouse gas reduction options in employee commuting patterns. The survey shows that about 48 percent of City of Madison employees use an alternative form of transportation (i.e., not personal vehicle) at least once per week.

Figure 4 summarizes City of Madison employee alternative commute choices. Public transit is the single most common alternative mode of transportation (about 23 percent of employees). Approximately 10 percent of City of Madison employees use public transit to commute five days per week, and about 11 percent bike to work at least once per week. Figure 4 also shows that City employees tend to use public transit more frequently than other alternative modes of transportation: public transit commuters tend to use public transit an average of 3.6 days per week, compared to an average of 2.9 days per week for bicycle commuters.

Figure 4. Estimated City of Madison employees that use alternative modes of transportation and average number of days per week that commuters use each alternative mode



Source: 1,081 responses to authors' survey of employees

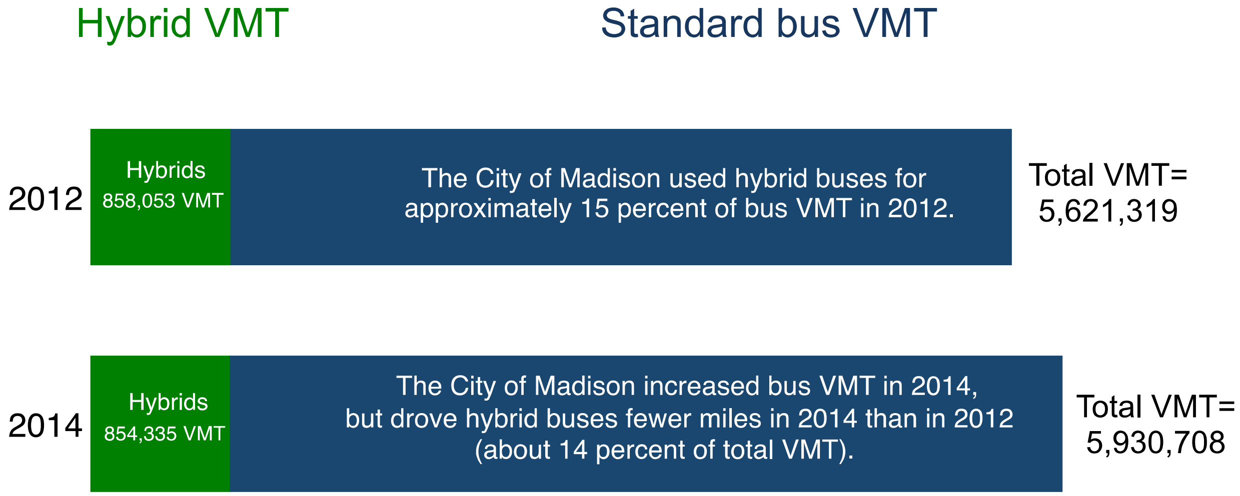
2.3 Metric Analysis of VMT Share of Hybrid Buses in the Metro Transit Fleet

Main result: Transit fleet greenhouse gas emissions have remained relatively stable despite an expansion of the hybrid vehicle fleet.

The increase in transit fleet emissions in the 2014 inventory is associated with an increase in transit fleet vehicle miles travelled (VMT) from about 5.6 million miles in 2012 to 5.9 million miles in 2014. Over this period, the VMT from hybrid buses declined by 3,718 miles despite the acquisition of two additional hybrid vehicles. The hybrid share of VMT fell from 15.3 percent to 14.4 percent. Figure 5 summarizes the change in hybrid share of total VMT from 2012 to 2014.

Metro Transit owns 21 hybrid buses or roughly 10 percent of the bus fleet. The City acquired five hybrids in 2007 as a pilot and fulfilled the entire order for buses in 2010 using hybrids. However, Metro purchased 46 diesel buses from 2011-2013 and added two new hybrids in 2014. Since the 2007 inventory, emissions associated with the City of Madison transit fleet have declined or remained relatively stable. We estimate that the use of hybrid buses resulted in a carbon reduction of more than 340 tons of carbon dioxide equivalent, or approximately 1.5 tons per bus in 2014.[2] This reduction is roughly 2.4 percent of total emissions from buses.

Figure 5. Change in share of City of Madison transit VMT from hybrid buses from 2012 to 2014



Source: Transit fleet fuel use data provided by City of Madison

These trends show that hybrid buses can reduce emissions from transit service, but are underutilized. We estimate that a full conversion of the transit fleet to hybrid buses would result in an annual reduction of approximately 1,800 tons of carbon dioxide equivalent or about 2 percent of the 2014 greenhouse gas inventory and 12.7 percent of emission from transit buses.

---

[2] These figures are based on average fuel efficiency for hybrid and conventional buses derived from 2014 City of Madison transit fleet data. Fuel efficiency for conventional buses for all model years after 2006 is 4.5 miles per gallon. We applied this fuel efficiency to hybrid VMT and fuel usage to estimate fuel use reduction per hybrid bus. We estimated carbon emissions with ClearPath software.

2.4 Metric Analysis of Building Energy Use per Square Foot

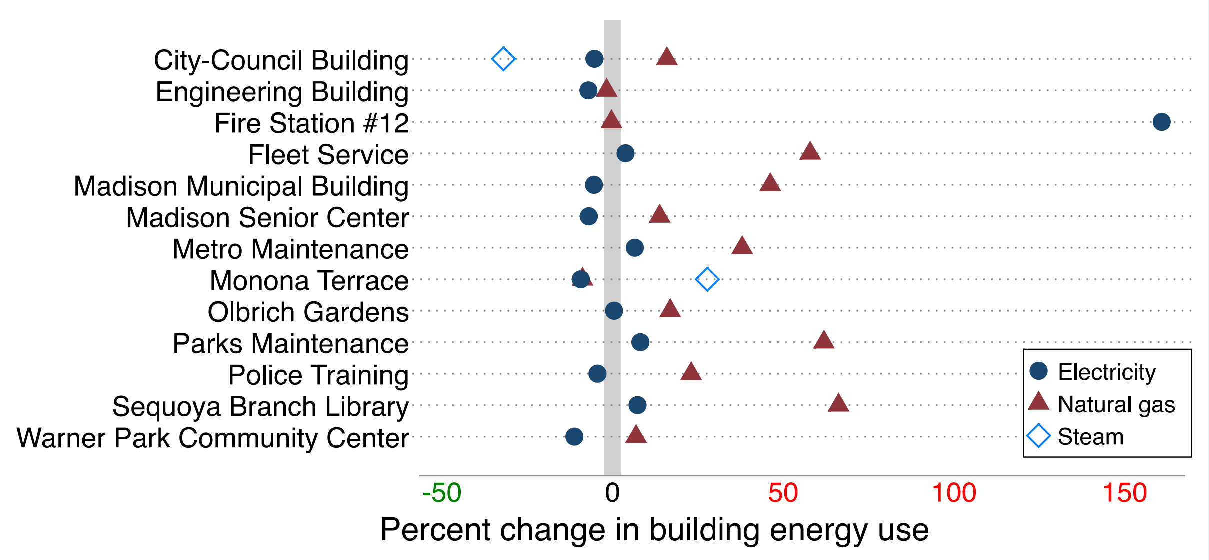
Main result: Building energy use intensity increased from about 24 kilowatt hours per square foot in 2012 to 29 kilowatt hours per square foot in 2014 in large City of Madison buildings due to increased natural gas use associated with cold temperatures in 2014.

Greenhouse gas emissions from City of Madison building and facility energy use declined significantly from 2007 to 2014. However, a large portion of the reduction is attributable to the privatization of the Overture Center, which accounted for approximately 25 percent of building emissions prior to 2012 (Bray-Hoagland et al. 2011). Excluding the reduction from the Overture Center, buildings and facilities emissions have not changed significantly.

Total emissions from all City of Madison buildings and facilities decreased marginally from 2012 to 2014. However, energy use intensity increased from 24 kilowatt hours per square foot in 2012 to 29 kilowatt hours per square foot in 2014 in 44 large City of Madison buildings. Almost all of the increase in building energy use intensity is associated with increased natural gas use, possibly associated with cold temperatures in 2014.

Figure 6 plots percentage changes in building electricity, natural gas, and steam use for 13 large City of Madison building energy users.

Figure 6. Percent changes in building electricity, natural gas, and steam use from 2012 to 2014 for a selection of large City of Madison buildings



Source: Energy use data provided by City of Madison

Plots such as Figure 6 are useful tools in a tracking framework to easily identify outlier facilities that significantly increased energy use (e.g., Fire Station #12 and Metro Maintenance) or reduced energy use (e.g., Monona Terrace, Warner Park Community Center).

3. Policy Analysis

The metrics developed for the tracking framework identify areas of emphasis for policy action. By analyzing the causes of trend direction and magnitude through the tracking metrics, the City can identify data-driven policy objectives and assess policy alternatives using a consistent framework. The City can also use metrics to track and communicate policy outcomes. This cycle enables the City to reassess and make evidence-based decisions, leading to effective and efficient sustainable improvements.

3.1 Evaluative Criteria

We recommend evaluating policies based on four criteria: 1) jurisdictional influence, 2) community scalability, 3) abatement potential, and 4) cost-effectiveness. We developed the criteria based on sustainability literature and input from the Sustainable Madison Committee (Erickson et al. 2013; Urge-Vorsatz et al. 2010). The criteria are summarized in Table 4 following their explanations.

Jurisdictional Influence

A municipal government has different carbon reduction tools than individuals, businesses, states, or nations. High jurisdictional influence exists when a municipality can directly affect emissions without coordination with other actors. Policies have low jurisdiction if they face legal constraints from other actors or rely behavioral change and voluntary participation.

Community Scalability

The City should focus on policies that can have a greater impact on carbon emissions by enabling reductions in the community.[3] "Leading-by-example" and proving sustainability initiatives are practical, affordable, and benefit the bottom line for the City, and encourage initiatives by individuals and private organizations. Examples of how the City's policies could reduce community emissions include: 1) building institutional infrastructure that also supports community emissions reduction, 2) providing physical infrastructure accessible to the public, 3) creating markets for clean technology, and 4) encouraging sustainable practices and behaviors through highly visible city efforts.

