Quantifying and Reducing Greenhouse Gas Emissions from Local Government Cement and Asphalt Purchasing

Jacob M Tracy

A thesis
submitted in partial fulfillment of the
requirements for the degree of:

Master of Urban Planning

University of Washington
2015

Committee:
Jan Whittington
Steve Muench

Program Authorized to Offer Degree:
Urban Design and Planning

University of Washington

Abstract

Quantifying and Reducing Greenhouse Gas Emissions from Local Government Cement and Asphalt Purchasing

Jacob M Tracy

Chair of the Supervisory Committee:

Dr. Jan Whittington

Department of Urban Design and Planning

As the effects of anthropogenic climate change come to bear, increasing numbers of local governments are engaging in climate action planning to quantify and reduce their greenhouse gas emissions. Only recently, however, have local governments begun to become aware of the impact of emissions from the materials that they purchase. Some agencies that have completed an inventory of purchasing emissions have found that they constitute more than half of total emissions, with emissions from construction purchasing at the making up the largest portion of these.

Despite the large impact that emissions from construction purchasing can have on a local government's emissions profile, there is a lack of coordinated action mitigate these emissions in most cities and counties. In many cases, these emissions have not even been quantified in a greenhouse gas inventory, or, if they have, have only been quantified in a very rough manner. To assist in the process of reducing these emissions, this thesis scans the available academic and practical literature of planning and engineering and uses these to develop tools and strategies that can be utilized by any local government to quantify and reduce greenhouse gas emissions from purchased cement and asphalt, two of the biggest contributors to construction-related greenhouse gases (GHGs). The deliverables developed here include (1) a materials reporting form that calculates project-level GHG emissions, (2) recommended changes to policies and specifications, and (3) a project-level alternatives analysis methodology. The use of these tools and strategies is then demonstrated through their application to a hypothetical city, "Greenville." The purpose of this hypothetical case is

to show that planning and design techniques for reducing concrete use and low-GHG cement and asphalt engineering technologies, in combination with policies that encourage these practices, have the potential to reduce emissions from these materials by over 50% within an individual project. These reductions, in combination with accurate reporting, can allow a local government to set and meet greenhouse gas reduction targets in this important, yet often overlooked, sector.

Acknowledgements

Special thanks to my thesis chair, advisor, and mentor **Jan Whittington**, for all her help prior to and during this thesis, and for bringing a critical eye to the process that greatly improved the quality of this work.

Special thanks as well to thesis committee member **Steve Muench**, for all of the helpful advice, guidance, and connections throughout the process that made this thesis possible.

A very big thanks to **Shirli Axelrod** of Seattle Public Utilities, who originally suggested that I study emissions from cement and asphalt purchasing at the City of Seattle, and without whom this thesis would not exist. Her help in making professional connections with relevant professionals in multiple agencies is greatly appreciated.

Thanks as well to everyone who contributed information for this thesis, including:

Shannon Davis (EPA Pacific Southwest Region)
Jason Edens (Seattle Financial and Administrative Services)
Erich Ellis (Seattle Department of Transportation)
Paul Fleming (Seattle Public Utilities)
Abner Gallardo (Seattle Department of Transportation)
Larry Garcia (Seattle City Light)
Denise Healy (Seattle Department of Transportation)
Jemae Hoffman (VIA Architecture)
Ray Hoffman (Seattle Public Utilities)
David Jackson (Seattle Financial and Administrative Services)
Leslie Kochan (Oregon Department of Environmental Quality)
Oradoña Landgrebe (Seattle City Light)
Sandra Mallory (Seattle Office of Sustainability and Environment)
Rob Shogren (LaFarge Cement)
Jill Simmons (Seattle Office of Sustainability and Environment)
Steve Read (Seattle Public Utilities)

Finally, thanks to my family and all of my friends in the MUP program who have helped and supported me along the way, and Cory.

Table of Contents

Chapter 1: Introduction

Local governments purchase large quantities of cement and asphalt every year. These materials are used to build roadways, sidewalks, buildings, vaults, pipes, parking lots, retention ponds, and a number of other key pieces of infrastructure. Indeed, they are essential to providing the services that the city needs to remain a livable, thriving metropolis.

However, the manufacture of these materials results in greenhouse gas (GHG) emissions—the primary cause of anthropogenic climate change that threatens to have an enormous negative impact on the world over the next century and beyond. Cement manufacture alone results in over 3% of global emissions, and at the local government scale, emissions from the manufacture of purchased construction materials can represent one of the largest emissions sectors (Hanle, 2004, 1; WCCF, 2014; Good Company, 2015, 1).

Though many local governments have committed to eliminating or significantly reducing emissions over the coming decades, no city has yet to produce a robust plan for quantifying and reducing the emissions that result from the manufacture of the cement and asphalt it purchases. This is largely because a lack of clean, uniform, extant data has made accurate and complete accounting "prohibitively complex." (City of Seattle OSE, 2008, 38). Additionally, though some work has been done to reduce emissions from cement and asphalt purchasing, this work has mainly been confined to Departments of Transportation.

In order to assist local governments in the inventory and reduction of these GHGs, this thesis asks three questions regarding cement and asphalt purchasing:

- How can local governments quantify the amount of cement and asphalt concrete used in construction projects?
- What planning techniques and engineering technologies exist to reduce the emissions associated with manufacture of cement and asphalt, and what policies can be implemented to encourage their use?

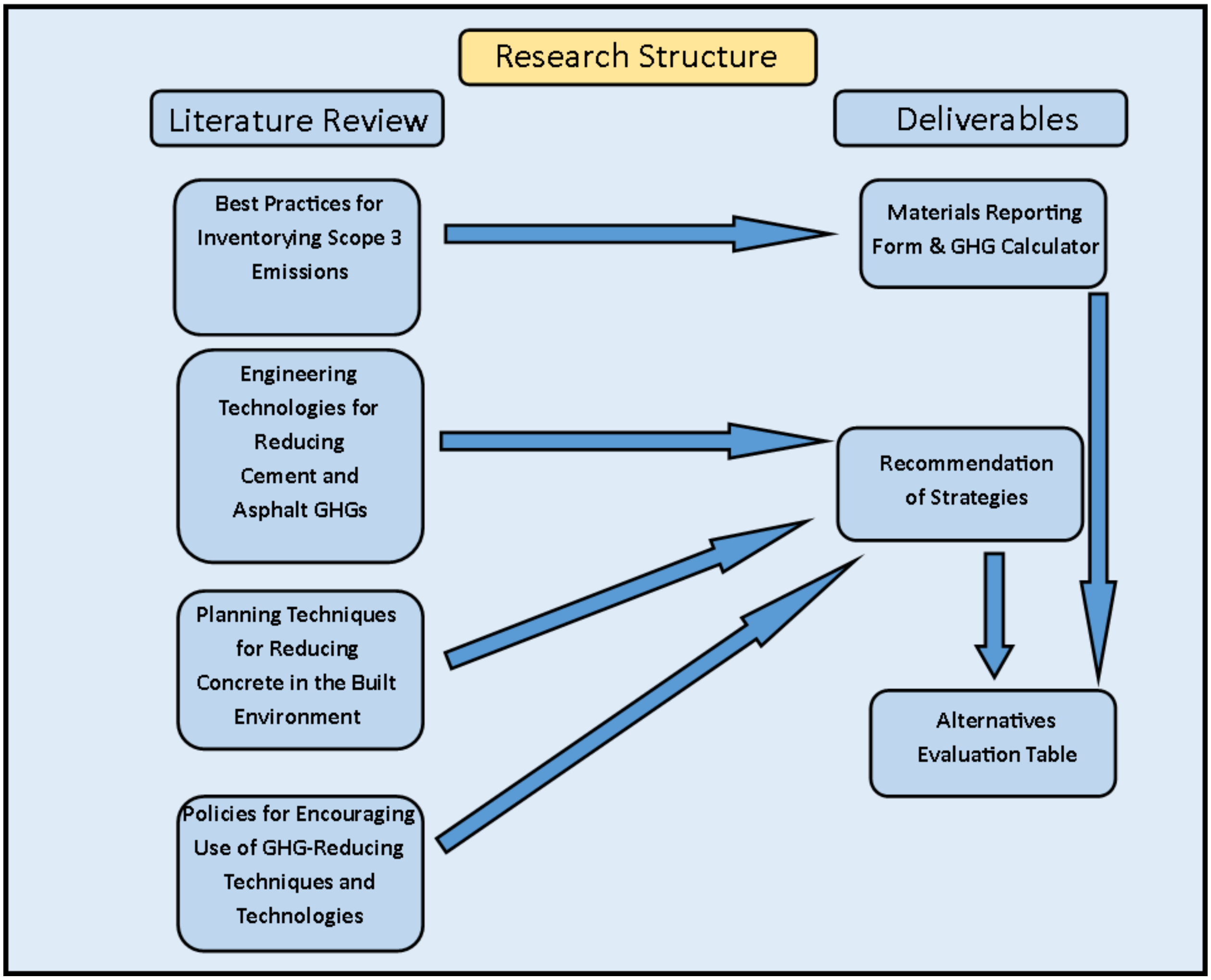
- How can local governments weigh alternative practices on the project-level to work towards reduction targets?

In an attempt to answer these questions, this thesis produces three deliverables, which encompass the greenhouse gas mitigation steps put for by ICLEI (2015) in its "Five Milestones for Climate Mitigation." These deliverables are:

- **A Materials Reporting Form and Greenhouse Gas Calculator** that can be used by project managers and staff to record the amount of cement concrete and asphalt concrete used in construction projects, as well as the amounts of low-GHG substitutes that were used. This will allow for uniform data collection across departments will output the amount of emissions resulting from the manufacture of these materials.
- **Recommendation of Strategies** that will be most effective for local governments to reduce its cement- and asphalt-related emissions. This will allow local governments to set a reduction target and develop an action plan for reducing emissions.
- **An Alternatives Evaluation Table** that decision-makers, during the project design phase, can use to evaluate how reductions in concrete and use of low-GHG alternatives will affect project emissions and costs. This allows a local government to make strategic decisions in order to reach its GHG reduction target.

These deliverables will be of use to project managers, project planners and designers, climate action planners, engineers, greenhouse gas accountants, and politicians in local governments around the country, and, if effective, will provide them with a means of inventorying and reducing the GHG emissions resulting from the purchase of cement and asphalt. Additionally, though this thesis is focused on local governments, these strategies could be adapted and adopted by other state and national governments, universities, and other agencies and firms that build with cement and asphalt or pay someone else to do so.

The diagram below shows how information gathered in the literature review phase of this thesis informs these three deliverables.



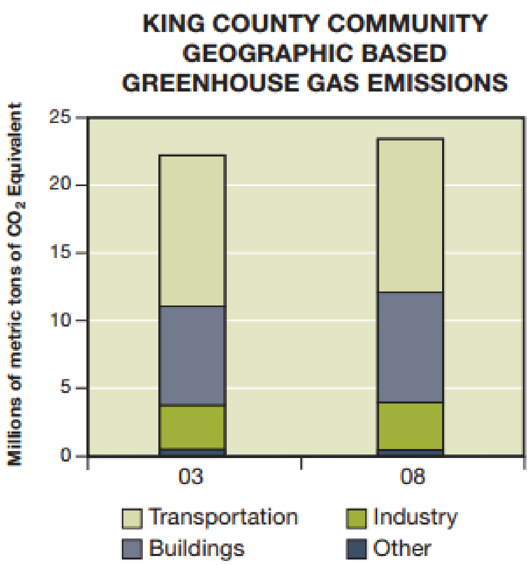
Chapter 2: Literature Review

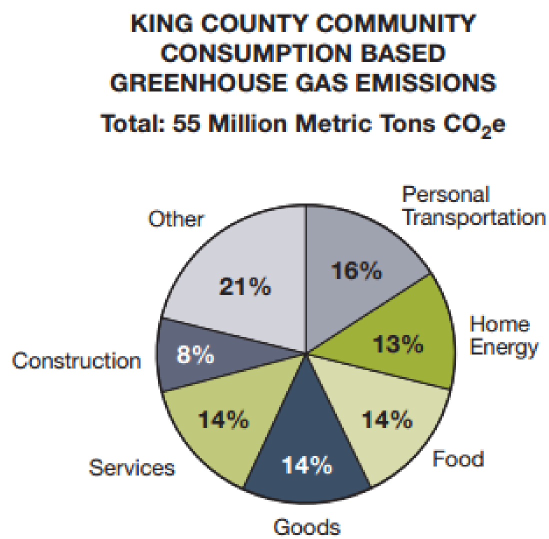
Climate Change and Consumption

Climate change is one of the most pressing issues of our age (IPCC, 2013; World Bank, 2013). Cities across the country and around the world are taking action in various ways to reduce their climate change inducing greenhouse gas (GHG) emissions (C40 Climate Leadership Group, 2015; European Commission, 2014). Though many cities are just beginning to take action to reduce greenhouse gas emissions, local and regional governments in the northwest have long been leaders in the fight against climate change. Indeed, former Seattle Mayor Greg Nickels spearheaded the U.S. Conference of Mayors Climate Protection Agreement in 2005, which brought the goals of the Kyoto conference down to the urban scale and has since been signed by over 1,000 mayors (U.S. Conference of Mayors, 2008). The signing of this agreement was only the beginning. That same year, Seattle City Light became the nation's first carbon-neutral utility, and by 2012, per capita emissions in the city had fallen twenty percent below 1990 levels (Shogren and Inskeep, 2005; City of Seattle OSE, 2014, 3). Portland, Oregon began the path towards cutting GHGs even earlier, producing the nation's first local climate action plan, and in 2014 won a presidential award for its efforts to combat climate change (City of Portland and Multnomah County, 2015; House, 2014).

Seattle's City Council has now committed to becoming the world's first carbon-neutral city by 2050, but this neutrality only accounts for "core emissions" from buildings, energy supply, transportation and waste (City of Seattle OSE, 2011, 8). Though not aiming for full carbon neutrality, Portland has committed to drastic emissions reductions, with a target of an 80% reduction below 1990 levels by 2050, and King County, Washington has pledged to cut community-level emissions to 80% below 2007 levels. (City of Portland and Multnomah County, 2015, 17; King County, 2012, 9). These targets are more robust than that set by the City of Seattle, because, in addition to "core" emissions, the also include emissions that result from consumption, which, while harder to quantify, play a large role in climate change. At the community scale, consumption-based emissions are defined as those that result from “the sum of consumer expenditures, government purchasing, and business capital investment (or net accumulations to business inventory),” (City of Seattle OSE, 2011, 36).

In its 2008 GHG Inventory, King County found that Seattle’s per-capita emissions from these core sectors was 11.6 metric tonnes of CO2 equivalent (MTCO2e) per capita, while consumption-based emissions resulted in roughly 25 MTCO2e per capita (King County, 2012, 13; City of Seattle OSE, 2011, 37). For King County as a whole, consumption-based emissions were also more than double the core, geographic-based emissions, as shown in the table below (King County, 2012, 5).



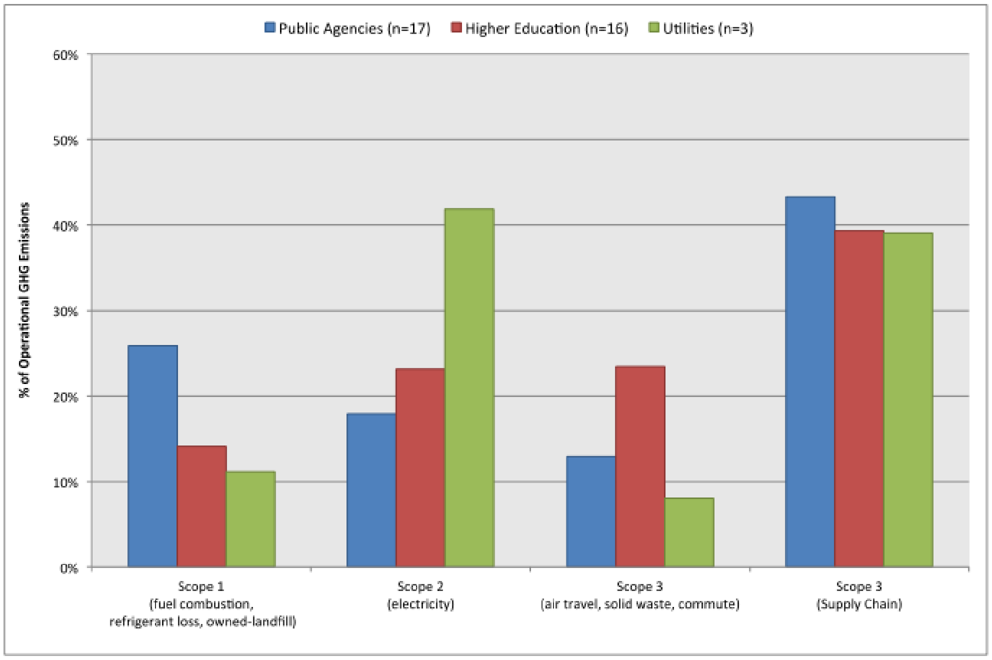


Two Types of Inventory Source: King County

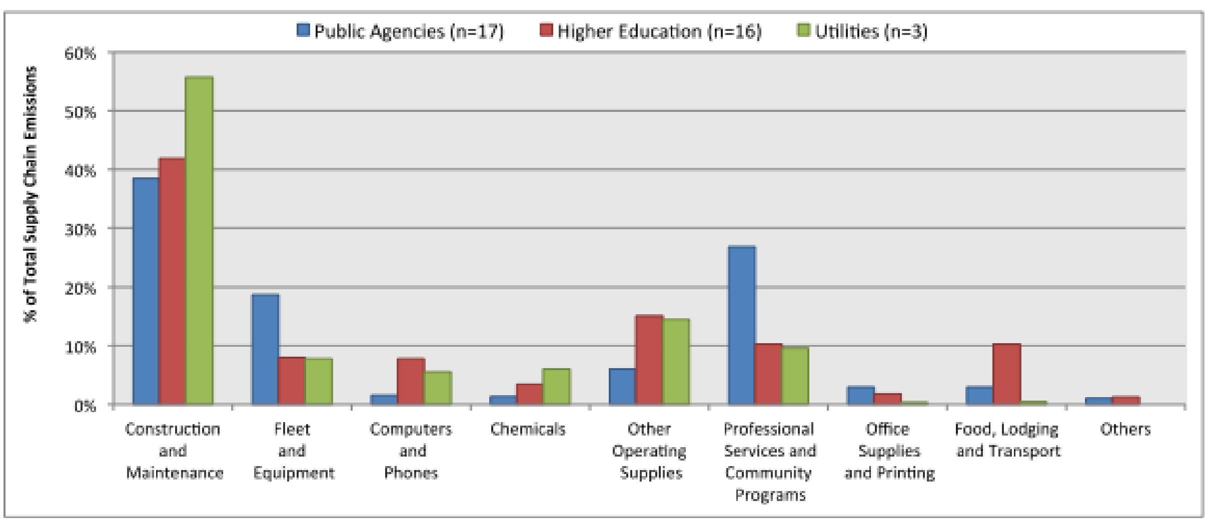
For Multnomah County (which contains Portland), the consumption based inventory was also twice as large as the geographically based one (City of Portland and Multnomah County, 2015, 37). If these three examples are representative of cities worldwide, it is obvious that emissions from consumption are significant when looking at the big picture of emissions.

Perhaps the most compelling evidence for the sheer scale of emissions from purchasing at the local government scale comes from a recent meta-analysis of 86 greenhouse gas inventories from 36 public agencies, universities and utilities. The study found that emissions from purchasing (called “supply chain” emissions in the study) were the largest source of emissions for most organizations.

In all cases, construction and maintenance emissions made up the largest proportion of supply chain emissions, with emissions from construction materials such as cement and asphalt dominating this category (Alameda County, 2015, 1).



Emissions from Purchasing are Significant Source: Good Company on Behalf of Alameda County



Breakdown of Purchasing Emissions Source: Good Company on Behalf of Alameda County

Another compelling example of the sheer scale of GHGs from cement comes from a memo produced for Seattle Public Utilities. The memo looks at cement-related emissions from three recent or ongoing construction projects undertaken by the utility. These three projects (A transfer station and two combined sewer overflow basins) likely resulted in 5,927 MTCO2e from cement. Considering that the utility's total recorded emissions for 2009 were roughly 14,000 MTCO2e, this means that one material used in three projects resulted in over 42% of a previous year's total recorded emissions (Tracy, 2015, 1). If a complete inventory of emissions from cement, asphalt and other materials were undertaken, these emissions would likely dwarf the total emissions from the utility.

According to industry best practices, all emissions that are significant, under the control of an organization and that have clear reduction techniques should be mitigated (The Climate Registry, 2010, 122). As cement and asphalt emissions meet all of these criteria, they should be mitigated.

However, many cities, even those who have conducted a consumption-based GHG inventory, have not made concerted efforts to reduce these emissions. The City of Seattle is a prime example of this, as it has, at least at the time of writing, chosen to exclude consumption emissions from its carbon neutrality pledge. The main barriers to reducing these emissions is that data is harder to collect, and that cities have less control over them than they do over emissions that occur within their boundaries (City of Seattle, 2011, 20 & 38). While this may be true at the community scale, this reasoning does not hold quite so strongly when looking at emissions from government purchasing. A city government has direct control over its purchases and can utilize a variety of tools and strategies to ensure that the products that it purchases are as low-GHG as possible. It also has the capability to implement data reporting standards in order to allow for the quantification of purchased goods and services and the emissions that result from them. It is "lack of policy and experiences in material and product service efficiency" that restrains action in this sector (IPCC, 2014, 24).

Climate Milestones Source: ICLEI

ICLEI (Local Governments for Sustainability) is one of the foremost organizations in greenhouse gas mitigation, and was one of the principle architects of the mitigation methodology that the City of Seattle follows. The Climate Milestones Wheel above shows the five steps that should be taken in order to mitigate emissions. The city of Seattle has already implemented this methodology with respect to "core" emissions (energy, buildings, transportation and waste), but has not done so for purchasing. (SEI and City of Seattle, 2011, 8). This thesis provides a framework with which local governments can progress through these five steps.

Greenhouse Gas Emissions Scopes

Greenhouse gas (GHG) inventories are the documents that local governments and other entities use to record their emissions, set baselines, determine mitigation strategies and goals, and track their progress in reducing emissions (USEPA, 2014b; WRI and WBCSD 2012; Climate Registry, 2010, 3).

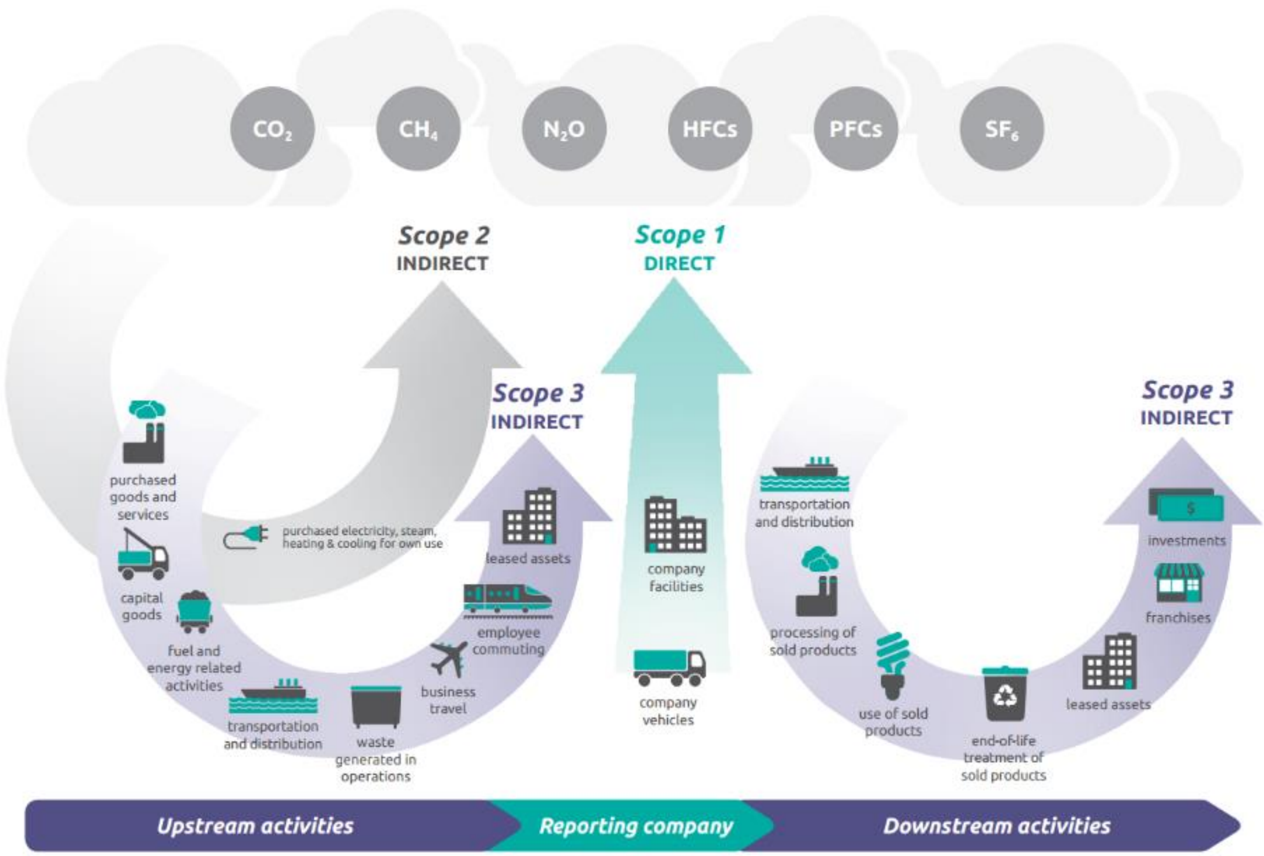
The City of Seattle uses the Local Government Operations Protocol created by the Climate Registry to inventory its emissions (Seattle OSE, 2011, 10). This protocol follows the standards set by the World Resources Institute's GHG Protocol Corporate Standard in defining the types of emissions (Climate

Registry, 2010, 22). Emissions from local government operations are broken down into three categories or *scopes*. WRI and WBCSD (2012, 25) defines the three scopes as follows:

Scope 1 covers all *direct emissions*. Direct emissions are those that "occur from sources that are owned or controlled by the company, for example, emissions from combustion in owned or controlled boilers, furnaces, vehicles, etc.; emissions from chemical production in owned or controlled process equipment."

Scope 2 covers electricity-related *indirect emissions*. These emissions come from "purchased electricity consumed by the company. Purchased electricity is defined as electricity that is purchased or otherwise brought into the organizational boundary of the company. Scope 2 emissions physically occur at the facility where electricity is generated."

Scope 3 covers all other indirect emissions. These emissions "are a consequence of the activities of the company, but occur from sources not owned or controlled by the company. Some examples of scope 3 activities are extraction and production of purchased materials; transportation of purchased fuels; and use of sold products and services." The Corporate Protocol defines these emissions as optional in reporting.



A graphic representation of the three emissions scopes with examples. Source: WRI and WBCSD

As should be obvious from the definitions and figure above, the purchasing of cement, asphalt, and other construction materials falls under the category of scope 3. Because this category is labeled as optional, many cities and other entities do not account for these in their GHG inventories. The Climate Registry states that a scope 3 source should be included in an inventory when it meets a certain set of criteria, including being a large emission source, being crucial to core services, having clear mitigation actions that can be taken, and having reliable data (Climate Registry, 2010, 122). The discussion in this and the previous section should make it clear that emissions from the manufacture of purchased cement and asphalt meet all of these criteria.