Abatement Potential

Policies will have a greater impact if they act on identified drivers of City emissions and have resulted in measurable emissions reductions in other jurisdictions. The City should pursue policies based on abatement achievable in the timeline of the Sustainability Plan goals rather than adopting policies based on short-term improvements that are highly visible (Erikson et al. 2013). Short-sighted initiatives can lead to lock-in of suboptimal solutions, when considering the objectives of the plan for 2050. We use "lock-in" to describe capital investments that fail to achieve long-term reduction goals, but divert capital resources from alternative policies that could meet goals (Urge-Vorsatz et al. 2010). Sufficiently aggressive policies must be implemented early on and consider the future policy trajectory.

---

[3] The City of Madison emits a relatively small portion of the community's overall greenhouse gases. See Anderson et al. 2014 for the 2012 communitywide inventory to compare the magnitude of government and community emissions.

Cost-effectiveness

Cost-effectiveness analysis helps decide how efficiently a policy achieves an abatement goal. Cities may find it easier to implement policies with low overall cost, but which have higher costs per unit of carbon abatement. High costs may be justifiable if they reduce the total cost to meet emission reduction goals. Many policies increase current capital costs and reduce ongoing operations and maintenance costs. We discount future costs using a 3.5 percent discount rate.

Table 4. Criteria for evaluating policies

Evaluative criteria	What the criteria mean	Key questions
Jurisdictional Influence	The City has the legal authority to implement a policy; the municipal scale does not preclude effectiveness; and the City has direct control over all areas of a policy.	• Can the City implement the policy without cooperation from other entities or political jurisdictions? • Is this policy most effectively implemented at the local level?
Community Scalability	The City can lead by example on sustainability in Madison. Effective leadership facilitates reductions in community emissions through potential community interactions with a city operations policy.	• Does this policy make it easier to implement a related policy at the community level in the future? • Will this policy encourage business and community members to engage in sustainable practices? • Does this policy affect a city operations emissions source that is also a major source of community emissions?
Abatement Potential	The emissions that would be feasible to eliminate in an ideal implementation. Major drivers of city operations emissions should be emphasized. Long-term abatement, rather than short-term, incremental abatement, is emphasized.	• What percentage of total city emissions does the policy have the potential to eliminate? • Has the policy effectively reduced emissions in other cities and will it be similarly effective in Madison? • Does the policy avoid lock-in and lead a policy environment that will meet o emissions abatement goals from 2050?
Cost Effectiveness	Cost to reduce carbon emissions using the proposed policy.	• What is the cost per ton of carbon dioxide equivalent abated by this policy?

3.2 Introduction to Policy Evaluation Examples

A tracking framework uses evaluative criteria to identify the optimal policy for addressing an area of emphasis identified through analysis of the emissions inventory and tracking metrics. Here, we use the criteria to evaluate three policies:

- Greening the City of Madison's vehicles
- Installing end-of-trip bike infrastructure
- Raising construction standards for City building energy efficiency

Jurisdictional Influence

We chose these policies for consideration based on their high level of jurisdictional influence. Erickson et al. (2013) identify transportation and buildings to be the community emissions sectors where local influence is the greatest. Energy supply and agriculture are less subject to local influence. The City has direct control over vehicle purchases, installation of infrastructure at City buildings, construction standards, and staffing levels. None of the policies considered could be more effectively carried out at a different level of government, although most could be imposed on the City by other entities. These policies minimize reliance on behavioral change in the broader community.

Community Scalability

All policies considered also meet the criteria of scalability. Initiatives to prove the effectiveness and financial viability of improvements to buildings and vehicles allow the community at large to recognize the benefits of these policies and replicate them at their own level. All of these policies are replicable by commercial entities that own buildings and vehicles, and wish to encourage their staff to commute by alternate modes and pay attention to energy use in their facilities.

Each of the policies identified satisfies the first two criteria of jurisdictional influence and scalability. We evaluate each policy below in greater detail in terms of abatement potential and cost effectiveness.

3.3 Evaluation of Greening City of Madison Vehicles

Policy: Establish pathways for converting several segments of the fleet to zero-emissions technologies, such as 1) renewable electricity and waste-derived biofuels; 2) convert the remaining segments of the fleet to low-carbon fuels and hybrid vehicles and implement technology to improve efficiency; and 3) use biofuels to reduce emissions in the interim.

Impact: Vehicles emitted more than 25,000 tons of carbon dioxide equivalent in 2014. We examine vehicle policies with abatement potentials ranging from 200 and 4,400 tons of carbon dioxide equivalent using current technology and energy sources. The policies assessed set goals for reductions in fuel purchases or changes in the share of vehicle usage powered by alternative engine types. These targets are measured directly by the metrics laid out in Section 2 of the tracking framework.

Meeting carbon and energy targets for vehicles will require not just increased fuel efficiency but eventual de-carbonization of most segments of the fleet. Efficiency improvements should target fleet segments that cannot be decarbonized economically. In fleets planned for de-carbonization, efficiency improvements should be implemented to save the City money on fuel and maintenance in the short-term. Transition to zero-emission vehicles should be complemented by a review of departmental use of vehicles and efforts to reduce VMT.

We assess five example components of a comprehensive green fleet policy:

- Conversion to 20 percent biodiesel for diesel-fueled vehicles
- Conversion of all 216 transit buses to electric drivetrains
- Conversion of 80 percent of passenger vehicles and 50 percent of light trucks to electric drivetrains
- Replacement of 31 Jeeps with electric vehicles
- Conversion of 50 percent light trucks, heavy trucks, and pursuit vehicles to compressed natural gas

Zero-carbon technology is becoming available for more of the types of vehicles the City uses. Segments of the fleet will become feasible and economical to convert to zero-carbon technology as technology evolves and infrastructure develops. Lock-in of sub-par fleet improvements must be avoided so that vehicle purchases will achieve long-term emissions reduction goals. For example, spending on hybrid vehicles may reduce financial resources available for zero carbon vehicles. A hybrid maintains fossil-fuel dependency over the 15 year life of that vehicle.

Figure 7 shows a hierarchy of engine types and fuels to consider for improving the fleet. Renewable electricity and waste-derived biofuels are the ultimate goal, because they generate no carbon emissions.[4] Grid electricity and standard biofuels are stepping stones to a zero carbon fleet. Low carbon fuels lock in emissions for at least the life of the asset and possibly longer as

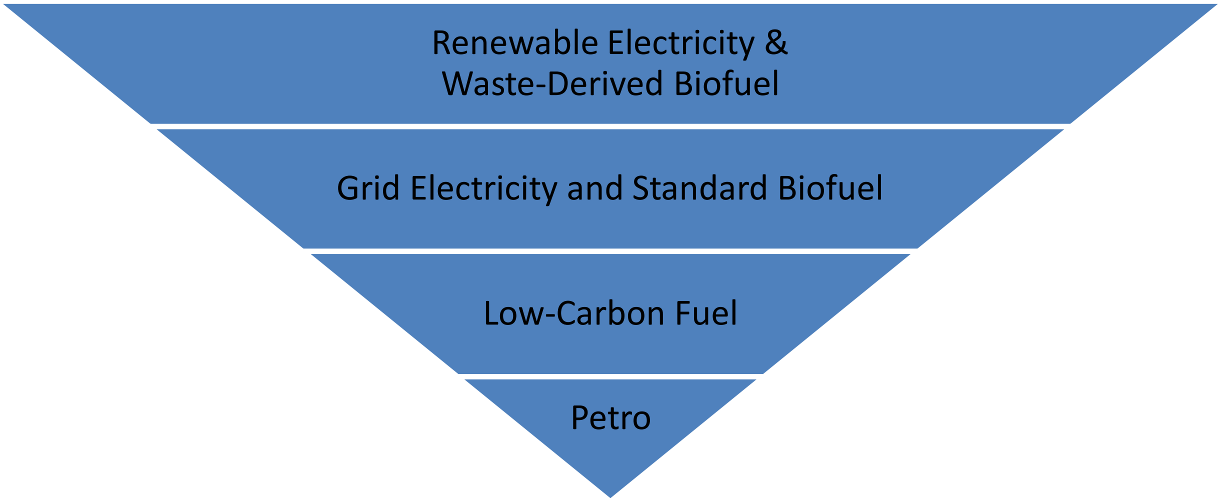
---

[4] Electricity generated from renewable solar, wind, hydro and nuclear sources produce no carbon. Waste-derived biofuels, such as methane from landfills or biodigesters and waste oil from the food service industry, are zero-carbon as these their feedstock would emit greenhouse gases if disposed of in some other way.

the City invests in infrastructure and training. Low carbon fuels are still preferable to standard petroleum vehicles.

Green fleet policies will have sustainability impacts in the community beyond the transportation sector. Production of biogas and biodiesel from waste sources eliminates emissions and social costs from landfilling and disposal. A green fleet reduces emissions of local pollutants that threaten public health and reduces noise pollution. Electric vehicles could serve as storage for locally generated renewable energy.

Figure 7. The hierarchy by which the City of Madison should prioritize fuel use to achieve decarbonization of the fleet



Source: Authors adaptation of framework used by Pratt 2014.

Abatement Potential

Table 5 summarizes the estimated abatement potential of the five green fleet policies. Appendix D.1 includes calculations of the abatement potential from each of the policies.