Scope 3 Emissions Guidance and Accounting Methods

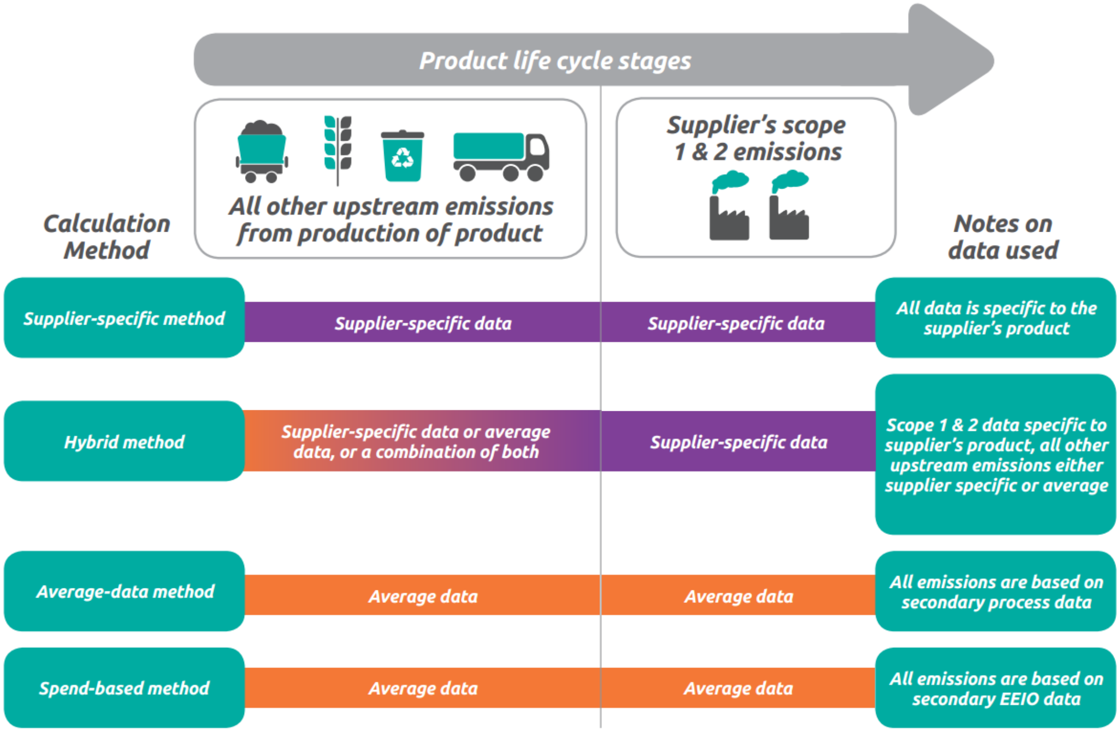
The World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD) have created guidance for calculating Scope 3 emissions on the government/corporate scale. They identify four main methods of accounting for emissions from purchased goods (e.g. cement and asphalt).

The first of these is a *supplier specific method,* in which the institution collects all relevant emissions data from individual suppliers and then uses that to calculate the emissions from their own purchasing (WRI and WBCSD, 2013, 21). For example, in one year, a city buys cement concrete from Supplier X which contains 100 tons of cement. Supplier X, from their own GHG inventory, knows that each ton of cement it manufactures results in a total of .75 tonnes of CO2e. The city then multiplies the amount of cement it bought by the emissions factor from the supplier. 100 tons x .75MTCO2e/ton = 75 MTCO2e.

The second method is a *hybrid method,* which incorporates supplier specific data for the supplier's scope 1 and 2 emissions, but then uses secondary data to calculate the upstream emissions (from mining materials, etc.) (WRI and WBCSD, 2013, 21).

Third is the *average data method,* in which the institution uses the quantity of materials purchased (in this tons of cement and asphalt) and then multiplies in by an industry average emissions factor (WRI and WBCSD, 2013, 21). For example, the EPA states that each pound of cement results in .9 pounds of CO2e. Therefore, each ton results in .82 metric tons (tonnes) of CO2e. The institution would multiply its total quantity of cement by this emission factor to arrive at a total CO2e number.

The final accounting method listed by WRI and WBCSD is the *spend-based method.* In this method, the institution determines the economic value of the product (e.g. the city bought $5 million worth of cement this year) and multiplies this by an industry average emissions factor (e.g. x amount of CO2e per dollar) (WRI and WBCSD, 2013, 21). The figure below graphically represents these four methods.



Methods of Scope 3 Accounting Source: WRI & WBCSD

These methods can take a variety of forms. One of the most popular, the Economic Input-Output Life Cycle Analysis (EIO-LCA) method was developed at Carnegie Mellon University and is a spend-based method of Scope 3 accounting that uses industry average emissions per dollar factors (CMU Green Design Institute, 2015). The screenshot below shows the EIO-LCA calculator's output for $5 million dollars' worth of cement.

Sector #327310: Cement manufacturing
Economic Activity: $5 Million Dollars
Displaying: Greenhouse Gases
Number of Sectors: Top 10

Change Inputs (Click here to view greenhouse gases, air pollutants, etc...)

Documentation:
The environmental, energy, and other data used and their sources.
Frequently asked questions about EIO-LCA.

This sector list was contributed by Green Design Institute.

	Sector	Total t CO2e	CO2 Fossil t CO2e	CO2 Process t CO2e	CH4 t CO2e	N2O t CO2e	HFC/PFCs t CO2e
	Total for all sectors	*57800*	*26700*	*30300*	*654.*	*42.4*	*63.1*
327310	Cement manufacturing	51500	21500	30000	0.000	0.000	0.000
221100	Power generation and supply	4090	4030	0.000	11.1	25.0	25.9
211000	Oil and gas extraction	332.0	93.5	60.8	178.0	0.000	0.000
3274A0	Lime and gypsum product manufacturing	324.0	121.0	204.0	0.000	0.000	0.000
212100	Coal mining	295.0	33.3	0.000	262.0	0.000	0.000
486000	Pipeline transportation	148.0	67.7	0.186	80.1	0.000	0.000
484000	Truck transportation	109.0	109.0	0.000	0.000	0.000	0.000
221200	Natural gas distribution	100	9.07	0.000	91.4	0.000	0.000
327992	Ground or treated minerals and earths manufacturing	92.7	92.7	0.000	0.000	0.000	0.000
324110	Petroleum refineries	86.2	85.9	0.000	0.267	0.000	0.000

EIO-LCA Calculator output for cement manufacturing Source: Carnegie Mellon University

The advantage of this method is that it is easy to use, and that cost data is likely more readily available than data on amounts of materials. The main drawback, however, is that it is a very blunt tool. It is unable to take into account regional or supplier-specific information, and is unable to account for GHG reducing techniques and technologies. For instance, there is no listing for warm mix asphalt or for cement containing SCMs. It is thus likely to overestimate emissions and is unable to show how an institution's practices are reducing GHGs, unless the practice involves using less of the material in the first place.

The CBEI method, which was used by King County, among other institutions, to estimate its scope 3 emissions, is also a spend-based method of accounting. This method uses the U.S. Bureau of Labor Statistics IMPLAN input-output model to estimate consumption of goods, rather than using actual purchasing data (King County, 2012, 22). In King County's case, local data was used when available, but most of the data was scaled down from national averages. Again, this tool is simple, but also very blunt.

Project-Level Scope 3 Accounting

While EIO-LCA and CBEI models are useful for getting broad-stroke overviews of scope 3 emissions, they lack the ability to account for emissions from individual projects and take into account GHG-reducing measures used in these projects. This makes it more difficult to set targets and track progress, because the project level is where emissions from cement and asphalt occur, and where engineers, project managers and contractors make the decision whether or not to use low-GHG alternatives.

WRI and WBCSD have developed a protocol for GHG project accounting, which is specifically tailored to projects whose main goal is to reduce GHGs. The protocol is intended to be used in the early phases of a GHG reduction project. Project staff determine a baseline amount of emissions that would result from the project, typically using emissions that would result from building using conventional practices to estimate this baseline (WRI & WBCSD, 2003, 13-14). This is then compared to the level of emissions that would be released due to *additionalities,* which are defined as emissions reductions that would not have occurred without the low-GHG aspect of the project (WRI & WBCSD, 2003, 15-17). Projects can thus be evaluated on how much emissions would be reduced were the project to incorporate these additionalities. Of course, once the final project design is chosen and the project is built, reporting is necessary to ensure that the predicted emissions were accurate (WRI & WBCSD, 2003, 80-82).

Though this protocol is specifically designed for projects whose primary focus is to reduce greenhouse gas emissions, it is possible that a very similar method could be used to evaluate emissions from all capital projects. The World Bank recommends project level accounting that does exactly this in its *Climate-Smart Capital Investment Planning Handbook* (Whittington, 2014). In this methodology, cities estimate emissions for all capital projects during the design phase. Projects with emissions over a certain limit are then subjected to alternatives evaluation, where city staff develop two alternatives to the "conventional" project, which can have alternative scales, sources of energy, and technologies that reduce emissions (Whittington, 2014, 43-44). The "conventional" and "alternative" choices in this methodology are analogous to the "baseline" and "additionalities" in the WRI and WBCSD model.

There is also guidance in the literature regarding project-level scope three accounting, specifically for roadways. Kim et al. (2012) for recommend estimating emissions per lane-mile using information from design documents combined with an emissions factor, as follows:

GHG emissions (tCO2e/lane-km) = 1,000 × (width/# of lanes) x (thickness) x (loss conversion factor) x (density (t/m3)) x (emissions factor) (Kim et al., 2012, 1316).

Though this equation was created for asphalt roadways in particular, it could be used for cement concrete roadways as well. Additionally, by removing the references to "lanes" and instead calculating length x width x height x emissions factor, this equation can be used to determine the GHG emissions per m3 of structural concrete, or any material for that matter.

Doing a project-level analysis of GHG emissions would not only create detailed and accurate data to be included in the local government's greenhouse gas inventory, but would also have the added benefit of encouraging project designers and engineers to evaluate GHG reducing measures during the early phases of a project.

Scope 3 Accounting in Practice

The City of Seattle accounts for several types of scope 3 emissions in its government operations inventory, but those from production of purchased materials are not (Seattle OSE, 2011, 33). The figure below shows the types of emissions that the City of Seattle accounted for in its most recent (2010) inventory. The only scope 3 emissions included were from employee commuting, business travel, and solid waste from government operations.

Scope 1	Scope 2	Scope 3
Fuel consumed to heat/cool facilities	Purchased electricity consumed by facilities	Solid waste generated by government operations
Fuel consumed by vehicle fleet and mobile equipment	Purchased steam for heating or cooling facilities. Purchased electricity consumed by electric vehicles	Fuel consumed for employee vehicles used for commuting
Fuel consumed to generate electricity	Purchased steam for heating or cooling facilities	Fuel consumed for airplanes used for employee business travel
Electricity, steam, and cooling purchased from an outside utility		
Leaked refrigerants from facilities and vehicles		
Solid waste in government landfills		

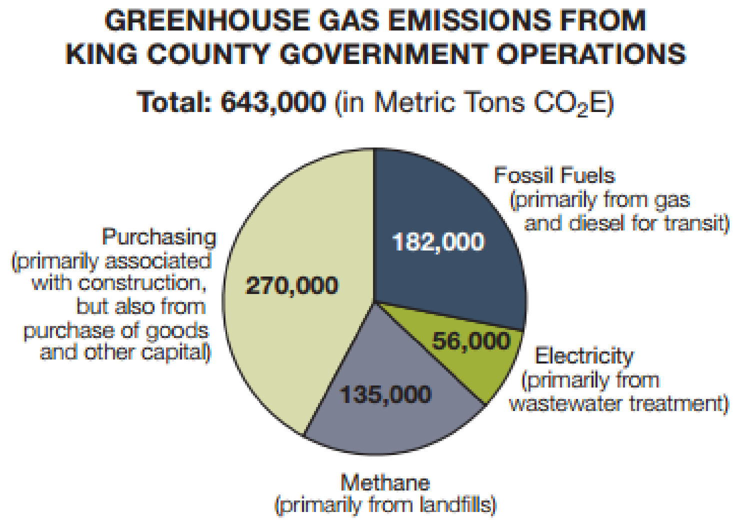
City of Seattle Emissions by Scope Source: Seattle OSE

Though the City of Seattle does not currently inventory emissions from purchasing, its 2005 inventory did include a partial inventory of emissions from cement and asphalt. The emissions included in the inventory came from cement and asphalt concrete purchased by the Seattle Department of Transportation and used in road repair and construction projects, and totaled 4,240 MTCO2e. It was noted at the time that the city's total emissions from this sector were "much greater in scope" but were "prohibitively complex to estimate," (Seattle OSE, 2008, 38). SDOT has continued tracking their cement- and asphalt-related emissions on a yearly basis, but they have never been included in a Seattle government operations inventory again, and no other agency within the City has taken steps to inventory their own cement- and asphalt-related emissions (Tracy and Axelrod, 2014, 2). The work that SDOT did and continues to do falls in between the hybrid method and the average-data method. The emissions factor for cement comes from industry average data, but the emissions factor for asphalt from a test done at an asphalt manufacturing plant (Healy, 2014). Because the hot mix and warm mix asphalt emissions factors only came from one test at one plant and is applied to all hot and warm mix asphalt from all purchasers, it cannot be considered supplier-specific data.

The accounting recommended in Kim et al. (2012) is precisely how SDOT accounts for cement and asphalt emissions from its large projects. While the project is still in the design and construction phase, staff evaluate emissions using information on materials quantities from project bid forms, and emissions factors based on industry averages and some supplier-specific data (Healy, 2014). This allows for a much more accurate and fine-grain analysis of emissions than a blanket method using cost data. Additionally, the projected numbers from the largest projects are later compared to truck ticket data (i.e. receipts for materials purchased) to determine the accuracy of the design-phase estimates (Healy, 2014).

To test the theory that a complete inventory Seattle's of cement and asphalt emissions at the was "prohibitively complex, Tracy and Axelrod (2014) attempted to use SDOT's emissions calculation model to complete an inventory of emissions from cement and asphalt purchasing across all city bid projects in 2013 using existing data and documentation. Their study found that data on quantities of materials purchased was not available for more than half of these projects, due to lump sum bidding methods and a lack of standardized reporting procedure. Due to this lack of data, emissions from just 22 projects were able to be quantified, using quantities of cement and asphalt listed in bid forms in combination with GHG emission factors used by SDOT (Tracy and Axelrod, 2014, 3). Tracy and Axelrod concluded that, though data was not currently collected on quantities of cement and asphalt used in City projects, collecting this data would not be difficult if a standardized reporting system was put into place. As stated in the report, "contractors already have this information; all the city has to do is ask for it," (Tracy and Axelrod, 2014, 4). This was confirmed by a technical memo produced by Sound Transit (2014), in which researchers obtained relevant information regarding materials quantities and use of low-GHG technologies in projects.

Since 2005, however, many local governments have begun inventorying their purchasing-related emissions, proving that, with the right data reporting and collection methods in place, inventorying these emissions does not have to be "prohibitively complex." A survey of twenty of local governments and universities found that purchasing-related emissions accounted for between 20% and 80% of total emissions. Of these, emissions from construction purchasing were the largest proportion in nearly every case (WCCF, 2014). These findings were echoed in the meta-analysis done by Good Company of behalf of Alameda County (Alameda County, 2015, 1).



Construction Materials result in large amounts of GHGs. Source: King County

King County found that building materials made up 22% of its construction purchasing-related emissions in 2008. Of these, cement manufacture resulted in nearly half. The materials sector was exceeded in emissions only by direct fuel use by construction vehicles and equipment (Hamilton, 2014, 8). Not only does purchased cement make up a large portion of the emissions from government purchasing, but cement manufacture also is a major contributor to overall GHG emissions—in 2000, emissions from cement represented 3.4% of total global emissions (Hanle, 2004, 1).

At the time of writing, 19 of the 20 institutions in the survey had included construction purchasing in their inventory, and 3 of those specifically recorded the amount of emissions from cement manufacture (WCCF, 2014). This survey also lists the methodology each institution used to record its purchasing emissions. By far the most popular methodology was and Economic Input-Output Life-Cycle Assessment (EIO-LCA), with a few other entities using a Consumption Based Emissions Inventory (CBEI) model, and two using other methodologies (WCCF, 2014). Each of these methodologies is discussed below.

GHG Reduction Targets

A greenhouse gas reduction target (sometimes called a mitigation goal) is a way for a community, business or government to focus its mitigation actions and track its progress in reducing emissions (ICLEI, 2015b; WRI, 2014, 5). There are four types of reduction targets, as displayed in the table below, but the "base year emissions goal" is the most common (ICLEI, 2015b).

Goal Type	Description	Reductions in what?	Reductions relative to what?
Base year emissions goal	Reduce, or control the increase of, emissions by a specified quantity relative to a base year. For example, a 25% reduction from 1990 levels by 2020.	Emissions	Historical base year emissions
Fixed-level goal	Reduce, or control the increase of, emissions to an absolute emissions level in a target year. One type of fixed-level goal is a carbon neutrality goal, which is designed to reach zero net emissions by a certain date.	Emissions	No reference level
Base year intensity goal	Reduce emissions intensity (emissions per unit of another variable, typically GDP) by a specified quantity relative to a base year. For example, a 40% reduction from 1990 base year intensity by 2020.	Emissions intensity	Historical base year emissions
Baseline scenario goal	Reduce emissions by a specified quantity relative to a projected emissions baseline scenario. A baseline scenario is a reference case that represents future events or conditions most likely to occur in the absence of activities taken to meet the mitigation goal. For example, a 30% reduction from baseline scenario emissions in 2020.	Emissions	Projected baseline scenario emissions

Types of GHG Reduction Targets Source: WRI

This type of reduction target sets one year for which emissions are known as a baseline, and then sets another year in the future as the year it reaches its goal. The Kyoto Protocol, one of the most famous GHG agreements, is an example of a baseline year emissions reduction target. In it, countries agreed to reduce emissions by at least 5% below 1990 levels by 2012 (UNFCCC, 2014). Seattle's existing short- and medium-range community-scale reduction targets are also baseline year emissions goals. Seattle City Council passed a resolution in 2011 setting a 30% reduction in core emissions from 2008 levels by 2020, a 50% reduction by 2030, and carbon neutrality by 2050 (City of Seattle, 2011, 8). While the first two are baseline year, the commitment to carbon neutrality is a fixed-level goal, because it sets an absolute target that is not relative to a given benchmark.

The process of setting a goal is rather straightforward—the City or other entity decided on a baseline and target year, agrees on the boundaries of the goal (which types of emissions are to be covered and geographical/organizational boundaries) and then sets the emissions reductions it wants to achieve by that year (WRI, 2014, 29).

When setting a goal for scope three emissions, the World Resources Institute's Mitigation Goal Standard allows cities to choose whether these emissions are included in the primary reduction target or if they are subject to their own reduction target (WRI, 2014, 34). The City of Portland and King County both chose to include their consumption-related emissions into their overall reduction targets, but the City of Seattle has not yet created an emissions reduction target for consumption, either on a government operations scale or a community-wide scale (King County, 2012; City of Portland and Multnomah County, 2015; City of Seattle, 2011, 8). It could choose to set a separate emissions reduction target for its emissions from cement and asphalt purchasing, or could include these emissions into its existing target. One issue with the latter choice is that it might cause a large bump in the City's emissions trend, which may be politically unpopular.

While the community-wide reduction target is the greatest in scale and thus includes all other reduction targets, local governments as a whole or individual departments may set their own, more ambitious reduction targets. For instance, King County has set a number of goals for emissions from government operations—a 15% decrease by 2015, 25% decrease by 2020 and a 50% decrease by 2030. Seattle City Light has been carbon neutral (from core sources) since 2005, and Seattle Public Utilities plans to become carbon neutral (again, from core sources only) in 2016 (Landgrebe, 2014; Fleming, 2015). This neutrality is achieved, of course, with the help of carbon offsets. Even when "neutrality" takes effect, there will still be ample opportunities to reduce emissions and lower the cost that these city departments pay towards offsets.

Conclusions

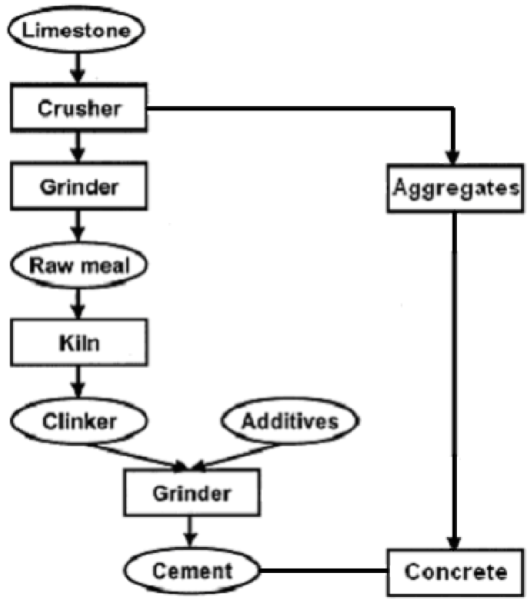
Several options exist for accounting of Scope 3 emissions. Project-level accounting, while not the most common method, gains the most accurate data. For project-level accounting of Scope 3 emissions from cement and asphalt purchasing to begin at the City of Seattle, standardized project reporting practices would need to be put into place. Once project-level accounting begins, the City departments, or preferably the City has a whole, can set a reduction target for these emissions.

Engineering Technologies for Reducing GHG Emissions from Concrete

Once a reduction target is set, the next step in the climate milestones wheel is to devise strategies to reduce emissions in order to meet the target. Before strategies can be devised and policies can be implemented, however, City technical staff and decision-makers must have a working, if not thorough understanding of the techniques and technologies that can be used to reduce said emissions. This section describes the cement and asphalt manufacturing processes, how these processes result in GHG emissions, and what engineering technologies exist to reduce them.

Cement

In 2013, 75.1 million tons of portland cement (the most common type of cement) was produced in the US alone, the sales of which totaled $7.6 billion (USGS, 2014, 38). Globally, consumption of cement as a material is 2nd only to consumption of water, and almost all of it is used to construct buildings and other infrastructure (Naik, 2005, 1, IPCC, 2014, 759). Obviously, cement and the concrete it creates are essential to modern life, and make up a large portion of the infrastructure that cities build and maintain.



Concrete manufacturing process Source: Naik, 2005

Though used interchangeably, the terms *cement* and *concrete* actually refer to different things. *Cement* is a paste made from limestone, calcium, silicon, aluminum, iron, water, and other ingredients, which, when combined with sand and rock (called *aggregates)* creates cement concrete (PCA, 2014). The figure above shows the process through which cement and cement concrete are formed.

As shown in the diagram, limestone is the main ingredient from which cement is manufactured. Once crushed and ground, the limestone is heated to 1400 degrees Celsius (roughly 2500 degrees Fahrenheit) in a process called *calcination,* which transforms the limestone ($CaCO_3$) into lime (CaO) (IPCC, 2001, 176; Provis et al., 2008, 28; USEPA, 2010b, 4). This can be represented by the equation:

$$CaCO_3 + heat \rightarrow CaO + CO_2$$

The resulting CaO (Lime) is known as clinker, and this is the fundamental component in finished portland cement.

Where do the GHGs come from?

In addition to CaO, the calcination process yields the waste gas CO2, which happens to be the most prevalent greenhouse gas responsible for global climate change (Provis et al., 2008, 28; IPCC, 2013, 14). On average, for each pound of clinker produced, between .5 and .52 pound of CO2 result from calcination (IPCC, 2000, 177, USEPA, 2010b, 5). Additionally, the fuel needed to reach such high kiln temperatures results, on average, in .46 pounds of CO2 per ton of clinker, for a total of .98 pounds of CO2 per pound of clinker (USEPA, 2010b, 5). As each pound of cement contains roughly .92 pounds of clinker, each finished pound of portland cement results in roughly .90 pounds of CO2 (USEPA, 2010b, 5).

However, these numbers are based on national averages. SDOT and Seattle Public Utilities (SPU), for instance, use .96 lbs. CO2/lb. cement as their emissions factor (Healy, 2014; Read, 2015). Lafarge, one of the largest suppliers of cement in the northwest, estimates that one pound of its portland cement on average results in .8 pounds of CO2e (Shogren, 2015). It is obvious then that, while .9 may be a national average, there is some variability from plant to plant. The sources of this variability are described in the section below.

How can they be reduced?

While process-related CO2 emissions from cement production are the second largest source of industrial emissions in the US, there are proven ways that cement plants can reduce these emissions. These strategies fall into four main categories: Switching to a lower-carbon source of energy, improving energy efficiency of the process, carbon capture and storage (CCS) and reducing the amount of clinker in the finished cement product (USEPA, 2010b, 7). These strategies are described and discussed below.

Switching to lower-carbon sources of energy

In 2011, roughly 12-15% of total industrial energy usage came from the cement sector (Madlool et al., 2011, 2042). As noted above, roughly half of the CO_2 resulting from the manufacture of cement is a result of fuel use during the calcination process (USEPA, 2010b, 5). In the US, roughly 64% of the energy used to make cement comes from coal, one of the highest-GHG fuels in use (USEPA, 2008a, 9). Use of heavy oil rather than coal can yield an emissions reduction of 18%, while switching to natural gas can reduce emissions by about 40% (USEPA, 2010b, 39). In addition to switching among fossil fuels, some cement manufactures have begun using energy from biomass to supplement these more traditional forms of energy. Though it is unlikely that a cement kiln could be powered solely by biomass energy, in at least one case a manufacturer was able to replace 40% of the traditional fuel (USEPA, 2008a, 96). Biomass' emission factor varies with the type of biomass fuel used. Some common types are waste wood, animal meal, sawdust and sewage sludge. There are several concerns with the use of biomass, however, not least of which is that trace compounds such as heavy metals may be transferred into the cement from the biomass materials (USEPA. 2010b, 39). Using materials that are more likely to be contaminated (sewage, for instance) likely increases this risk.

Renewable energies such as solar and wind, while fairly new to the cement industry, also provide opportunities for greenhouse gas reductions, with reductions being equivalent to the amount of CO_2 that would have resulted from the replaced traditional fuel (Miller et al., 2008, 112; USEPA, 2010b, 40). While largely untested, there is at least one cement plant that has met 30% of its power demand through wind power (USEPA, 2010b, 40).

Improving the energy efficiency of the process

As roughly half of cement manufacture emissions come from energy use during the calcination process, improving the energy efficiency of this process is one way that cement plants can reduce their emissions. Some strategies for doing so include:

- Installing automated control systems to maintain optimum conditions in the clinker kiln

- Regular maintenance of kiln seals to avoid heat loss
- Improve the kiln combustion system to avoid incomplete fuel burning
- Use fluxes and mineralizers to reduce energy demand
- Recover exhaust heat for power (cogeneration)
- Shifting to a more energy efficient process (e.g. from wet and long dry to preheater/precalciner process),
- And others (US EPA, 2010b, 19-28; Madlool et al., 2011, 2052-2053).

Carbon capture and storage (CCS)

Carbon capture and storage, alternatively known as carbon capture and sequestration, is “a family of technologies and techniques that enable the capture of CO2 from fuel combustion or industrial processes, the transport of CO2 via ships or pipelines, and its storage underground,” (IEA, 2014). Though there are currently no Carbon Capture and Storage facilities operating in tandem with cement plants in the North America, the International Energy Agency predicts that there will be 35 operating in 2050. Globally, it is hoped that by 2050 this technology will be capable of sequestering roughly .5GTCO2e/year (MITei, 2015; IEA, 2015).

Reducing the amount of clinker in the finished product

As noted above, clinker production accounts for nearly all of the energy use and emissions from cement manufacture. Thus a process that reduces the amount of clinker per unit of cement reduces both the energy-related and the process-related emissions. *Supplementary cementitious materials* (SCM), alternatively known as *pozzolans,* are materials that replace clinker in the finished cement product, or in some cases, replace the cement itself in cement concrete (Provis et al., 2008, 28). Accurately defined, a pozzolan is “a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties,” (ACI, 1980, 34). In this thesis, the terms “SCM” and “pozzolan” are used interchangeably. A technical director at Lafarge North America estimated that 90% of all cement used in the northwest contained some amount of SCM, but that the percentage in any given mix was typically very low (and much lower than could safely be used) (Shogren, 2015).

The reduction in emissions due to SCM use is proportional to the amount of clinker replaced (USEPA, 2010b, 30). Therefore, a ton of blended cement in which 50% of the clinker has been replaced by SCM would result in 50% of the GHG emissions compared to traditional portland cement. In addition to emissions reductions, cement concrete made with SCMs has many added benefits over traditional Portland cement concrete, including:

- Higher long-term strength (Loreti Group, 2009, 10; Naik, 2005, 3, Shogren, 2015);
- Higher durability (Loreti Group, 2009, 10; Naik, 2005, 3, Shogren, 2015);
- Conservation of natural resources such as limestone and coal (Loreti Group, 2009, 10);
- Excellent resistance to sulfate and chloride (good for coastal areas) (Loreti Group, 2009, 10; Shogren, 2015),
- Low heat of hydration (making it highly suitable for dams, bridges and other large projects) (Loreti Group, 2009, 10), and;
- Energy use reductions of up to 40% in buildings made with SCMs, due to increased insulation (Naik, 2005, 3).
- Lower life-cycle costs due to increased durability and decreased energy use (Shogren, 2015, Naik, 2005, 3).