Table 5: Abatement potential from example green fleet policies

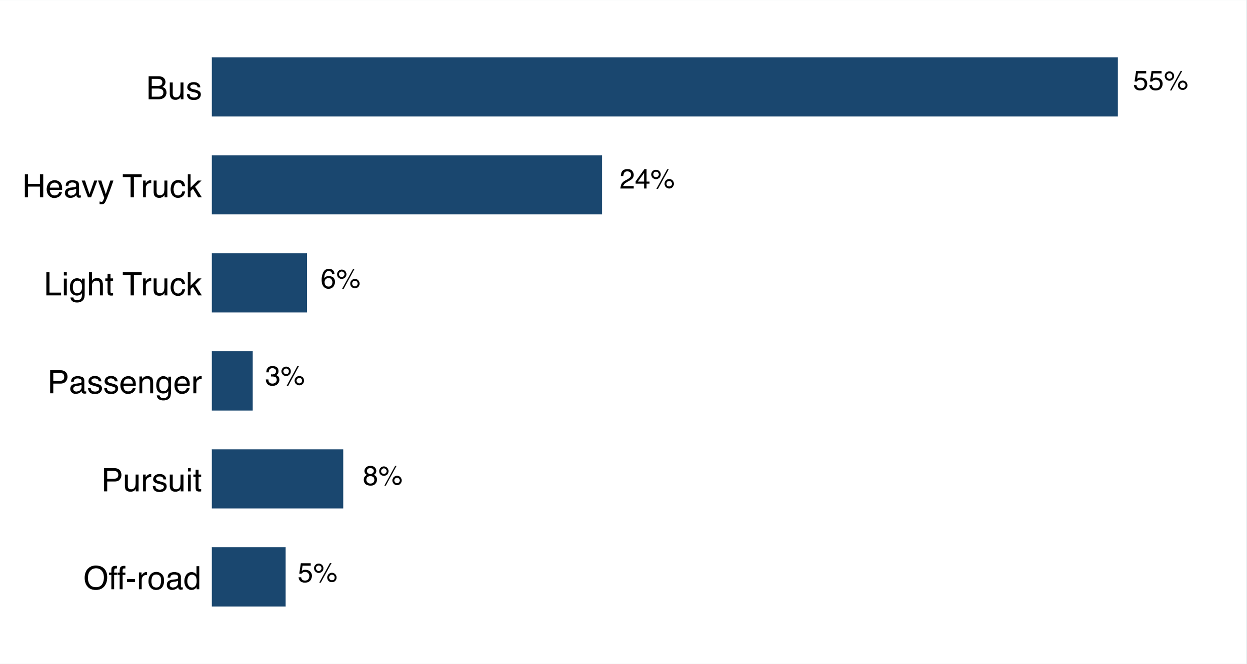
	Annual tons of carbon dioxide equivalent abated (percentage of city total)
All diesel fuel used contains 20 percent biodiesel	4,100 (4.4%)
All 216 transit buses use full electric drivetrains	4,400 (4.8%)
80 percent of passenger vehicles and 50 percent of light trucks use full electric drivetrains	700 (0.7%)
31 Jeeps are replaced with electric cars (represents 43 percent of passenger vehicle emissions)	200 (0.2%)
50 percent of light trucks, heavy trucks, and pursuit vehicles use compressed natural gas engines	1,000 (1.1%)

Source: Author's calculations based on data provided by Metro Transit and Fleet Management

The abatement potentials of transportation policies depend on initial levels of emissions attributable to specific vehicle types. Figure 8 segments the City of Madison's vehicles into different use categories to assist in identifying which type of vehicles are the greatest driver of carbon dioxide equivalent emissions.[5] Segments offer different opportunities for emissions reduction through efficiency improvements and decarbonization. Without technological and financial constraints, the greatest potential for abatement is clearly in the Metro Transit bus fleet, City-owned heavy trucks, and police pursuit vehicles.[6]

Capturing all of these savings would require large investments in zero-carbon energy through infrastructure investment or purchase of renewable energy credits. By 2050 many of these technical constraints, and some corresponding fiscal barriers, may be eliminated. The City must plan for these changes and aim for aggressive de-carbonization to meet its sustainability goals.

Figure 8. Fuel use by fleet segment (percentage of total gallons of gasoline equivalent use)



Source: Author's calculations based on inventory data received from City agencies

Few options are available for efficient police vehicles. Other cities have established plans to push equipment manufactures to provide options (Pratt 2014). Options for large efficiency improvements in heavy trucks have become available, but remain difficult to quantify due to users limited experience.[7] Additional analysis of the heavy truck and off-road fleet is beyond the scope of this report due to the diversity of vehicle purposes within these categories.

---

[5] Shares of fuel use are reported in gallons of gasoline equivalents, which convert directly to carbon emissions. See Appendix C for emissions coefficients.

[6] Heavy trucks are used to provide city services. They include snow plows, waste collection trucks, street and utility maintenance vehicles, and fire and emergency vehicles..

[7] The City of Denver has seen 25 percent reductions in fuel use from hybrid-hydraulic refuse trucks (City of Denver 2010), and European cities are now operating electric and hybrid-electric refuse trucks and other large vehicles efficiently (O'Neill and Rudden 2014). Hybrid-hydraulic drivetrains are also used in bucket trucks.

Cost Effectiveness

Widespread adoption of alternative propulsion systems continues to be uneconomical for the City. Table 6 summarizes the results of our cost-effectiveness analysis. Many of the alternative fuel technologies are maturing rapidly and could make some of the scenarios we examine much more attractive in the near future. Based on the findings using available information, it may be most cost-effective for the City to reduce emissions in the short-term through use of biodiesel as the City identifies the specific vehicle groups for transition to electric propulsion.

Table 6: Green fleet policy costs and cost-effectiveness

Type of vehicle	Net present value of policy costs	Cost-effectiveness (dollars per ton of carbon dioxide equivalent)
Biodiesel	$200,000	$50
Electric buses	$260,000 per bus	$630 to $850
Electric cars and trucks	-$3,300 to $11,000 per vehicle	-$90 to $300
Jeeps to electric cars	-$3,600 to $3,600 per vehicle	-$160 to $50
Compressed natural gas Light truck, heavy truck and pursuit vehicles	Averages $6,000 to 15,000 per vehicle	$160 to $400

Source: Authors' calculations – more detail provided in Appendix D.1.

Due to the high cost of compressed natural gas fueling infrastructure, it seems unlikely that this alternative fuel will be a viable option for the City. With less than 50 percent penetration of compressed natural gas it is even more difficult to justify the cost of a fueling station;[8] however conversion or purchase of that many vehicles requires millions of dollars of capital investment. At 50 percent of light and heavy trucks and police vehicles, the price difference between compressed natural gas and petroleum fuels would need to reach around $2.00 for the lifetime fuel savings to justify capital expenses. If the City makes major commitments to internal production of biogas through anaerobic digestion and capture of methane from landfills it may be worthwhile to revisit compressed natural gas as a fuel for City vehicles.

Despite the large abatement potential of electric transit buses, current cost-effectiveness is not favorable. The vehicle cost differential would have to fall from $400,000 to $200,000, and diesel prices return to $4.00 per gallon for electric transit buses to be cost neutral over their 15 year lifetime. Use of electric buses could result in significant adjustment to transit fleet management, not only to account for charging needs, but also because of changing lifetime maintenance needs. It is plausible that electric bus costs could fall by as much as $200,000 in the next five years as the technology develops. Batteries are the most expensive component of electric vehicles and have fallen in price by 14 percent year-after-year for the past seven years (Nykvist and Nilssen 2015). The capital cost gap could also be closed by financial incentives from federal agencies.

Electric cars share much of the uncertainty of electric buses. The purchase price premium may be as little as half what is a few years ago, which leads to the lower bound of $20 per ton of carbon dioxide equivalent at $3.00 per gallon of diesel and $2.50 per gallon of gasoline. Changes in fuel

---

[8] Smith and Gonzales (2014) estimate the cost of a municipal scale compressed natural gas fueling station to range from $1.2 million to $1.8 million.

prices could offer even better cost-effectiveness or even cost parity. After examining the costs of converting 220 representative vehicles from the passenger vehicle and light truck segments, we chose to also examine a specific group of vehicles where conversion may have a large impact.

Jeeps account for about 43 percent of the fuel use in the passenger vehicle category and represent 18 percent of total vehicles. A significant portion of these vehicles appear to be used for parking enforcement. The stop-and-go nature of services such as parking enforcement makes them ideal for electric drivetrains. Transition to use of available electric vehicle models provides a strong opportunity to save the City money while reducing emissions.

Tracking Policy Impacts

Despite the goal of 20 percent reduction in fuel consumption by City Fleet by 2020 set by the 2009 Administrative Procedure Order No. 4-9 (City of Madison 2009), the quantity of gasoline or diesel purchased for City Fleet has not changed. New policy actions such as the alternatives examined in this section will be necessary to reduce emissions from one of the largest City sources. Use of 20 percent biodiesel will directly reduce diesel purchases by nearly 20 percent, while most of the other policies examined set goals for conversion of a percentage of fleet VMT to new drivetrain technologies. Growing fleet penetration of alternative engine types will also be tracked directly through the proposed metrics. By targeting VMT shares of the fleet, the City can identify which vehicles will offer the greatest fuel savings over time to compensate for higher upfront costs.

3.4 Evaluation of Biking Infrastructure

Policy: Build end-of-trip biking infrastructure at all City buildings where they are not available. These facilities include showers, indoor and outdoor bike storage, personal lockers, and bike maintenance services.

Impact: End-of-trip biking infrastructure will decrease VMT from employees commuting via other modes by 700,000-2,300,000 miles, equating to carbon emissions reductions of 290 to 860 tons of carbon dioxide equivalent per year.

One way to reduce carbon emissions is to transition from inefficient transportation that requires use of fossil fuels to greener transportation alternatives, like bicycling. Madison has extensive roadway biking infrastructure (City of Madison 2015a), but there remains room for improvement in end-of-trip facilities. The majority of current programs and structures help employees get to work, but do not provide the necessary accommodations to transition from commuting to the work environment. Lack of showers and fear of bike theft can be particularly strong deterrents to commuting by bike. Installing showers, covered bicycle storage, lockers, and other amenities at agency facilities should promote bicycle use by City of Madison employees, accruing health benefits to individuals and city reductions in carbon emissions. Alternatively, if city facilities have a private fitness center nearby, they could partner with the private center to provide local area commuters with off-site permanent clothes storage, shower facilities, and secure bike parking, thereby reducing infrastructure investment by the city while still providing a similar impact (Seattle Department of Transportation 2011).

End-of-ride biking infrastructure at city buildings is highly scalable to the broader community. In "Guidelines for Metropolitan Planning Organizations & Communities in Planning Bicycle Facilities" the Wisconsin Department of Transportation stated that "one of the most important employer-provided improvements is the availability of showering facilities and workplace lockers" in addition to bicycle racks and other storage facilities (Wisconsin Department of Transportation 2003). According to a 2010 report by the Nelson Institute for Environmental Studies, if 20 percent of Madison commuters biked to work, 16,687 tons of carbon dioxide equivalent would be avoided, equivalent to potential savings of $366,577 based on the European Climate Exchange (Grabow, Hahn, and Whited 2010).

Abatement Potential

Several studies show that end-of-trip bike infrastructure can induce bike commuting (Akar and Clifton 2008; Buehler 2012; Pucher, Dill, and Handy 2010). Abatement potential is based on the employee commuter survey results and VMT reductions estimated from a low and high estimate of bike commuting uptake (Appendix D.2). Improved bicycle-commuter infrastructure could result in a greenhouse gas reduction ranging from 290 to 860 tons of carbon dioxide equivalent, or approximately 0.2 to 0.9 percent of all City of Madison greenhouse gas emissions.

Cost-effectiveness

We estimated Madison biking infrastructure costs based on one-time installation fees and building need, which was determined by a bicycle infrastructure survey delivered to City department heads (Appendix D.2). Based on these estimates for infrastructure cost and the estimates of abatement potential described above, cost-effectiveness varies from $110 to $330 per tons of carbon dioxide equivalent. Shower installation was by far the most expensive contributor to this calculation and the tons of carbon dioxide equivalent City usually does not do this type of remodeling independently and would combine it with a larger remodel. There are many other reasons to promote bicycling besides carbon abatement, including economic and health benefits (Grabow, Hahn, and Whited 2010). At a minimum, the City should consider pursuing this option if remodel opportunities arise and/or partnerships with private actors such as gyms are feasible.

Tracking Policy Impacts

This policy should increase share of employees commuting by bicycle and decrease the share commuting by personal vehicle as measured by annual services. According to employee commute survey results, approximately 11 percent of City of Madison employees bike commute an average of 2.9 days per week. We estimate that end-of-trip bike infrastructure could increase bike commuting to 20 to 38 percent of City of Madison employees.

3.5 Evaluation of an Aggressive Building Energy Standard

Policy: Update building energy standards from American Society for Heating Refrigeration and Air Conditioning Engineers (ASHRAE) 90.1-2007 to 20 percent more energy efficient than ASHRAE 90.1-2013.

Impact: Updated building energy standards would abate approximately 340,000 tons of carbon dioxide equivalent during a 35-year period. Updated building energy standards are highly cost-effective due to a continuous stream of cost savings from reduced energy use.

The City of Madison requires all new buildings and large renovations meet ASHRAE 90.1-2007 standards and “strive for the highest level of certification that project resources and conditions permit.” This requirement applies to all buildings primarily funded by the City, any building on City land, any new construction, renovation, or change in use of 5,000 gross square feet or more of a City-owned building that requires building, plumbing, electrical, and/or heating permits (City of Madison 2008). We propose that all new buildings and large renovations meet energy use standards 20 percent above ASHRAE 90.1-2013 standard.

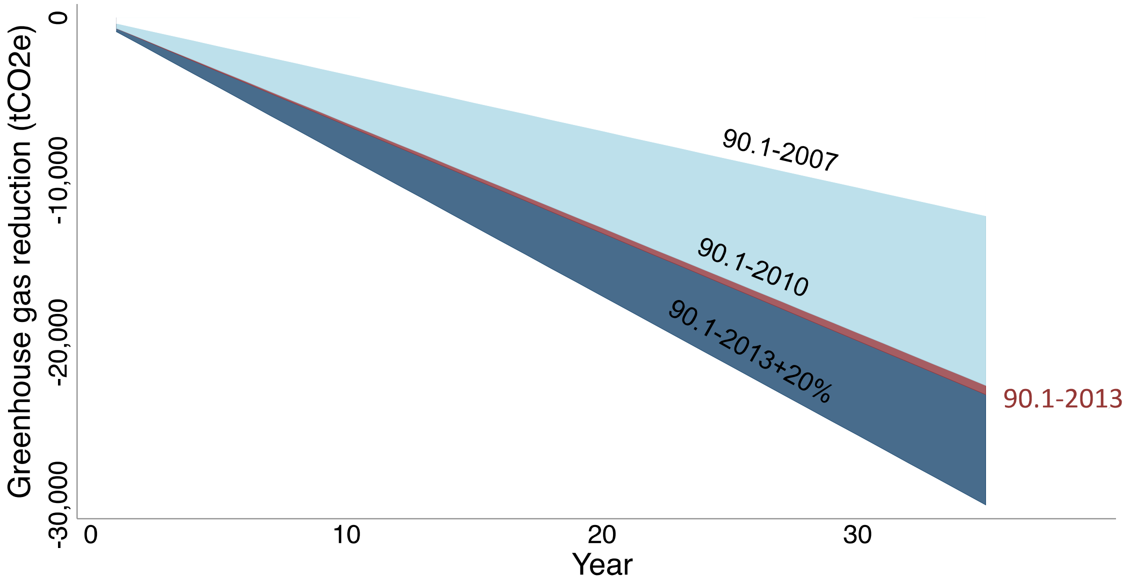
Abatement potential

Halverson et al. (2011) found 0.015 tons of carbon dioxide equivalent per square foot emitted in new construction with ASHRAE 90.1-2007 standards. With full implementation of 20 percent improvement over ASHRAE 90.1-2013 this study estimates 0.01 tons of carbon dioxide equivalent per square foot, representing a 33 percent decrease in emission intensity. We assume on average 3 percent City of Madison building stock will be replaced each year from 2016 to 2050 due to major renovations or reconstruction. By 2050, 100 percent of building stock would be upgraded and 88 percent of status quo building emissions would be abated. The city’s emissions from buildings would decrease from approximately 26,000 to 5,000 tCO_2e by 2050.

Figure 9 illustrates the lifetime carbon abatement associated with a building energy standard upgrade. Figure 9 compares carbon abatement projections under the current building energy standards (ASHRAE 90.1-2007) and three alternatives: ASHRAE 90.1-2010, ASHRAE 90.1-2013, and the proposed ASHRA 90.1-2013+20. The area between abatement under ASHRAE 90.1-2007 and ASHRAE 90.1-2013+20 corresponds to the estimated abatement potential of the building energy standard change of 340,000 tons of carbon dioxide equivalent.

Figure 9. Abatement potentials of building energy standards

Emissions decline over time under ASHRAE 90.1-2007 standards. The marginal abatement potential of each code corresponds to the area of each triangle below the ASHRAE 90.1-2007 standard.



Source: Authors' modeling

Cost-effectiveness

The estimated cost effectiveness of implementing a building energy standard change from ASHRAE 90.1-2007 to a 20 percent improvement from ASHRAE 90.1-2013 is -$260 per ton of carbon dioxide equivalent (Appendix D.3). The negative cost-effectiveness estimate indicates that implementation of stricter building energy standards results in a net savings through reduced energy use.

Tracking Policy Impacts

An upgrade in all buildings to the ASHRAE 90.1-2007 energy standards results in an estimated energy intensity of 71.5 kilowatt hours per square foot. An upgrade to ASHRAE 90.1-2013 plus an additional 20 percent efficiency results in an energy intensity of 43.4 kilowatt hours per square foot. The marginal abatement potential of this aggressive standard equals the difference between the ASHRAE 90.1-2007 building energy standard and the policy proposal of 20 percent above the 2013 standard. This represents a 39 percent gain in efficiency.

3.6 Summary

Table 7 summarizes the results of our analyses of the proposed policies with evaluative criteria. The results suggest that the building energy standard upgrade is a cost-effective policy with significant abatement potential.

Table 7. Summary of abatement potential and cost-effectiveness evaluative criteria for policies

Policy	**Abatement potential (tons of carbon dioxide equivalent per year)**	**Cost-effectiveness (dollars per ton of carbon dioxide equivalent)**
Green fleet	200-4,400	<0-850
End-of-trip bike infrastructure	290-860	110-330
Building energy standard upgrade	10,000	<0

Source: Authors' calculations as presented in the preceding sections

Conclusion

The City of Madison should improve the implementation of the Madison Sustainability Plan through the development and use of a tracking framework. An effective tracking framework will require an institutional willingness to improve data collection, compile tracking metrics, conduct policy analysis, and act on the insights gleaned from tracking metrics. We recommend two first steps in the implementation of a tracking framework: establish an institutional structure and implementation authority for the tracking framework.

Establish Institutional Structure

The City of Madison should develop a structure for consistent data collection and the compilation of tracking metrics. The structure should identify personnel responsible for specific data items and outline protocol to ensure data consistency.

The City of Madison should establish an internal institutional structure for data collection and compilation of tracking metrics. The current collaboration between the City of Madison and the University of Wisconsin–Madison does not ensure progress toward sustainability goals. This collaboration depends on a third party to become familiar with City of Madison data and greenhouse gas emissions estimation techniques. The third-party partnership cannot ensure data consistency across inventories, nor can it improve data format and structure over time. For example, the measurement inconsistency in the estimation of employee commute emissions effectively reduced City of Madison emissions by about 1.5 percent from 2012 to 2014. An internal structure would improve data consistency and inventory quality.

The City of Madison should charge personnel with the compilation of tracking metrics. The City should identify a responsible authority to maintain metrics over time and analyze trends in metrics. The personnel responsible for tracking metrics would periodically identify areas of emphasis based on metrics trends and work with the Sustainable Madison Committee and other policymakers to identify policy objectives.