It is important to note, however, that while there are many benefits to using SCMs, there are drawbacks as well. The main drawback and barrier to widespread use of SCMs is the fact that concrete made with SCMs have low early strength, even though long-term strength is increased. Use of pozzolans may not be feasible in projects that need to set and be ready to use quickly, such as road repairs where the transportation must be resumed as soon as possible (Read, 2015; Shogren, 2015).

Some of the most common types of SCMs are fly ash, slag, silica fume and natural pozzolans, all of which are discussed in detail below (Naik, 2005, 5).

A variety of supplementary cementitious materials. Source: Portland Cement Association

Natural pozzolans are naturally reactive volcanic minerals, such as “volcanic ash, pumicite, opaline chert and shales, tuff, and some diatomaceous earths,” (ACI Committee 232, 2000, 3). The term pozzolan comes from the village of Pozzuoli near the eruption site of Mt Vesuvius in Italy, but natural pozzolans have been used in cement production for at least 6,000 years (Wilson and Kosmataka, 2011, 60; ACI Committee 232, 2000, 1). Many great monuments from ancient Greek, Roman, Egyptian and Indian cultures that are still standing today were built using natural pozzolans (Wilson and Kosmataka, 2011, 60; Provis et al., 2008, 29). The fact that these structures have remained intact over the millennia is a testament to the high long-term strength of cement made with natural pozzolans. More recently, the United States used natural pozzolans extensively throughout the first half of the 20th century, especially in the construction of dams and bridges. The Golden Gate Bridge in San Francisco and the Bonneville Dam Spillway in Washington are examples of modern projects in which natural pozzolans made up 25% of the overall cement content (ACI Committee 232, 2000, 8).

Natural pozzolans are found throughout the world, with large deposits present in the western United States (ACI, 1980, 8). The 1980 eruption of Mt St. Helens left 195 million cubic yards of volcanic ash across Washington State, some of which may still be stockpiled in eastern Washington (Moen and McLucas, 1981, 6). Testing done shortly after the eruption showed that the ash may be appropriate for use as an SCM, though grinding to an appropriate fineness may be necessary (Moen and McLucas, 1981, 26-27).

Fly ash (sometimes called flue ash) is a coal combustion product (CCP) defined by the American Concrete Institute as "the finely divided residue resulting from the combustion of ground or powdered coal and which is transported from the firebox through the boiler by flue gases," (ACI, 1980, 21). Fly ash has been used as a component in cement manufacturing in the US over 80 years, and is currently the most widely used pozzolanic material (Thomas, 2007, 1; Naik, 2005, 4; USEPA, 2010b, 33). In 2013, 53.4 million tons of fly ash was generated in the US, 43.7% of which were recycled (ACAA, 2014, 1). Use of fly ash as an SCM is the most common source of CCP recycling. While fly ash can be used to replace lime in the clinker production process, it is more commonly used to replace cement itself when the cement is mixed with aggregates to form concrete (Loreti Group, 2009, 21, Provis et al., 2008, 28). In 2013, over 12.3 million tons of fly ash were used as a concreted additive, while only 2.28 million tons were used to create blended cement (ACAA, 2014, 1). Use of fly ash in the production of concrete, rather than cement, yields more GHG reductions because it does not need to be heated to several thousand degrees in the cement kiln, thus reducing energy use (Loreti Group, 2009, 21).

Historically, fly ash concrete has used a 15% to 25% replacement rate, though amounts up to 40% are widely accepted for some applications, especially those that are used in structural projects (Thomas, 2007, 1; Loreti Group, 2009, 21, Shogren, 2015). However, testing has shown that concrete made with fly ash can perform to American Society for Testing and Materials (ASTM) standards at even higher replacement rates. Kumar et al. (2007) evaluated the compressive and flexural strength of concrete made with varying quantities of fly ash, up to 60%. Of the samples tested, the 40% fly ash sample had the highest long-term strength, exceeding even the one made entirely with traditional Portland cement (Kumar et al., 2007, 909).

Low early strength is often a concern with concrete made from SCM. However, by altering the water to cement ratio, all samples in the Kumar study, including the 60% fly ash one, exceeded the typical 28 day standards for compressive and flexural strength of roadway concrete (Kumar et al., 2007, 909). Other studies corroborate the finding that high-volume fly ash concrete, defined as concrete with 50% cement replacement or more, can perform at or above the level of Portland cement concrete, especially using a reduced water to cement ratio. This solution is not feasible in every case, however (Mehta, 2004, 12-13; Naik, 2005, 3; Thomas, 2007, 8).

In addition to the use of a lower water to cement ratio, the early strength of fly ash concrete is also dependent on temperature conditions during setting. During hot weather, the cement sets faster and gains strength more quickly than in cold conditions. However, artificial accelerators added to the concrete can overcome this deficiency (Thomas, 2007, 6, 8-9). Additionally, concrete that is not cast-in-place but is rather pre-cast in a special facility could be set in temperature controlled conditions, eliminating this concern.

Another common concern regarding use of fly ash as a supplementary cementitious material is the potential leaching (into water) and volatilization (into air) of hazardous substances, in particular mercury (Garcia, 2014; Loreti Group, 2009, 22; Gustin and Ladwig, 2004, 320). Mercury is contained in all types of coal and is present in fly ash as well. A literature review by the Loreti Group (2009, 22-25) as well as a study by Gustin and Ladwig (2004) found that any leaching of mercury from concrete made with fly ash over its lifespan was well within the Clean Water Act approved limits. Additionally, though the Environmental Protection Agency regulates CCPs, it does not regulate, and in fact encourages, what it considers beneficial uses of these products, one of which is encapsulated reuse in concrete (USEPA, 2014c, 4). This is likely due to the low likelihood of leaching and volatilization, as well as the fact that each ton of fly ash used as an SCM saves the equivalent of 455 days' worth of solid waste from a landfill (ACAA, 2009, 1).

Due to the fact that there are many coal plants in the northwest, the city of Seattle can easily obtain fly ash concrete from local sources. For instance, the fly ash that Lafarge uses in its cement mixtures comes from Centralia, WA.

Blast Furnace Slag

Blast Furnace Slag is a waste product that results from the manufacture of iron or steel, made up of lime, aluminates and silicates (Provis et al., 2008, 28; National Slag Association, 2013). Unlike fly ash, which is most often used to replace cement itself, blast furnace slag replaces clinker in the formation of the cement (Provis et al., 2008, 28). Slag is typically transported in a granular form from the ironworks to a cement plant, where it is dried and finely ground before being added to the cement mixture (Shogren, 2015).

Granulated Slag waiting to be dried *A slag grinder* Source: Author

Also unlike fly ash, high volume slag is better accepted for use in paving projects. Building code permits use of up to 50% replacement of clinker with slag in paving projects, and it is not uncommon to use 70-80% slag cement in structural projects. For instance, some of the cement used in Seattle's seawall project will contain between 60% and 80% slag (Shogren, 2015; Read, 2015).

Slag cement suffers the same drawbacks as fly ash cement in regards to its low early strength, but again, this can be improved by reducing the water to cement ratio (Shogren, 2015). Like other SCM, slag has the benefits of low heat of hydration, high long term strength and durability, excellent resistance to sulfate, and reduced environmental impacts through conservation of resources and reduced landfilling (Loreti Group, 2009, 10, Shogren, 2015).

Blended Cement being tested for sulfate resistance Source: Author

Due to the general absence of metal manufacturing facilities in the northwest, slag that is used in Seattle projects general comes from the eastern part of the US, particularly the rust belt states, or from Asia. Surprisingly, it is both cheaper and less GHG-intensive to import granulated slag from Kawasaki, Japan than it is to obtain it from the east coast and Midwest. This is because shipping materials by ocean vessel is cheaper than by rail, and because the vessels would be making the trip from Asia to the US empty otherwise, so greenhouse gas accounting practices do not count the fuel use from the ocean vessel (Shogren, 2015, Read, 2015).

Silica Fume

Though used less commonly and in smaller quantities than blast furnace slag and fly ash, silica fume is another important pozzolan (USEPA 2010b, 32). It is a byproduct of the creation of certain metals and alloys, and is made primarily of silicon dioxide (SiO_2). Due to its very fine particle size, it is highly reactive and can result in extremely high strength concrete, capable of bearing over 15,000 pounds per square inch (psi) (SFA, 2014, PCA, 2014).

When used on its own, silica fume has a number of drawbacks. In most cases, it can only be used in small amounts (typically between 5-10% replacement), which reduces its efficacy in curtailing greenhouse gas emissions (Medhat and Thomas, 2002, 341). Additionally, it increases water demand, has a higher cost than other SCM and limestone, can present handling difficulties (Thomas et al., 1999, 2107).

However, when silica fume is combined with fly ash or slag in what is known as a *ternary blend*, some of these negative aspects are reduced (Medhat and Thomas, 2002, 348; Thomas et al., 1999, 1208). Thomas et al. (1999, 1208) ran tests involving a ternary blend with fly ash and silica fume, and found

- "Silica fume compensates for low early strength of concrete with low CaO fly ash.
- Fly ash increases long-term strength development of silica fume concrete.
- Fly ash offsets increased water demand of silica fume.
- Silica fume reduces the normally high levels of high CaO fly ash required for sulphate resistance and ASR prevention.
- Very high resistance to chloride ion penetration can be obtained with ternary blends.
- Low CaO fly ash compensates for higher heat release from Type 10SF cement.
- The relatively low cost of fly ash offsets the increased cost of silica fume."

Thus these ternary blends may be useful in meeting specifications for individual projects while maximizing the GHG reduction from use of SCM.

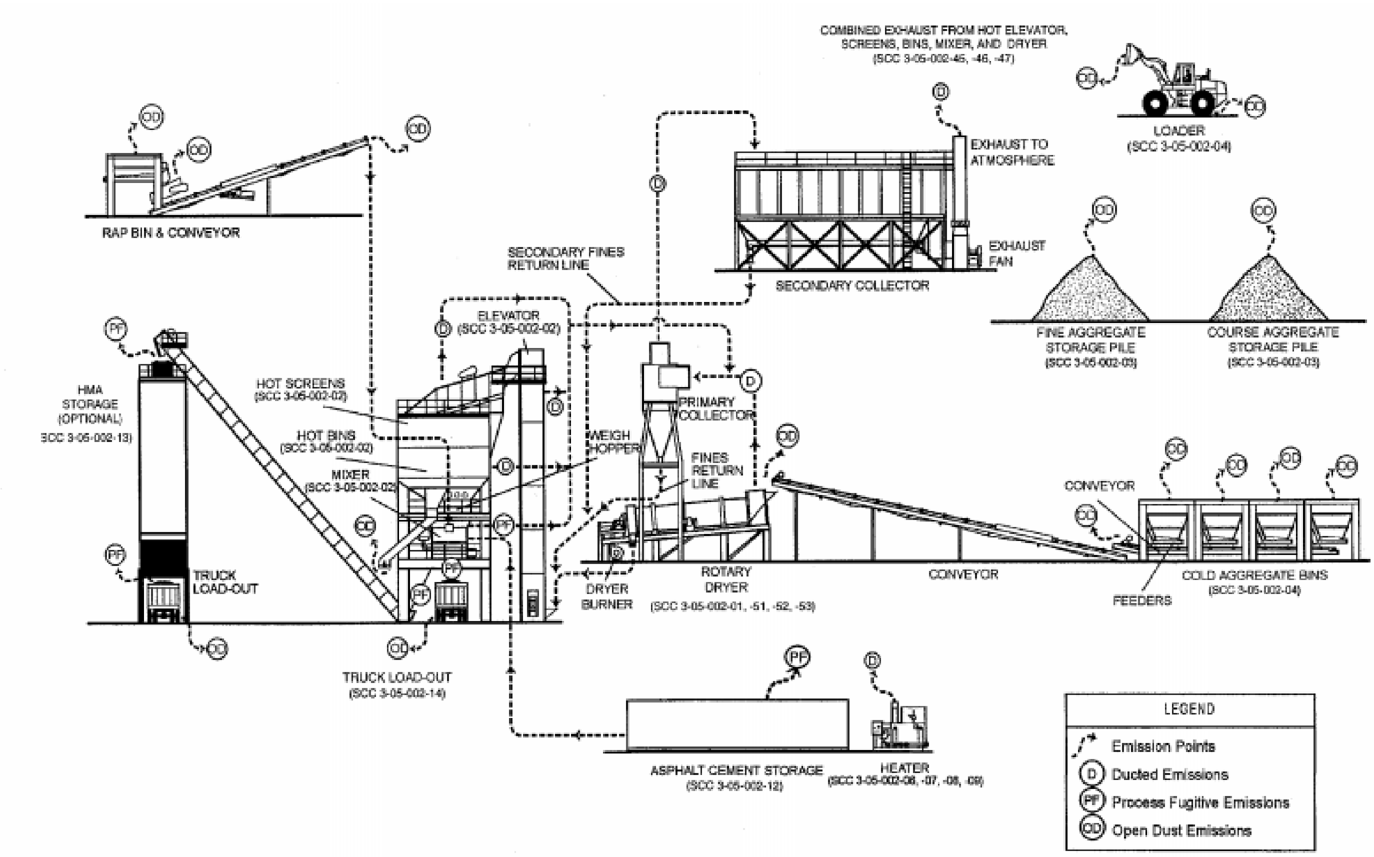
Asphalt

Asphalt concrete, also known as blacktop or tarmac, but typically referred to simply as asphalt, is a material used almost exclusively as a pavement (APA-MI, 2008; NAPA, 2015b). Like cement concrete, it is made up of a cementing substance that binds aggregates together to form a hard surface. The difference lies in the fact that, while Portland cement is derived from limestone, asphalt cement is a product of crude oil (APA-MI, 2008). This cement is then combined with aggregates such as sand and rock to form a paving material.