Provide Implementation Authority

The City of Madison should commit to action on the policy objectives identified through the analysis of tracking metrics. The tracking framework should be a decision-forcing tool to inform effective sustainability policies. Attaching an implementation authority to the tracking framework would make the City of Madison and University of Wisconsin–Madison collaboration a meaningful decision support effort.

To date, there is no evidence that the City of Madison has attempted to implement policy recommendations included in past inventories. Our proposed tracking framework would simultaneously improve the implementation of the Madison Sustainability Plan and increase the value of the City of Madison and University of Wisconsin–Madison collaboration. The tracking framework would convert the collaboration from a simple bi-annual reporting mechanism to an actionable tool to evaluate sustainability progress and inform effective policymaking.

Appendix A. City of Madison Government Profile

This section provides relevant City of Madison size, budget, and climate information required under the ICLEI Local Government Operations Protocol. This context informs the interpretation of City of Madison greenhouse gas inventory results.

A.1 Size

The US Census Bureau estimates that 243,344 people lived in the City of Madison in 2013. The populations of the City of Madison grew an estimated 4.3 percent from 2010 to 2013. The City of Madison covers approximately 77 square miles. The City of Madison's local government operates with about 2,800 full time employees.

A.2 Annual Budget

Table A1 provides figures for City of Madison expenditures and revenue in 2014.

Table A1. 2014 City of Madison budget

Revenue		**Expenditures**	
Budget item	**Amount (in thousands of dollars)**	**Budget item**	**Amount (in thousands of dollars)**
Property taxes	198,442	Public safety and health	115,028
Local revenues	38,238	Department of Public Works	61,311
State aid payments	35,100	Debt service	37,027
Other	3,996	Administration	19,411
		Department of Planning and Development	18,808
		Library	14,513
		Miscellaneous	8,517
		General government	1,710
Total revenue	275,776	Total expenditures	276,326

Source: City of Madison 2015b

A.3 Climate Characteristics

Table A2 presents Dane County climate data, including figures on heating and cooling degree days.[9]

Table A2. 2014 climate data for Dane County

Average temperature (degrees Fahrenheit)	**Annual precipitation (inches)**	**Heating degree days**	**Cooling degree days**
44.7	35	7,884	620

Source: NOAA 2015

---

[9] Degree days express how much heating and cooling a building requires to reach a baseline indoor air temperature. In Madison, a heating degree day occurs when the outdoor air temperature drops below 65°F, while a cooling degree day occurs when the outdoor air temperature exceeds 65°F.

Appendix B. Activity Data Disclosure

The 2014 City of Madison greenhouse gas inventory follows the ICLEI Local Government Operations Protocol using ICLEI ClearPath greenhouse gas inventory software. Under the protocol, local governments use a calculations-based methodology that estimates emissions as the product of activity data and emission factors. Activity data refer to the energy use or other greenhouse gas-generating process associated with local government operations. Emissions factors assign a quantity of greenhouse gas per unit of local government operation activity. Total emissions are the product of activity data and emission factors:

$$activity\ data * \frac{emissions}{unit\ of\ activity} = total\ emissions$$

This appendix provides methodologies for all calculations used to generate the results of the 2014 City of Madison inventory. This appendix is organized by government activity sector.

B.1 Buildings and Facilities (Scope 2)

Scope 2 emissions from the purchase of electricity and steam and Scope 1 emissions from the combustion of natural gas for heating are estimated from energy use data at City of Madison buildings and facilities. We used data compiled by the City of Madison EnergyCAP web-based tool, separately provided energy use information for the City-County Building, of which it owns 40.6 percent, and steam use bills for the City-County Building and Monona Terrace. Table B1 provides summary statistics for building energy use by fuel type. Table B1 includes figures for facilities that represent the smallest 10 percent of energy users (10th percentile) and the largest 10 percent of energy users (90th percentile), which show that there is considerable spread in building electricity use.

Table B1. Summary statistics for City of Madison building energy use

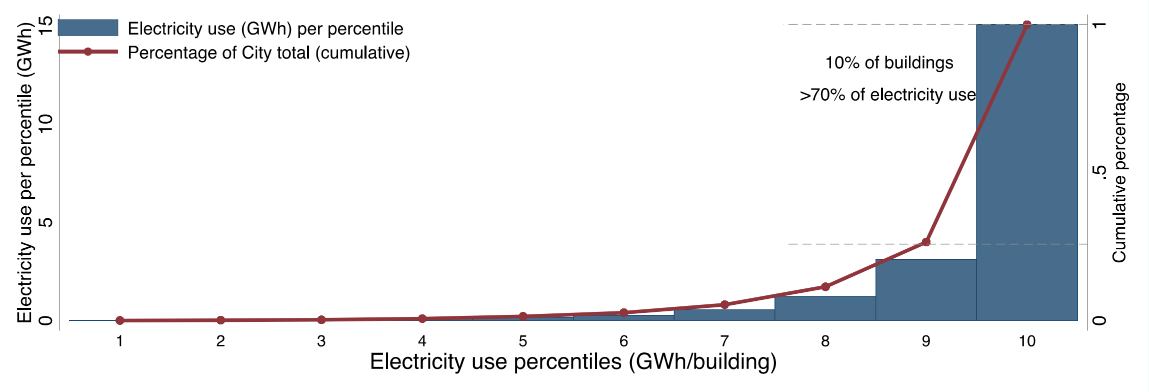
MWh = megawatt hours; mmBTU = million British Thermal Units

Fuel type	**Facilities**	**Average**	**10th percentile**	**90th percentile**	**Total**
Electricity (MWh)	243	95	0.4	198	22,978
Natural gas (1,000 therms)	89	12	0.4	21	1,093
Steam (1,000 mmBTU)	2	8.4	-	-	17

Source: Author's calculations from City of Madison EnergyCap facility management software

Figure B1 illustrates that the largest facilities use a disproportionate amount of electricity: 10 percent of the largest electricity users consume about 73 percent of electricity.

Figure B1. Building electricity use (cumulative and by decile)



Source: Author's calculations using EnergyCap data

Estimated emissions from steam purchases are based on reported data from the City-County Building (7,910 MMBtu) and Monona Terrace (8,892 MMBtu). Energy use for Monona Terrace steam is based on an enthalpy of steam delivered of 1,042 pounds per British thermal unit (Btu), based on enthalpy of steam delivered to the City-County Building. We assume a boiler efficiency of 80 percent and steam transport losses of 15 percent based on input from Keith Beck, Bureau Director of Building Management in the Wisconsin Department of Administration.

B.2 Streetlights and Traffic Signals (Scope 2)

Scope 2 emissions from acquired energy to power City of Madison streetlights and traffic signals are based on actual energy use data from the City of Madison EnergyCAP web-based tool. Total reported electricity use for 282 facilities classified as "Traffic-Engineering" in the EnergyCAP tool was 6,637 megawatt hours. One facility also reported 556 therms of natural gas use.

B.3 Vehicle Fleet (Scope 1)

Scope 1 emissions from fuel combustion are based on known fuel use and VMT. Bill Vandenbrook, head of City of Madison fleet services, provided vehicle fleet data. The data included two types of vehicle use measurements: odometer (mileage) for 651 vehicles and hour meter (hours) for 349 vehicles. Table B2 provides summary statistics of the City of Madison vehicle fleet for 2014.

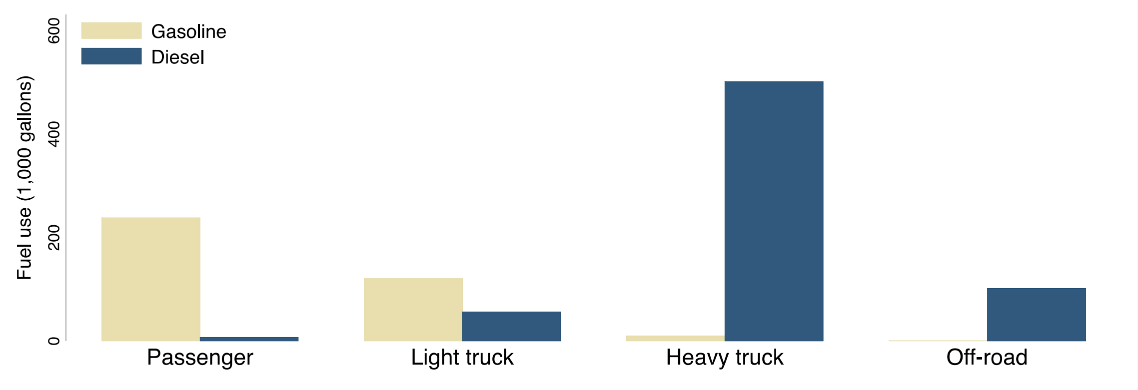
Table B2. Summary of reported vehicle data by fuel type

Fuel and reporting type	Gasoline	Diesel	Total
# of vehicles	526	474	1,000
Vehicle miles travelled (x1,000)[a]	4,223	3,648	7,871
Fuel use (1,000 gallons)	370	666	1,036

[a] *Includes estimated VMT for vehicles reporting hourly meter based on fuel efficiencies reported Table C4 of Appendix C.*

Figure B2 displays fuel usage for City of Madison vehicles organized by vehicle type and shows that diesel fuel consumption by heavy-duty trucks in the City of Madison fleet comprises a significant portion of total fleet fuel consumption.

Figure B2. Fuel use by fuel type and vehicle type, 2014 City of Madison vehicle fleet



Source: Data provided by City of Madison Fleet Management

Recommendations for Vehicle Fleet Data Collection

City of Madison fleet services should record and report all vehicle fleet data according to an odometer measure of mileage. Due to the 349 vehicles reporting usage by hourly meter we must rely on an estimate for vehicle miles traveled for the entire City of Madison fleet. This estimation reduces the accuracy of estimates for transportation-related methane and nitrous oxide emissions that depend on distance travelled rather than fuel use. City of Madison fleet services should require a single odometer measurement of all City vehicles at the first and last use of each calendar year.

City of Madison fleet services should endeavor to classify City vehicles according to: passenger vehicle, light-duty truck, heavy-duty truck, and off-road. City of Madison fleet services should report the classification as an additional variable during annual data reporting. Vehicle classification improves the accuracy of transportation-related emissions estimates.

B.4 Transit Fleet (Scope 1)

Scope 1 emissions from fuel combustion in the City of Madison transit fleet are based on known fuel use and VMT. Table summarizes the activity data by transit vehicle type:

Table B3. Transit fleet fuel use and vehicle miles travelled

Type	Fuel type	# of vehicles	Fuel use (gallons)	VMT
Bus	Diesel	199	1,104,219	5,076,373
Hybrid bus	Diesel	21	158,757	854,335
Para-transit	Diesel	17	35,540	370,491
Support	Gasoline	23	6,933	126,658
Support	Diesel	8	3,070	30,446
Total		268	6,311,202	1,455,620

Source: Data provided by Metro Transit management

B.5 Wastewater Facilities (Scope 2)

Scope 2 emissions from acquired energy to power City of Madison water utility facilities are based on actual energy use data from the City of Madison EnergyCAP web-based tool. Total reported electricity use for water utility facilities was 18,971 megawatt hours. Total reported natural gas use was 81,827 therms.

B.6 Fugitive Emissions (Scope 1)

The City of Madison owns and operates five landfills. Estimates of fugitive methane emissions from City of Madison landfills are based on a California Air Resources Board model. The model estimates fugitive methane emissions over time as a function of decay rate, composition, and amount of waste. For 2014, the model estimates fugitive methane emissions of (in tons of carbon dioxide equivalent):

- Demetral landfill: 1,054
- Greentree landfill: 4,307
- Mineral Point landfill: 1,271
- Olin landfill: 2,070
- Sycamore landfill: 4,738

The City of Madison also reports fugitive emissions of refrigerants. We used ICLEI protocol to estimate fugitive refrigerant emissions based on the net change in the City of Madison's refrigerant inventory. In 2014, the City of Madison made three refrigerant purchases and one retirement. Table B4 summarizes the net change in the City of Madison refrigerant inventory (only R410a is a greenhouse gas regulated under the Kyoto Protocol).

Table B4. Changes to City of Madison refrigerant inventory, 2014

HCFC = Hydroclorofluorocarbons; HFC = Hydrofluorocarbons

Refrigerant	Purchases (pounds)	Retirements (pounds)	Net change (pounds)
R-11 (HCFC)	100		100
R-22 (HCFC)	60	46	14
R410a (HFC)	1		1

Source: Data provided by City of Madison Engineering

B.7 Employee Commute (Scope 3)

Estimates of scope 3 emissions from City of Madison employee commuting are based on survey results obtained from 1,081 City of Madison employees. We extrapolated values for all employees based on 2,827 City of Madison full-time employees budgeted in 2014. We assumed that employees commuted 50 weeks out of the year. TableB5 summarizes the survey questions and results.

Table B5. Employee commute survey questions and results

Question	Average response	Sum of all responses
How many miles do you drive to work? (One way. Do not include portions which you take other forms of transportation)	10.9 miles	11,799 miles
How many days per week do you drive to work? Do not include days you ride as a passenger.	3.6 days	3,925 days
How many days per week do you walk, bike, carpool, or take public transit to work?	Walk: 0.32 Bike: 0.45 Carpool: 0.37 Transit: 1.06	Walk: 235 Bike: 345 Carpool: 275 Transit: 904
Please either enter the fuel economy (in miles per gallon) OR the make and model of your vehicle.	Free response	Free response

Recommendations for Employee Commute Data Collection

Simplicity was our primary goal in our survey to maximize the employee response rate. While this simple four-question structure increased the quantity of responses from 649 in the 2012 inventory to 1083 responses in this year's inventory, we received several comments from City of Madison employees on the survey structure. The main content of the comments were:

1. The survey does not allow flexibility for commuters who take multiple modes of transportation in any given day
2. The survey is not flexible enough for employees with seasonal commuting patterns, e.g., employees who bike in summer but take public transit in winter

Future inventories can address these comments in two ways: change the language of the simple four-question survey to clarify that all values are annual averages, or add questions to capture daily and seasonal variability. We addressed comment #1 early in the survey implementation language by adding the caveat "do not include portions which you take other forms of transportation" to question #1. Future inventories could provide a single caveat to address seasonal variations that reads:

Please provide estimates based on an estimate of the annual average of your commuting habits, e.g., if you drive 20 miles to work half of the year, but take a bus the other half of the year, your average daily driving commute is 10 miles.

Alternatively, future inventories could make questions 2 and 3 more flexible to seasonal and daily variation. Below is a suggested edited format of the survey:

Recommended survey for future inventories:

1. How many miles do you drive to work? (One way. Do not include portions for which you take other forms of transportation)
2. How many days per week do you drive to work? Do not include days you ride as a passenger.

  - In the spring:
  - In the summer:
  - In the fall:
  - In the winter:
3. How many days per week do you walk, bike, carpool, or take public transit to work?
  - In the spring:
  - In the summer:
  - In the fall:
  - In the winter:
4. Please enter the fuel economy (in miles per gallon) OR the make and model of your vehicle.

We recommended that future teams use Qualtrics.com to create the commuter survey, which every University of Wisconsin–Madison student can access at https://survey.wisc.edu/.

Appendix C. Methodology and Emissions Factors

This appendix summarizes the conversion factors and assumptions used in the 2014 City of Madison greenhouse gas inventory.

C.1 Recognized Greenhouse Gas Emissions

The ICLEI protocol recommends the assessment of six greenhouse gases regulated under the Kyoto Protocol: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. The protocol requires that local governments report emissions of each greenhouse separately in terms of carbon dioxide equivalent based on 100-year global warming potentials. Table C18 displays carbon dioxide equivalencies for the Protocol's six greenhouse gases. Ranges for hydrofluorocarbons and perfluorocarbons are based on the minimum and maximum carbon dioxide equivalency of chemicals within those families.

Table C18. Carbon dioxide equivalency of greenhouse gases based on 100-year global warming potentials

Greenhouse gas	Carbon dioxide equivalency
Carbon dioxide	1
Methane	21
Nitrous oxide	310
Hydrofluorocarbons	12-11,700
Perfluorocarbons	6,500-9,200
Sulfur hexafluoride	23,900

Source: ICLEI Local Government Operations Protocol

C.2 Electricity Emissions Factors

Emission factors for electricity use are based regional figures for the eastern portion of the Midwest Reliability Organization (MRO East) from the U.S. Environmental Protection Agency eGRID, 9th edition. TableC2 provides the greenhouse gas factors for City of Madison electricity use.

Table C2. Electricity emissions factors

Greenhouse gas	Factor (pounds per megawatt)
Carbon dioxide	1610.8
Methane	0.002429
Nitrous oxide	0.002752

Source: U.S. Environmental Protection Agency eGRID, 9th edition, regional figure for MRO East

C.3 Transportation Emissions Factors

Transportation greenhouse gas and fuel economy factors are drawn from a combination of statistics from the City of Madison provided data, the Environmental Protection Agency, and the U.S. Bureau of Transportation Statistics. All figures are based on the average model year of the vehicle types in the City of Madison fleet: passenger vehicles (2008), light-duty trucks (2007), heavy-duty trucks (2007), transit buses (2006), and paratransit buses (2012). Table C3 provides carbon dioxide emissions factors by fuel. Table C4 provides fuel economy factors by fuel and vehicle type used in the ClearPath software factor set. Table C5 provides methane and nitrous oxide emissions factors by fuel and vehicle type.

Table C3. Carbon dioxide equivalent emission factors for transportation fuels

Fuel	Emission factor (kilograms of carbon dioxide equivalent per gallon)
Gasoline	8.78
Diesel	10.21
Biodiesel (B100)	9.45

Source: EPA 2014

Table C49. Fuel economy for ClearPath factor set

Vehicle type	Fuel economy (miles per gallon)	Source
Passenger vehicle	31.5	Bureau of Transportation Statistics
Light truck	23.1	Bureau of Transportation Statistics
Gas heavy truck	5.36	Default fuel efficiency from Table TR.2.1., ICLEI Community Protocol Version 1.0
Diesel heavy-duty truck	6.06	Default fuel efficiency from Table TR.2.1., ICLEI Community Protocol Version 1.0
Diesel transit bus	4.69	Calculated from data provided by Metro Transit
Diesel para-transit bus	10.35	Calculated from data provided by Metro Transit

Table C510. Methane and nitrous oxide emission factors (grams per mile)

Vehicle type	Methane factor	Nitrous oxide factor
Gas passenger vehicle	0.0172	0.0038
Gas light truck	0.0161	0.0079
Gas heavy truck	0.033	0.0153
Diesel passenger vehicle	0.0005	0.001
Diesel light truck, diesel paratransit	0.001	0.0015
Diesel heavy truck, diesel transit bus	0.0051	0.0048

Source: Environmental Protection Agency 2014

C.4 Employee Waste Characterization

Table C6 displays ICLEI provided assumptions of employee waste composition used to estimate Scope 3 employee waste emissions. Note that percentages do not sum to 100 because only waste that contributes to greenhouse gas emissions is included.

Table C6. Employee waste composition assumptions

Waste type	Percentage of waste
Newspaper	1.5
Office paper	0.7
Corrugated cardboard	1.4
Magazines/third-class mail	1.0
Food scraps	10.6
Grass	3.6
Branches	0.4
Dimensional lumber	2.2

Source: ICLEI assumptions

Appendix D. Calculations for Abatement Potential and Cost-Effectiveness

In the following sections, we provide methodology and calculations we used to evaluate policies in Section 3 of this report.