An asphalt roadway Source: Chromalox Thermal Technologies

Though asphalt occurs naturally in some lakes and rock formations, and was used in some ancient societies as a sealant, it was not until the latter half of the 19^{th} century that it was used widely as a pavement (NAPA, 2015b). Today, asphalt covers roughly 2.4 million miles of roads in the US, 93% of all roads, and is a $30 billion industry (NAPA, 2015a).

The most common type of asphalt is Hot Mix Asphalt, or HMA. HMA is manufactured by heating the binding material and aggregates to 300 degrees Fahrenheit or higher in order to combine them and make them workable for paving (Hurley and Prowell, 2005, 1; Bower et al, 2012, 9). The figure below shows the process through which HMA is made.



Hot Mix Asphalt Manufacturing Process Source: Keches and Leblanc, 2007

Where do the GHGs come from?

Unlike cement concrete, in which roughly half the emissions are a result of the chemical reaction that occurs during the manufacturing process, asphalt concrete's emissions come almost solely from the energy used to heat the mixture. Because the temperature needed is much lower than that of cement (300 degrees Fahrenheit compared to 2500 degrees Fahrenheit), the emissions from asphalt are also far lower on a ton by ton basis. On average, each ton of HMA results in .06 MTCO2e from energy use, including energy used to extract materials (USEPA, 2010a, 5). Because this number is relatively low, the emissions from transportation of materials becomes significant. The USEPA's calculation of the average transportation emissions for a ton of HMA is .05MTCO2e/ton (USEPA, 2010a, 5-6). This produces a total of .11 MTCO2e/ton of HMA on average.

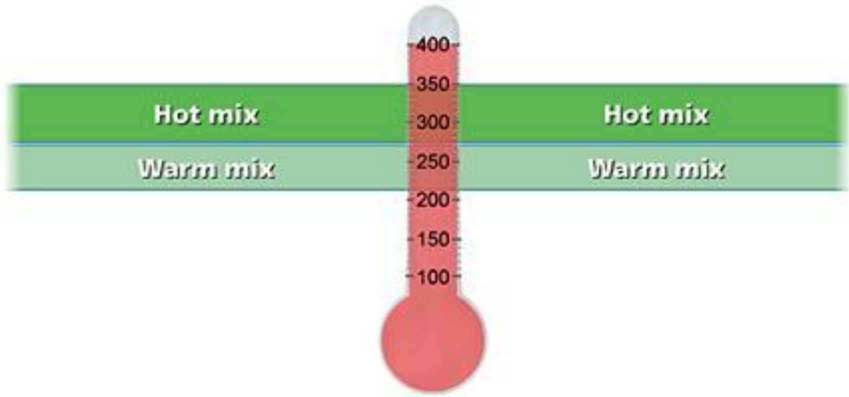
Of course, the actual amount of emissions will vary greatly depending on the source of energy used to heat the mixture—asphalt manufactured using hydroelectric power will have almost no emissions, whereas asphalt created using coal power may have more than the national average. In some cases, many fuels are used at different points in the process (NAPA, 2015a). Likewise, asphalt that is transported very short distances from the mixing plant can have significantly less emissions. This is why plant-level data is important for truly accurate results.

How can they be reduced?

Though the emissions from asphalt concrete are far less on a ton per ton basis when compared with cement concrete, the fact that over 500 million tons of it is used in the US every year means that the total emissions are significant (APA-MI, 2008). If all of this asphalt was HMA made and transported under "average" conditions, this would result in nearly 50 million MTCO2e per year. Fortunately, there are three technological methods of reducing asphalt's per-ton emissions. The first two, Warm Mix Asphalt (WMA) and Cold Mix Asphalt (CMA) involve reducing the temperature to which the asphalt mixture is heated (and thus reducing the energy used) and the third involves using recycled asphalt pavement or shingles in place of virgin materials, in order to reduce the energy from materials extraction.

Warm Mix Asphalt

As the name implies, Warm Mix Asphalt (WMA) is asphalt that does not need to be heated to as high of temperatures as HMA. There are a variety of technologies and products available that allow manufacturers to create asphalt that performs to the same standards as HMA but that require up to 20% less heat, 30% less fuel energy and thus 30% less GHG emissions (Hurley and Prowell, 2005, 1).



HMA and WMA Temperatures Source: Pavement Interactive

One common method of creating WMA involves using an organic wax such as Sasobit® to lower the asphalt's viscosity and thus decrease the working temperature needed. Such substances need only be added at a 1%-3% rate by mass of the binder in order to achieve this (Hurley and Prowell, 2). In addition to organic waxes, chemicals, foams such as Gencor®, Green Machine Ultrafoam GX®, and Aquablack™, and certain minerals can achieve the same effect of decreasing working temperature (USDOT, 2015b, 4; Bower et al., 2012, 13-18). Many of these technologies and products can be incorporated with little or no modifications to asphalt manufacturing plants, making them very feasible (USDOT, 2015b, 3-4).

The Washington State Department of Transportation conducted an extensive study in 2011 to determine how the various WMA technologies performed compared to each other and to HMA, both in the field and in the laboratory. They determined that all of the WMA technologies tested, all performed at or above the level of HMA, except "the rutting performance (IDT) in the laboratory of the Gencor® and water injection mixes, and fatigue by the Sasobit®, though in the field none of the WMA sections have shown significant rutting or fatigue," (Bower et al., 2012, 93).

In addition to emissions reductions, some of the co-benefits of WMA use are:

- Energy Savings (USDOT, 2015b, 3; Hurley and Prowell, 2005, 1; NDDOT, 2014, 6);
- Improved compaction and performance (USDOT, 2015b, 3; Hurley and Prowell, 2005, 1);

- Reductions in fumes and odors—good for workers (USDOT, 2015b, 3; NAPA, 2014, 4; NDDOT, 2015, 6);
- Can incorporate recycled asphalt pavement (USDOT, 2015b, 3; USDOT, 2013, 40; Buss et al., 2015, 1), and;
- Workable in cooler climates, extending the paving season (USDOT, 2015b, 3; NDDOT, 2014, 6).

Due to all of these factors, WMA is beginning to gain widespread acceptance in the construction industry. According to the National Asphalt Pavement Association (2014, 4), WMA use increased from 86.7 tons in 2012 to 106.4 tons in 2013, a 23% increase. WMA made up more than 30% of the total asphalt market in the latter year.

In 2013, the Seattle Department of Transportation (SDOT), Seattle Public Utilities (SPU) and Seattle City Light (SCL) combined used 24,692 tons of Warm Mix Asphalt and 10,442 tons of Hot Mix Asphalt in their open bid projects. However, all of the WMA use occurred in 3 of the 22 projects studied, all of which were undertaken by SDOT (Tracy and Axelrod, 2014, 5). There is thus sufficient opportunity for the City of Seattle to increase its use of WMA.

Eugene, Oregon has also used WMA extensively. In 2009, over 20,000 tons of WMA was used to pave city streets, and the program continues (City of Eugene Public Works Administration, 2009). Portland, Oregon has also begun a pilot program of using WMA, finding comparable quality to WMA and long-term benefits. The study did note, however, that WMA can cost up to $4 more per ton, depending on the method of manufacture (City of Portland, 2013, 1-2).

Cold Mix Asphalt

Unlike Warm Mix Asphalt, Cold Mix Asphalt (CMA) is not widely accepted or used, due to high air-void content, long curing times and a low early-life strength (Gomez-Meijide and Perez, 2014, 520). CMA use is currently limited only to minor road repair, such as filling potholes or upgrading thin pavements on small, local roads (ASMG, 2015). While its use is limited, the low temperatures needed (approximately 200 degrees Fahrenheit) mean that emissions can likely be reduced to 60% the level of HMA, though emissions from CMA have not as of yet been studied (NDDOT, 2015, 3; USEPA, 2010a, 9). The City of Portland is currently testing CMA for use in pavement patching (City of Portland, 2013, 2).

Recycled/Reclaimed Asphalt Pavement and Shingles

The final strategy for reducing emissions from asphalt manufacture involves taking old asphalt pavement, grinding it, and using it again as aggregate and binder for new asphalt pavement (USDOT, 2011, 2). Additionally, asphalt shingles from roofs can be melted down to use as asphalt binder (NAPA, 2014, 4). Recycled Asphalt Pavement and Recycled Asphalt Shingles are known as RAP and RAS, respectively. It is estimated that 99% of all asphalt pavement—67.8 million tons—is recycled, though asphalt shingle recycling is newer and not nearly as widespread, with only 11.6 million tons being recycled in 2014 (NAPA, 2014, 4). In Seattle, recycling asphalt pavement is required by law, and recycling asphalt shingles will be required by law beginning in 2015 (Seattle Public Utilities, 2014b, 8).

Recycled Asphalt Pavement Source: Minnesota DOT

The GHG benefit of using recycled materials is that the emissions associated with obtaining and transporting virgin materials are eliminated. The USEPA (2010a, 7) estimates that using 100% recycled inputs results, on average, reduces emissions from .11MTCO2e/ton of asphalt to .03 MTCO2e/ton of asphalt—a reduction of nearly 73%. However, using 100% RAP is not technically feasible. On average, RAP is only used at a 12% replacement rate, though many state DOTs allow up to 29% RAP in in their asphalt pavements (USDOT, 2011, 8-9). Indeed, study by USDOT has shown that asphalt with 30% RAP behaves identically to asphalt with all virgin materials (USDOT, 2011, 38). RAS, on the other hand, can be successfully used at levels up to 5% (Yang et al., 2014, 137). Assuming a 30% replacement, emissions could conceivably be reduced by roughly 22%.

Combining WMA and RAP in combination can further decrease the emissions factor per ton of asphalt. However, testing within Seattle Public Utilities has found that asphalt made with a combination of RAS and WMA does not perform up to City standards (Read, 2015).

Co-benefits of using RAP and RAS include:

- Decreased landfilling (USEPA 2014a, 6);
- Decreased crude oil demand (USDOT, 2011, 2);
- Decreased transportation costs (USEPA, 2014a, 6; USDOT, 2011, 1), and;
- Decreased energy costs (USDOT, 2011, 1).

Planning Techniques for Reducing Concrete in the Built Environment

While engineering technologies such as SCMs, WMA, RAP and RAS are very useful for reducing the emissions associated with each ton of cement or asphalt concrete a city uses in its projects, the most effective strategy for eliminating the GHGs associated with these materials is to reduce their overall use whenever possible.

Reduction of impervious surfaces is an important topic in urban planning and design, and the literature has many examples of techniques for reducing impervious surfaces in the built environment. There are a number of reasons for reducing impervious surfaces, including improving stormwater drainage, improving water quality, mitigating urban heat island effect, habitat loss and degradation, carbon sequestration, and aesthetics (Barnes et al., 2012, 4; Arnold and Gibbons, 1996, 245-246; Seattle Public Utilities, 2014a, 3; City of Chicago, 2008. 6; Brabec et al., 2002, 499). While these strategies are expressly designed to serve other purposes than GHG reduction from materials, the fact that they minimize use of concrete means that they reach the same end goal.

Green Stormwater Infrastructure

One set of planning techniques that has the potential to significantly reduce GHG emissions by eliminating use of concrete is Green Stormwater Infrastructure (GSI), also known as Low-Impact Development (LID) or Stormwater Control Measures (SCM) (Seattle Public Utilities, 2014a, 1; USEPA, 2013, 1). To avoid confusion with *supplementary cementitious materials,* these are here forth referred to as GSI.

GSI "mimics natural ecological function by cleaning, slowing, and/or reducing runoff close to where it falls as rain. GSI uses infiltration, evaporation, filtration or rainwater harvesting and reuse. When used in the public right-of-way (street and planting strip), GSI may be referred to as 'natural drainage systems'" (Seattle Public Utilities, 2013, 1). There are a variety of GSI techniques, including rain gardens/bioswales, permeable pavement, green roofs, urban canopy cover, and rain barrels, to name a few (Seattle Public Utilities 2014a 1, USEPA, 2013, 13). While each of these have a number of benefits, not all reduce the amount of cement or asphalt used in the built environment. For instance, a green roof, while beneficial for stormwater management and mitigating urban heat island effect, does not eliminate the concrete beneath it. Indeed, in some cases, extra structural support (i.e. cement concrete) is needed to support the weight of the plants (USEPA, 2008b, 4).

Installation of rain gardens, bioswales and natural drainage systems, on the other hand, does have the potential to reduce concrete. This is because these GSI techniques can involve replacing existing concrete with soil and plants. For instance, the first bioswale built in the public right-of-way in Seattle involved narrowing of the street, resulting in an 11% reduction of impervious surface (Seattle Public Utilities, 2015). Even when swales and rain gardens replace existing planting strips, they can still eliminate the need for concrete pipes to convey stormwater, as was the case with the swale project at the Oregon Museum of Science and Industry (City of Portland, 2005, 5). Though the literature on GSI only speaks of GHG reductions in regards to the sequestration power of the plants used, the potential from GHG reductions from eliminating cement and asphalt are likely higher if a bioswale or other GSI is constructed on an area that was once 100% concrete (Flynn and Traver, 2013, 14; Seattle Public Utilities, 2014a, 2; USEPA, 2013, 25).

Street Narrowed to make room for GSI Source: Design Sponge

Urban Parks, Forests and Green Site Design

Investing in urban parks and forests are another way of reducing the amount of concrete used in a city. *Brownfield sites,* which are "abandoned, environmentally contaminated industrial or commercial sites," are found in many cities and are excellent candidates to new parks, once any toxics are cleaned up by plants and microbes (ASLA, 2015). By investing in a park or an urban forest rather than building new grey infrastructure on the site, the site becomes a community amenity, in addition to reducing the need for more concrete in the urban environment (ASLA, 2013). Parking lots are also candidates for becoming parks, as happened in Los Angeles with the Spring Street Park. In that case, although the park uses some concrete, it did eliminate a significant amount of cement and asphalt, which otherwise would have required repaving on a regular basis (Meinhold, 2013).

Spring Street Park in LA, which replaced a parking lot Source: Lehrer Architects

Investment in an entire park is not necessary to reduce the amount of concrete in the urban environment, however. Simply replacing portions of a parking lot or other impervious site with vegetation reduces the materials-related GHG emissions, mitigates heat island effect and reduces stormwater runoff (Onishi et al., 2010, 323).