D.1 Green Fleet

Abatement potential for various components of the green fleet assessment are calculated based on the emission coefficients in Appendix C as well as additional information from the U.S. Environmental Protection Agency on biofuel and natural gas emissions. Abatement potentials closely follow the inventory results presented in Section 1 but are scaled back due to application to only part of each applicable fleet segment. We derive fuel use and mileage numbers from high level reports received from Metro Transit and Fleet Management. These reports did not make detailed analysis based on vehicle use possible. The general format of abatement calculations follows and it adapted to different fuel technology and data availability:

$$Abatement\ Potential = (PetroFuelUse * CarbonIntensity) - (VMT * AltEngineEfficiency * CarbonIntensity)$$

Detailed calculations are available upon request. Abatement potential is calculated for a single year at the specified level of penetration.

To calculate cost-effectiveness, we estimated lifetime abatement quantities for a representative vehicle within each example fleet policy. We assumed lifetimes of 10 years for vehicles covered by compressed natural gas conversion, 12 years for light duty vehicles converted to electric and 15 years for transit buses. Total costs for each assessed policy included fueling infrastructure, rolling stock, and fuel costs. We assumed maintenance cost differences were negligible based on several studies that assumed a wide range of cost differences. The general cost calculation formula follows:

$$Total\ Cost = FixedFuelingInfrastructure + \#OfAffectedVehicles * VehiclePriceDifferential + NPV(FutureFuelCostDifference)$$

Each policy required slightly different calculations to utilize the information available regarding heterogeneous fleets. As such, detailed calculations are not provided here. We will provide them at request and further explain their calculation.

Ranges are the result of sensitivity analysis on some of the most uncertain variables. The range for compressed natural gas cost-effectiveness results from calculating benefits with a price difference between petroleum and compressed natural gas ranging from $1.00 per gallon of gasoline equivalent to $1.50 per gallon of gasoline equivalent.

Electric vehicles prices have a wide range due to uncertainty about future fuel prices as well as rapidly changing battery prices, which drive the price differential between electric and traditional internal combustion engine vehicles. Gasoline prices were modeled at $2.50 and $3.50, while the price differential range from $10,000 to $20,000.

D.2 End-of-Trip Bicycle Infrastructure

Abatement depends on the number of miles of petroleum-based commuting that can be shifted to zero-emission bicycle trips. An international review by Pucher, Dill, and Handy (2010) found that outdoor bike parking, indoor bike parking, and showers would increase bike commuting uptake by 9 to 22 percent. Because of Madison's bike friendly-environment, we estimate uptake would range from 10 to 30 percent.

Based on our employee commuter survey results, approximately 12 percent of City of Madison employees bicycle commute an average of 2.9 days per week. Of the 88 percent of City of Madison non-bicycle commuters, we estimate a range of 10 to 30 percent take-up, or a range of 8.8 to 26.4 percent of all City of Madison employees. The greenhouse gas abatement potential is a function of the VMT reduction associated with mode switching in the two scenarios:

Low take-up:

$$0.088 * 2{,}800\ employees * \frac{2.9\ days}{week} * \frac{50\ weeks}{year} * \frac{21.8\ miles}{day} = 708{,}064\ VMT\ shifted\ to\ bike$$

High take-up:

$$0.264 * 2{,}800\ employees * \frac{2.9\ days}{week} * \frac{50\ weeks}{year} * \frac{21.8\ miles}{day} = 2{,}336{,}611\ VMT\ shifted$$

We use an average commute distance of 21.8 miles based on the employee commute survey. We used the ClearPath inventory tool to convert the VMT shift to tons of carbon dioxide equivalent abated.

To identify infrastructure needs, an online survey was sent to City building managers asking:

1) What is the name and/or address of the city building where you work?
2) Approximately how many employees work in this building?
3) Approximately how many car parking spaces are designated for employees at this building?
4) Please select all types of end-of-trip biking facilities currently available at this building:
    a. Outdoor bike parking racks
    b. Indoor bike parking
    c. Bike lockers
    d. Showers
    e. Bike repair/maintenance toolkit
    f. Other
5) Please provide any other comments you'd like to share regarding end-of-trip biking infrastructure for this building.

We received 51 responses, which are summarized in Table D111D1.

Table D111. Survey results: Number of buildings requiring infrastructure

End-of-trip infrastructure	Buildings needing facilities
Shower	27
Bike locker	48
Indoor bike storage	34
Outdoor bike parking racks	8
Bike repair station	48

Source: Survey responses collected by authors

We establish a baseline need for infrastructure based on the survey responses and estimate the cost to provide it at buildings where it was unavailable. We present the potential costs of different infrastructure components in Table D212D2.

Charging monthly or annual fees to rent lockers and use showers can go toward mitigating these costs. The city may be able to partner with nearby private gyms and facilities to secure benefits from end-of-trip infrastructure without paying all upfront costs.

The total cost of all of these infrastructure improvements is expected to be $3,223,550 to $3,391,850, with the greatest cost arising due to limited shower facilities in current City buildings. In Table D313D3, we calculate cost-effectiveness based on minimum and maximum costs and abatement potentials. These results are discussed in Section 3.4 Evaluation of Biking Infrastructure.

Table D212. Estimates of costs of and need for end-of-trip biking infrastructure

End-of-trip infrastructure	Installation cost per unit	Recommended number of units needed	Baseline	Estimated Cost
Shower	$100,000	one per 50 employees	1,576 employees	$3,100,000
Bike locker	$700-$2,000 for two	one per 10 automobile spaces	1,158 automobile spaces	$81,200-$232,000
Indoor bike storage	$50-$150 per space	one per 10 automobile spaces	735 automobile spaces	$3,700-$11,100
Outdoor bike parking racks	$50-$150 per space	one per 20 automobile spaces	89 automobile spaces	$250-$750
Bike repair station	$800-$1000	one per building	48 buildings	$38,400-$48,000

Source: Cost estimates from Jeanne Hoffman, facilities and sustainability manager, City of Madison; number of showers based on Bike to Work Day recommendation (Commuter Connections 2015); number of bike lockers, indoor bike storage, and outdoor parking racks (assuming two bikes per rack) from the U.S. Federal Highway Administration's (2006) recommendation of one bike space per 10 automobile spaces in museums, libraries, and places of assembly. Hoffman said operations and maintenance add a negligible cost to regular building maintenance; therefore, cost-effectiveness is calculated as total costs divided by abatement per year times 35 years.

Table D313. Cost-effectiveness for all recommended bike infrastructure

	Abatement	
Infrastructure cost	**High (860 tons of carbon dioxide equivalent)**	**Low (290 tons of carbon dioxide equivalent)**
High ($3,391,850)	$113 per ton	$334 per ton
Low ($3,223,550)	$107 per ton	$318 per ton

Source: Authors' calculations

D.3 Building Energy Standard Upgrade

The abatement potential of upgrading from ASHRAE 90.1-2007 to 20 percent more efficient than ASHRAE 90.1-2013 depends on the proportion of buildings occupied by employees, the percent of building stock upgraded per year, and the emissions factors for electricity, natural gas, and steam applied as a percentage for each energy standard's emissions intensity. The abatement potential for City of Madison buildings can be estimated by sum of the difference in emissions intensity (ton of carbon dioxide equivalent per square foot (ft^2) under ASHRAE 90.1-2007 and ASHRAE 90.1-2013+20 percent annually for 35 years.

Greenhouse gas abatement from ASHRAE 90.1-2007 and ASHRAE 90.1-2013+20 percent is associated with the change in energy use between the two energy standards ($\Delta kBTU/ft^2$).

$$\frac{\Delta kBTU}{ft^2} = \frac{kBTU_{90.1\ 2007}}{ft^2} - \frac{kBTU_{90.1\ 2013+20}}{ft^2}$$

$$\frac{\Delta kBTU}{ft^2} = \frac{71.5\ kBTU}{ft^2} - \frac{43.38\ kBTU}{ft^2} = \frac{28.12\ kBTU}{ft^2}$$

Change in emissions intensity ($\Delta tCO_2e/ft^2$) is then given by the product of the change in energy intensity and the appropriate emissions factor ($tCO_2e/kBTU$):

$$\frac{\Delta tCO_2e}{ft2} = \frac{\Delta kBTU}{ft^2} * \frac{tCO_2e}{kBTU}$$

We calculate change in emissions intensity separately for each fuel type based on the energy mix of City of Madison buildings. Based on City of Madison building energy use data, we estimate that approximately 55 percent of building energy use is electricity, 39 percent is natural gas, and 6 percent is steam. Change in energy intensity by fuel type is then:

$$\frac{\Delta kBTU}{ft^2}(electricity) = 0.55 * \frac{28.12\ kBTU}{ft^2} = \frac{15.47\ kBTU}{ft^2}$$
$$\frac{\Delta kBTU}{ft^2}(natural\ gas) = 0.39 * \frac{28.12\ kBTU}{ft^2} = \frac{10.97\ kBTU}{ft^2}$$
$$\frac{\Delta kBTU}{ft^2}(steam) = 0.06 * \frac{28.12\ kBTU}{ft^2} = \frac{1.69\ kBTU}{ft^2}$$

Change in emissions intensity by fuel type is then:

$$\frac{\Delta tCO_2e}{ft2}(electricity) = \frac{15.47\ kBTU}{ft^2} * \frac{0.293\ kWh}{kBtu} * \frac{8.1 * 10^{-4} tCO_2e}{\text{kWh}} = \frac{0.004\ tCO_2e}{ft^2}$$
$$\frac{\Delta tCO_2e}{ft2}(natural\ gas) = \frac{10.97\ kBTU}{ft^2} * \frac{0.1\ therm}{kBtu} * \frac{0.006\ tCO_2e}{therm} = \frac{0.006\ tCO_2e}{ft^2}$$
$$\frac{\Delta tCO_2e}{ft2}(steam) = \frac{1.69\ kBTU}{ft^2} * \frac{0.1\ therm}{kBtu} * \frac{0.006\ tCO_2e}{therm} * \frac{1}{0.85} = \frac{0.002\ tCO_2e}{ft^2}$$

The final term for steam is an adjustment for 15 percent transmission and distribution losses. Therefore total change in emissions intensity is:

$$\frac{\Delta tCO_2e}{ft^2} = \frac{0.004\ tCO_2e + 0.007\ tCO_2e + 0.002\ tCO_2e}{ft^2} = \frac{0.011\ tCO_2e}{ft^2}$$

Inputs do not sum perfectly due to rounding. The total annual change in emissions is the product of the change in emissions intensity and the area of buildings subject to the building energy standard change per year. Approximately 55 percent of City of Madison buildings will be subject to the building energy standard change over the next 35 years, or approximately 1,755,204 square feet. We assume that this entire building stock will be subject to energy standard changes over 35 years at a rate of 2.9 percent per year, or approximately 0.029*1,755,204=50,149 ft^2/year. Change in annual emissions is then given:

$$\frac{\Delta tCO_2e}{year} = \frac{tCO_2e}{ft^2} * \frac{ft^2}{year}$$

$$\frac{\Delta tCO_2e}{year} = \frac{0.011\ tCO_2e}{ft^2} * \frac{50{,}149\ ft^2}{year} = \frac{560\ tCO_2e}{year}$$

Inputs do not multiply perfectly due to rounding. The total abatement due to the building energy standard change is the cumulative reduction in emissions over 35 years. Assuming building energy standard changes occur continuously, we can estimate the total abatement of the building energy standard upgrade through the integration of the annual emissions over 35 years:

$$\Delta tCO_2e = \int_0^{35} 560t dt = 280t^2|_0^{35} = 340{,}000\ tCO_2e$$

The cost-effectiveness of the carbon abatement depends on the annualized cost per square foot and the change in emissions calculated above (0.01 tCO2e/ft2). Annualized cost is a measure to sum the value of up-front capital costs and all annual cost savings associated with reduced energy use:

$$annualized\ cost = \frac{\$}{ft^2} = \frac{capital\ cost - \sum annual\ energy\ savings}{ft^2}$$

We use an estimated annualized cost of -\$2.91/ft^2 from literature (Halverson 2011, 2013, 2014), i.e., the updated building code results in a net savings due to the summation of annual energy savings. Cost-effectiveness is the product of the annualized cost and the change in emissions intensity:

$$\frac{\$}{\mathrm{tCO_2}e} = \frac{\$}{ft^2} * \frac{ft^2}{tCO_2e}$$

$$\frac{\$}{\mathrm{tCO_2}e} = \frac{-\$2.91}{ft^2} * \frac{ft^2}{0.011\ tCO_2e} = \frac{-\$260}{tCO_2e}$$

The negative cost-effectiveness suggests that a net savings is possible through carbon abatement with building code changes. The value of the cost-effectiveness figure does not have a direct interpretation, however we can estimate the total potential cost savings of the policy as the product of the annualized cost and the area of the building stock subject to the code change:

$$potential\ annual\ cost\ savings = \frac{-\$2.91}{ft^2} * 1{,}755{,}204\ ft^2 = \$5{,}108{,}000$$

References

Akar, Gulsah, and Kelly J. Clifton. 2009. "Influence of Individual Perceptions and Bicycle Infrastructure on Decision to Bike." *Transportation Research Record* (2140):165-172. doi: 10.3141/2140-18.

Anderson, Adam, Tyler Brandt, Iseul Choi, Bridget Holcomb, Kendi Larrabee, and Leona Ti-Fan Su. 2014. *Madison Community Operations Carbon Inventory 2012.* Madison, WI: University of Wisconsin - Madison.

Bray-Hoagland, Kolby, Molly Casperson, Keith Cronin, and Dylan Mathieu. 2011. *City of Madison Greenhouse Gas Emissions Inventory: 2010 Baseline.* Madison, WI: Nelson Institute for Environmental Studies.

Buehler, Ralph. 2012. "Determinants of Bicycle Commuting in the Washington, DC Region: The Role of Bicycle Parking, Cyclist Showers, and Free Car Parking at Work." *Transportation Research Part D-Transport and Environment* 17 (7):525-531. doi: 10.1016/j.trd.2012.06.003.

Chandler, Chelsea, Peter Erickson, Michael Lazarus, Ramon Bueno, Jeffrey Cegan, Charles Munitz, Elizabeth A. Stanton, and Mi Daudon. 2012. *Greenhouse Gas Emissions In King County: An Updated Geographic-plus Inventory, a Consumption-based Inventory, and an Ongoing Tracking Framework.* King County, Washington: Stockholm Environment Institute.

Chung, Bui (Daisy), Jesse Durst, Nishant Mehta, and Jason Myatt. 2013. *Inventory of City of Madison Local Government Operations Greenhouse Gas Emissions: Inventory Year 2012.* Madison, WI: Nelson Institute of Environmental Studies.

City of Denver. 2010. *Greening Denver's Fleet.* Public Works Fleet Division. Denver, CO.

City of Madison. 2008. *Requiring Green Building Certification for New City Buildings.* Madison, WI: City of Madison Common Council.

City of Madison. 2009. *Policy for the Acquisition of Energy Efficient and Safe Vehicles.* Madison, WI: Office of the Mayor.

City of Madison. 2015a. “Bike Infrastructure: Completed.” http://www.cityofmadison.com/bikeMadison/planning/completed/.

City of Madison. 2015b. “City of Madison Budget Conversations.” http://www.cityofmadison.com/budget/2014/.

Dart, Liese, Andrew Kell, Mitch Myhre, and Corey Singletary. 2010. *City of Madison Greenhouse Gas Emissions Report: 2007 Baseline.* Madison, WI: Nelson Institute for Environmental Studies and La Follette School of Public Affairs.

Ellingson, Maria, and Leslie Hunter. 2010. *Compendium of Best Practices: Sharing Local and State Successes in Energy Efficiency and Renewable Energy from the United States.* Washington, DC: Renewable Energy and Energy Efficiency Partnership, Alliance to Save Energy, and American Council on Renewable Energy.

Erickson, Peter, Michael Lazarus, Chelsea Chandler, and Seth Schultz. 2013. "Technologies, Policies and Measures for GHG Abatement at the Urban Scale." *Greenhouse Gas Measurement and Management* 3 (1-02):37-54. doi: 10.1080/20430779.2013.806866.

Federal Highway Administration. 2006. *Federal Highway Administration University Course on Bicycle and Pedestrian Transportation.* Washington, DC: U.S. Department of Transportation.

Fiksel, Joseph, Tarsha Eason, and Herbert Frederickson. 2012. *A Framework for Sustainability Indicators at EPA.* Washington, DC: U.S. Environmental Protection Agency.

Grabow, Maggie, Micah Hahn, and Melissa Whited. 2010. *Valuing Bicycling's Economic and Health Impacts in Wisconsin*. Madison, WI: Nelson Institute for Environmental Studies.

Halverson, Mark, Michael Rosenberg, Weimin Wang, Jason Zhang, Vrushali Mendon, Rahul Athalye, Yimin Xie, Reid Hart, and Supriya Goel. 2011. *ANSI/ASHRAE/IES Standard 90.1-2010 Final Determination Quantitative Analysis*. Richland, WA: Pacific Northwest National Laboratory.

Harger, Robin and F. M. Meyer. 1996. "Definition of Indicators for Environmentally Sustainable Development." *Chemosphere* 33 (9):1749-1775. doi: 10.1016/0045-6535(96)00194-4.

Ness, B., E. Urbel-Piirsalu, S. Anderberg, and L. Olsson. 2007. Categorising Tools for Sustainability Assessment. *Ecological Economics* 60 (3):498-508. doi: 10.1016/j.ecolecon.2006.07.023.

National Oceanic and Atmospheric Administration (NOAA). 2015. "Quality Controlled Local Climatological Data (QCLCD)." http://www.ncdc.noaa.gov.ezproxy.library.wisc.edu/data-access/land-based-station-data/land-based-datasets/quality-controlled-local-climatological-data-qclcd.

Nykvist, Bjorn, and Mans Nilsson. 2015. "Rapidly Falling Costs of Battery Packs for Electric Vehicles." *Nature Climate Change* 5 (4):329-332. doi: 10.1038/nclimate2564

O'Neill, Katie, and PJ Rudden. 2014. *Good Practice Report of the European Green Capital Award*. Brussels, Belgium: European Commission.

Pratt, Andrea. 2014. *A Clean and Green Fleet: An Updated Action Plan for the City of Seattle.* Seattle, WA: Fleet Management Division Department of Finance & Administrative Services.

Pucher, John, Jennifer Dill, and Susan Handy. 2010. "Infrastructure, Programs, and Policies to Increase Bicycling: An International Review." *Preventive Medicine* 50:S106-S125. doi: 10.1016/j.ypmed.2009.07.028.

Seattle Department of Transportation. 2011. N.D. *Seattle Transit Master Plan Briefing Book*: *7 BEST PRACTICES Bicycle Access to Transit*. Seattle, WA: Seattle Department of Transportation.

Singh, R. K., H. R. Murty, S. K. Gupta, and A. K. Dikshit. 2012. "An Overview of Sustainability Assessment Methodologies." *Ecological Indicators* 15 (1):281-299. doi: 10.1016/j.ecolind.2011.01.007.

Smith, Margaret, and John Gonzales. 2014. *Costs Associated with Compressed Natural Gas Vehicle Fueling Infrastructure.* Washington, DC: U.S. Department of Energy.

Sustainable Design and Energy Committee (SEDC). 2011. *The Madison Sustainability Plan: Fostering Environmental, Economic and Social Resistance.* Madison, WI: City of Madison.

Urge-Vorsatz, Diana, Ksenia Petrichenko, Miklos Antal, Maja Staniec, Michael Labelle, Eren Ozden, and Elena Labzina. 2012. *Best Practice Policies for Low Carbon and Energy Buildings: A Scenario Analysis.* Research report prepared by the Center for Climate Change and Sustainable Policy (3CSEP) for the Global Buildings Performance Network.

Wisconsin Department of Transportation. 2003. *Wisconsin Bicycle Planning Guidance*. Madison, WI: Wisconsin Department of Transportation.