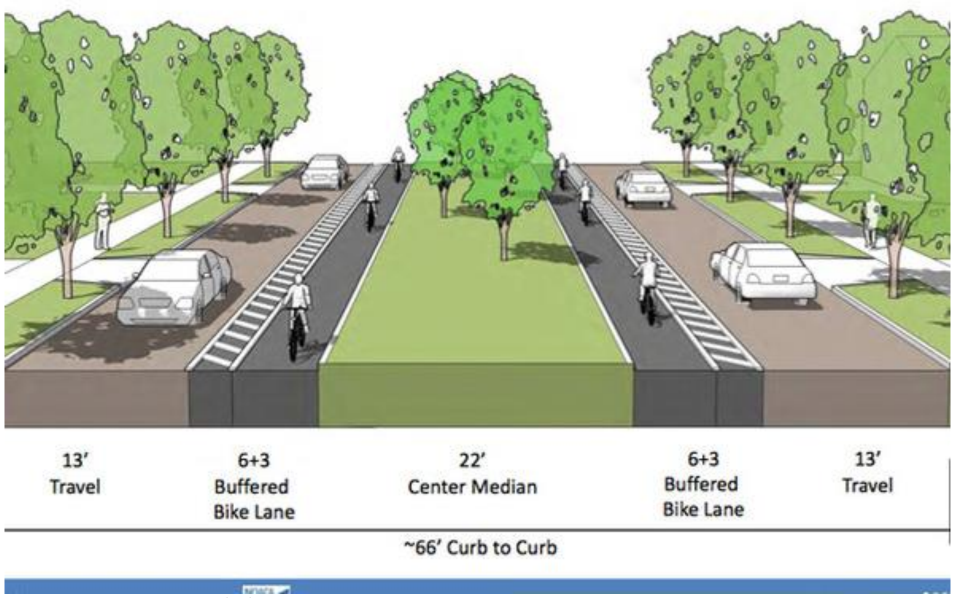
Green site design for buildings also can achieve this purpose. Chicago's *Adding Green to Urban Design* Plan is an excellent example of this. The plan specifies that site designs should include landscaped areas whenever possible, with a diversity of plant and tree species (City of Chicago, 2008, 19). The plan also encourages the adoption of "sustainable landscape standards" for areas including public owned plazas and grounds around public buildings (City of Chicago, 2008, 27). Again, while these strategies do not directly name reduction of GHGs from concrete as a goal, they can succeed in achieving this goal.

The US Green Building Council's LEED (Leadership in Energy and Environmental Design) rating system also has a number of credits for sites that directly or indirectly encourage reduction of cement and asphalt in site design, including restoring habitat, investing in open space, a minimum of 25% of which must be vegetated, investing in stormwater management practices, and mitigating heat island effect (USGBC, 2015, 34-38).

Road Diets and Complete Streets

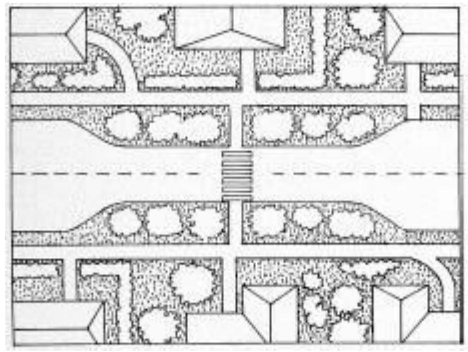
Finally, with respect to roads in particular, a variety of traffic calming measures can reduce concrete in the built environment. *Road Diets* are a planning technique in which number of lanes and/or lane widths are decreased. The purpose of a road diet is to promote traffic calming—that is, slower vehicle speeds and greater pedestrian and bike safety (SDOT, 2015, USDOT, 2015a). The "classic" road diet, as shown below, simply involves re-dedication of lanes, rather than a reduction in impervious surface. However, by combining road diets with other traffic calming measures, concrete-related GHGs can be reduced.

A "classic" road diet, as defined by Federal Highway Administration Source: USDOT



A greener road diet Source: GCBL

Replacing the middle lane in the first picture with a green median barrier benefits pedestrians trying to cross the street and thus qualifies as a traffic calming measure, but when this median is covered in turf, or better still a GSI, GHG reductions occur. (USDOT, 2015a).



A "choker" covered with vegetation Source: USDOT

Traffic calming can also result in reduction in the curb lane, whether only in one area (known as a "choker" or "chicane") or for the full length of a roadway. This also affords an opportunity to replace impermeable concrete surfaces with vegetation, in addition to enhancing pedestrian visibility and reducing crossing distance (USDOT, 2015a; SDOT 2015).

Finally, traffic circles are another traffic calming measure that affords the opportunity to reduce impervious surface. Traffic circles have been employed extensively in the City of Seattle, and serve to reduce traffic speeds as well as reduce the total impervious surface in the built environment (SDOT, 2015).

A vegetated traffic circle in Seattle Source: SDOT

Conclusions

Cement and Asphalt are both GHG-intensive materials that are used in large quantities. However, there are many planning techniques and engineering technologies already in use that can be used to reduce these emissions. Besides being proven to significantly reduce GHGs, these techniques and technologies also have a number of co-benefits that make them desirable for use in construction projects.

Policies for Reducing Emissions from Cement and Asphalt Purchasing

Given that there are several ways to reduce the emissions that result from the manufacture of cement and asphalt, local government officials then must determine how they can implement policies that will encourage or mandate the use of low-GHG alternatives while still meeting the schedule, cost and performance requirements of any given project. This is perhaps the most difficult part of the process, because it requires the changing of technical specifications and policies as well as the attitudes and beliefs of project managers, engineers, planners, and department executives. It is also difficult because the literature does not provide a wealth of information on this topic as it does for technical reduction methods.

Cement

The section on cement above listed a variety of ways that emissions from cement manufacturing can be reduced. However, most of these techniques involve changes to the cement plant itself, something that city officials have little or no control over. One area in which local governments do have influence is in reducing the clinker content of the cement by requiring or encouraging the use of Supplementary Cementitious Materials (SCMs) such as fly ash and blast furnace slag.

Strategies for the City to reduce GHG emissions from its cement purchasing fall into four categories: mandating minimum SCM use, raising allowable SCM use, providing financial incentives for SCM use, and requiring Environmental Product Declarations, all of which are discussed below.

Setting Mandatory Minimums

The Seattle Department of Transportation (SDOT), in addition to being a leader in inventorying emissions from construction materials, has also taken steps to reduce these emissions. As part of its environmental management program, “GreenDOT,” SDOT has successfully implemented a number of policies to encourage the use of low GHG concrete (Sound Transit, 2014, A.9; Healy, 2014).

SDOT currently requires all sidewalks that it installs use a concrete mix that contains a 25% replacement of portland cement with either fly ash or blast furnace slag, thus reducing emissions from sidewalk construction by 25% (SDOT Blog, 2011; Healy, 2014). SDOT added two pozzolan-specific specs to the city’s standard specs so that project specifiers could call out pozzolan use—these are “Non-Roadway Cement Concrete w/ 25% pozzolans” and “Roadway Cement Concrete w/ 25% pozzolans.” These specs indicate that for this item, a minimum of 25% pozzolans must be used (City of Seattle, 2014, 5-25). Though these specs have been around for several years, SDOT continues to be the only department within the city that calls out these specs, meaning that, while projects from other departments are likely using some level of SCMs, they are not being asked for specifically (Tracy and Axelrod, 2014, 4).

One concern around mandating minimum pozzolan replacement is that some feel it may transfer liability from the contractor to the specifying agency if something goes wrong (Sound Transit, 2014, B.21). Though SDOT has not run into issues with this in its 25% pozzolan sidewalk program, sidewalks are generally lower risk than roadways, bridges, or structures. This may thus be a legitimate concern. An expert on SCMs from Lafarge USA also suggested that mandatory minimums are perhaps not the best way to go for this reason (Shogren, 2015).

Raising Allowable Maximums

Additionally, there is another restraining factor that keeps local governments from using more SCMs. Use of fly ash and slag are often capped at percentages that are lower that what the literature suggests is feasible, and also in some cases at percentages that are lower than caps put in place by the state agencies, as is the case between SDOT and the Washington State Department of Transportation (WSDOT) (Sound Transit, 2014, A.6). Even with these lower-than-necessary limits, it would appear that most projects are replacing cement at well below the allowable maximum. The table below shows the results of a survey of SDOT and WSDOT projects. As the table makes clear, actual cement replacements are in most cases not reaching allowable maximums.

Application	Allowed Max. Fly Ash by either WSDOT or SDOT	Actual Max. Fly Ash in WSDOT or SDOT Mixes	Allowed Max. Slag by either WSDOT or SDOT	Actual Max. Slag in Peer Agency Mixes
General Purpose	35%	25%	50%	35%
Roadway Concrete	25%	25%	25%	25%
Bridge Decks	20%	16.7%	30%	0%
Elevated Approach	20%	16.7%	30%	0%
Temp. Guide Walls	Not Specified	0%	Not Specified	50%
Underwater	35%	0%	50%	0%
Pilings / Drilled Shafts	35%	25%	50%	50%

Allowed Versus Actual Replacement in WSDOT and SDOT Mixes Source: Sound Transit

It is thus likely that raising maximum amounts of fly ash or slag used, by itself, would not be an effective strategy in increasing SCM use. However, used in combination with other strategies, it could be effective in raising the total use of SCMs.

Financial Incentives

Another strategy that SDOT has used to reduce GHG emissions from cement concrete is incentivizing the reduction of cement content per cubic yard of concrete in road pavement (Sound Transit, 2014, A.9). This is calculated from the following equation:

"Portland Cement Adjustment = (maximum pounds of cementitious material per class – pounds of Portland cement in mix) x Q x $.09 Where Q is the volume in cubic yards of cement concrete installed and is calculated by taking the area of the concrete surface installed times the depth of the concrete as detailed on the Drawings or Standard Plans," (Sound Transit, 2014, A.9).

Through this incentive spec, the contractor gets money back for each pound of cement reduced in road construction. Monetary incentives have several benefits, including encouragement of contractors to save money by reducing concrete, no liability issues, and flexibility for the contractor in deciding which cement mix is best for a project (Sound Transit, 2014, A.9; Healy, 2014; Hoffman; 2015). For variable mix roadway cement concrete, the maximum allowable cement/CY of concrete is 675 lbs., and the minimum is 505 lbs., allowing contractors to replace up to 25% of the cement in the mix with SCMs (City of Seattle, 2014, 5-25).

Environmental Product Declarations

An as-of-yet untested but potential strategy for reducing GHG emissions from cement purchasing is requiring environmental product declarations (EPDs) for cement mixes. This strategy was the one ultimately recommended to Sound Transit by Sound Transit (2014, B19-B.20). An Environmental Product Declaration is "a verified document that reports environmental data of products based on life cycle assessment and other relevant information…" Emissions factors (called Global Warming Potentials or GWP by EPD International) are one of the main metrics produced in an EPD (EPD Intl., 2015).

Per the recommendation by Sound Transit (2014, B.20), concrete suppliers would be required to produce EPDs for the concrete mixes they intended to use in City projects. They would then be required to produce two alternatives—one in which the GWP was 20% less than the Northwest Industry Average and one in which the GWP was 40% less than the industry average, thus allowing the agency to weigh the emissions reductions of the alternatives against the cost impacts.

One potential issue does exist with this method. One issue is cost to concrete suppliers. Each EPD could cost a concrete supplier $1,000 to $5,000, a cost that would be passed on to the agency requiring it (Sound Transit, 2014, B.21).

Asphalt

Several agencies, including SDOT, the City of Eugene and the City of Portland have used Warm Mix Asphalt (WMA) as part of a campaign of emissions reductions, but it seems that this usage of WMA was the result of project engineers deciding to specify it, rather than an incentive or mandate (City of Eugene Public Works Administration, 2009; City of Portland, 2013, 1-2; Healy, 2014). Additionally, WMA, Recycled Asphalt Pavement and Recycled Asphalt Shingles (RAP, and RAS, respectively) are being used in other cases due to concerns such as cost and not environmental ones (WSDOT, 2011, 7).

However, though the types of changes suggested or implemented for cement concrete have not yet been suggested for asphalt concrete, the same strategies—namely *mandatory minimums, increased allowable maximums, financial incentives and* use of *Environmental Product Declarations* can all be applied in similar ways.

Conclusion

There are several changes to policies or specifications that can be utilized to encourage the use of low-GHG concrete alternatives, each of which has associated pros and cons. Some of these changes have been implemented and some are only theoretical at this point, but local governments ought to weigh all of these options when devising strategies for emissions reductions based on their own capabilities and political context.

Chapter 3: Methodology

Five Milestones for Quantifying and Reducing Emissions from Cement and Asphalt Purchasing

Having been established that local governments can and should mitigate its emissions from cement and asphalt purchasing, the question becomes, “how should they?” Section B develops a plan for quantifying and reducing these emissions, following the Climate Milestones framework developed by ICLEI (Local Governments for Sustainability). The City of Seattle currently follows GHG Accounting and Climate Action Planning methodologies developed in part by ICLEI, so this methodology follows uses the same framework in order to ease the transition to accounting for these emissions.

Climate Milestones Source: ICLEI

The climate milestone wheel, pictured above, directs cities to mitigate their emissions through five steps. These five steps are all contained within the sections to follow, and their alignment is as follows:

The **Materials Reporting Form & GHG Calculator** covers **Milestones One and Five** by allowing local governments to quantify both the amounts of cement and asphalt concrete that they purchase, as well as the emissions associated with these materials. This serves as a baseline for inventorying GHG emissions as well as method of quantifying emissions from finished projects to verify and track the usefulness of emissions reduction strategies.

The **Recommendation of Strategies for Emissions Reductions** covers **Milestones Two** and **Three** by devising a path by which local governments can set a GHG reduction target and incorporate strategies to reduce emissions from cement and asphalt purchasing into their existing Climate Action Plan.

The **Alternatives Evaluation Table** represents **Milestone Four** on the wheel, by allowing project managers, designers, and staff to evaluate different options for emissions reductions during the design phase of any given construction project.

Purpose and Structure of the Materials Reporting Form & GHG Calculator

Determining a baseline of GHG emissions is the first step in any climate change mitigation project or program, and is step one on the Climate Milestones Wheel (ICLEI, 2015). Without a baseline, goals cannot be set and progress cannot be tracked. Because many local governments do not currently have a standard reporting practice for its construction-related GHG emissions, they cannot adequately manage these emissions. The main bottlenecks to reporting these emissions are

1. GHG accountants do not have information on the quantities of materials that are used in city projects, and
2. They do not have information regarding whether low-GHG substitutes, such as supplementary cementitious materials (SCM) or warm mix asphalt (WMA) are being used.

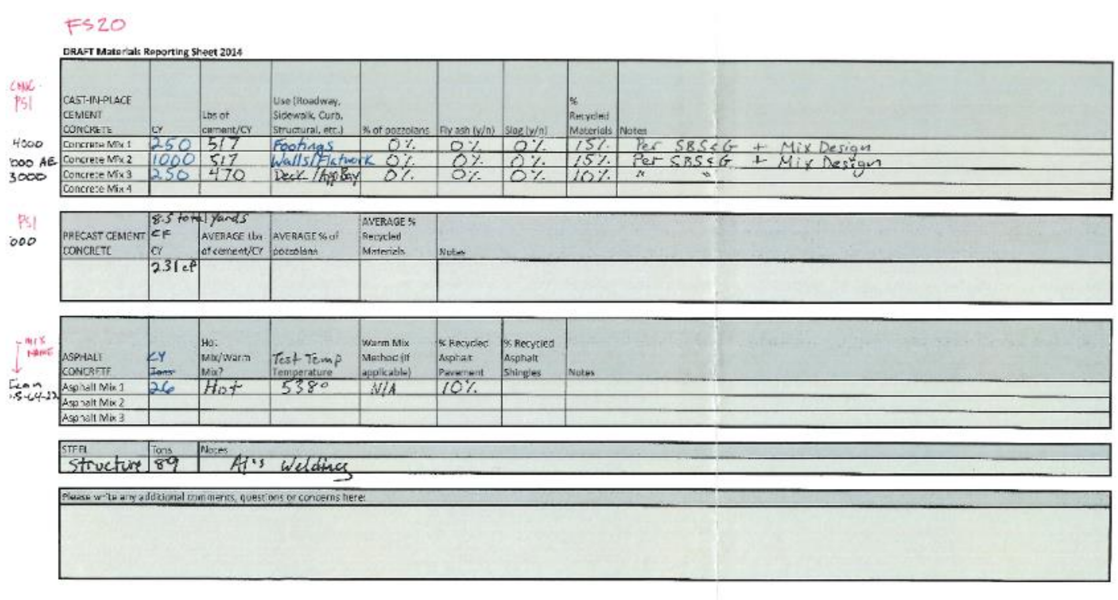
This information is attainable, as proven by the Sound Transit (2014) technical memo. What is needed is a simple reporting form that the project manager can fill out and submit at the conclusion of the project, pulling information from a variety of sources, including quantity takeoffs, as built drawings, submittals, and contractor information. This would provide the employees who contribute to a City's Government Operations Inventory the information necessary to begin accounting for the scope three emissions that result from the construction purchasing. Additionally, the form can be filled out during the design phase as an input into the alternatives evaluation process, using information from project specifications, bid forms (if the bid uses the unit price method) and from construction drawings (if unit price data is not available).

	116	802360	TREE ROOT BARRIER	1,220 LF	10.00	12,200-
	117	802610	SEEDED LAWN INSTALLATION	44,276 SF	1.00	44,276-
	118	802700	LANDSCAPE ESTABLISHMENT, MIN. BID = $10,200	1 LS	10,200.00	10,200-
SP	119	802s01	PRUNING	1 LS	3,500.00	3,500-
SP	120	802s02	TREE ROOT EXCAVATION	100 LF	80.00	8,000-
SP	121	802s03	TREE ROOT PRUNING EVALUATION	10 EA	600.00	6,000-
SP	122	803s01	DRIP IRRIGATION WATERING BAG	120 EA	35.00	4,200-
	123	804025	CURB, CEM CONC W/ 25% POZZOLANS	11,034 LF	20.00	220,680-
SP	124	804s01	CURB, PEDESTRIAN CEM CONC	236 LF	50.00	11,800-
SP	125	804s02	CURB, MODIFIED TYPE 410C FOR COMBINATION INLET	16 LF	100.00	1,600-
	126	813120	RESET MONUMENT FRAME AND COVER	27 EA	300.00	8,100-
	127	814030	DETECTABLE WARNING PLATE	111 SF	30.00	3,330-
	128	814205	SIDEWALK, CEM CONC W/ 25% POZZOLANS	9,796 SY	70.00	685,720-

Information on concrete quantities and pozzolan use in a project bid form Source: City of Seattle

The Materials Reporting Form & GHG Calculator was developed using the relevant variables discerned from the literature review above and through discussion with City of Seattle officials, and was reviewed by relevant experts, such as the head of Seattle Public Utilities (SPU)'s Materials Testing Lab, several project managers with Seattle Financial and Administrative Services, the head of the City of Seattle Green Purchasing Network, a Technical Director and tester of SCM mixes for Lafarge North America, and a former employee of SDOT who worked extensively on the GreenDOT program. The feedback from these experts was generally positive—it was generally agreed that project managers had access to the information needed to complete the form, and that it shouldn't take an inordinate amount of time to complete.

An early version of the Materials Reporting Form & GHG Calculator was piloted in The City of Seattle's Fire Station 20 Project. This project, which meets LEED Platinum Certification criteria, used three cast-in-place concrete mixes, one precast mix and one asphalt mix. From the information gathered, and using industry average emissions factors, it is likely that the project resulted in 321.71 MTCO2e. Feedback from David Jackson, project manager for the Fire Station 20 Project, was incorporated into the final version of the form.


FS20

DRAFT Materials Reporting Sheet 2014

CAST-IN-PLACE CEMENT CONCRETE	CY	Lbs of cement/CY	Use (Roadway, Sidewalk, Curb, Structural, etc.)	% of pozzolans	Fly ash (y/n)	Slag (y/n)	% Recycled Materials	Notes
Concrete Mix 1	250	517	Footings	0%	0%	0%	15%	Per SBS&G + Mix Design
Concrete Mix 2	1000	517	Walls/Flatwork	0%	0%	0%	15%	Per SBS&G + Mix Design
Concrete Mix 3	250	470	Deck/App Bay	0%	0%	0%	10%	" "
Concrete Mix 4								

PRECAST CEMENT CONCRETE	CY	AVERAGE Lbs of cement/CY	AVERAGE % of pozzolans	AVERAGE % Recycled Materials	Notes
	8.5 total yards CF 231 cf				

ASPHALT CONCRETE	CY	Hot Mix/Warm Mix?	Temperature	Warm Mix Method (if applicable)	% Recycled Asphalt Pavement	% Recycled Asphalt Shingles	Notes
Asphalt Mix 1	26	Hot	538°	N/A	10%		
Asphalt Mix 2							
Asphalt Mix 3							

STEEL	Tons	Notes
Structure	89	Al's Welding

Please write any additional comments, questions or concerns here:

Pilot Version of Materials Reporting Form Source: Author

One change to the methodology that resulted from professional feedback was to include cells that would auto-populate with emissions information based on the values entered into the form. Originally the form's intent was to be used solely for the purpose of collecting data, which would later be used to calculate GHG emissions. However, by having emissions factors embedded in the form, which use national average emissions data but can be altered to include supplier-specific information, the reporting form also doubles and a GHG calculator.

Additionally, a concern arose that even if the form was complete and usable, it may be difficult to achieve widespread usage (Hoffman, 2015). Other environmental reporting efforts at the city have not had success in getting participation from most or all projects (Mallory, 2014). In order to get near-100% participation, a directive from a department executive might be necessary. Because the city government is split into several semi-autonomous departments, reporting such as that recommended here might have to happen piecemeal, with more departments adopting the standard if they see that the early adopters are having success in inventorying and mitigating their emissions using this or a similar form.

If used, the form will allow for project-level accounting of greenhouse gases advocated by The World Bank (2015), WRI and WBSCD (2003), and Kim et al., (2012). This project-level accounting alone will make the form far more accurate than spend-based methods such as EIO-LCA and CBEI.

Additionally, the form also contributes to the final Climate Milestone, Reporting and Monitoring, by automatically calculating a project's cement- and asphalt-related emissions based on the inputs from the project manager.

The materials reporting form is comprised of three main sections: Cast-in-place cement concrete, pre-cast cement concrete, and asphalt, each of which are discussed below.

Cement and Asphalt Materials Reporting Form and GHG Calculator	Project Name:	Project Manager:	Phone Number:

CAST-IN-PLACE CEMENT CONCRETE	Use (Roadway, Sidewalk, Curb, Structural, etc.)	CY	Lbs cement/CY	% of fly ash or Slag IN CEMENT MIX	% Recycled Materials	Supplier	Notes	Emissions (MTCO2e)
Concrete Mix 1								0.00
Concrete Mix 2								0.00
Concrete Mix 3								0.00
Concrete Mix 4								0.00
Concrete Mix 5								0.00
Concrete Mix 6								0.00
Concrete Mix 7								0.00

PRECAST CEMENT CONCRETE	Item name	CY concrete/item	# of items	Lbs cement/CY	% of Fly ash or Slag IN CEMENT MIX	% Recycled Materials	Supplier	Notes	Emissions (MTCO2e)
Item 1									0
Item 2									0
Item 3									0
Item 4									0
Item 5									0

ASPHALT CONCRETE	Use (Roadway, Pavement Patch etc.)	Weight (Tons)	Hot Mix/Warm Mix?	Temperature	Warm Mix Method (if applicable)	% Recycled Asphalt Pavement	% Recycled Asphalt Shingles	Supplier	Notes	Emissions (MTCO2e)
Asphalt Mix 1										0
Asphalt Mix 2										0
Asphalt Mix 3										0

Please write any additional comments, questions or concerns here:	Total Emissions
	0.00

Materials Reporting Form and GHG Calculator Source: Author

Cast-in-Place Cement Concrete

Cast-in-place (CIP) cement concrete has a wide variety of uses, including roadways, foundations, walls, and beams. It is transported in a truck agitator (“cement truck”), place into forms on site and hardened in the position it will remain (PCA, 2015).

Because CIP cement concrete may be used for many purposes within a project, each with its own mix design, the form has rows to accommodate many different mixes. This allows accurate recording the variables in the columns, rather than using averages, minimums, or maximums.

First, project staff are asked to list the *use* that the concrete mix is for. These text entries would be pulled directly from specifications for the project, no matter what project phase the form was used in. For example, a mix used for a sidewalk might be listed as “Pervious Concrete Sidewalk,” “Sidewalk, Thickened Edge,” “6 in Sidewalk, Cem Concrete,” “Roadway Cem Concrete, Variable Mix,” etc., depending on the specification that is being referred to. This not only helps identify the individual mixes in the form, but also allows GHG accountants to determine if there are any particular uses of concrete that tend to result in more or less emissions, and use this information to determine if there are specific means that can be taken to reduce these emissions.

The next input for each mix is the *total amount of concrete in cubic yards (CY).* In one method of generating inputs for this column, project staff could use a methodology similar to that proposed by Kim et al. (2012) and calculate concrete volume from dimensions expressed in the design documents.

However, as things are wont to change throughout the design and construction process, a much more accurate input into the CY column would come from either from truck ticket data—essentially receipts for the purchased quantities of materials—or from as-built drawings, which show the project as it was actually built. Whatever way the data is generated, a single number representing total cubic yards of concrete for each mix will be placed in each cell in the CY column.

The next input is *pounds of cementitious content per cubic yard of concrete (lbs. cement/CY).* Depending on the type of concrete, the City of Seattle's standard specifications set a minimum value of anywhere from 564 lbs./CY, to 660 lbs./CY (Sound Transit, 2015). There is thus quite a bit a variability in what the cement to aggregate ratio for any given concrete mix might be. It is easy to see how this variable, combined with total cubic yards, will give GHG accountants a total weight of cement used per each mix. It is important to note here that all cementitious material is included in this number. This means that if a project used blended cement with 50% blast furnace slag in each pound of cement, that slag would be counted toward the weight of cement. However, if fly ash was added directly to the concrete mix in place of cement (rather than being a component of the cement itself), that weight of fly ash would not be included in the weight of cement/CY.

Next, each concrete mix is given a value for the *percentage of fly ash and slag in the cement mix*. This variable, unlike the previous one, looks only at SCMs that are a component of blended cement, not SCMs added to the concrete mix. Therefore, a value of 50% in this column means that each pound of cement in the mix contains 50% of combined slag and fly ash content by weight.

The next variable in the cast-in place cement concrete table is *percentage of recycled materials used.* Though using recycled cement concrete as aggregate has a negligible impact in terms of GHG reductions when compared to the emissions reduced from using SCMs, it is beneficial for a number of other reasons, and thus deserves to be tracked. This table seems to be a logical place to record the percentage of recycled materials used in cement concrete.

Finally, the *CO2 emissions* for each line item are calculated, using the following formula:

(CY x Lbs. Cement/CY x (1-% of fly ash and slag) x .9)/2204.62

Where .9 is the industry average emissions factor and 2204.62 is the conversion factor from pounds to metric tons.

Precast Cement Concrete

Precast cement concrete, unlike cast-in-place, is cast in a controlled environment and then shipped to the construction site. It is often used in applications where many identical items are needed, or when it isn't feasible to wait for the concrete to dry on the job site. It is used in a variety of applications, including water and wastewater infrastructure, utility structures, and bridges (NPCA, 2015).

The final three variables in the Materials Reporting Form for precast cement concrete (*% fly ash and slag, and % Recycled Materials)* are the same as those for cast-in-place cement concrete, and thus do not need further discussion. However, some of the variables are different, and are discussed below.

Rather than being listed by concrete mix, precast concrete is listed by item, reflecting the fact that precast concrete comes in discrete items such as lengths of pipe, bridge sections or vaults for water storage. The first variable in the precast table is thus *Item Name*. Like *Use* in the cast-in-place table, this variable is a call-out for the listing the project's specifications. Examples include "Curb, Traffic, Precast," "Service Cabinet Footing," and "Vault, Type 507LA." This allows for accurate tracking of different items as well as comparisons among manufacturers that provide the same item.

The next variable is *cubic yards of concrete per item*. Unlike cast-in-place cement concrete, this information likely can only be gained by looking at the design drawings or at as-built documents—truck ticket data will not give the total cubic yardage of concrete per item. Thus the dimensions of the item, as given in the drawings, will be the best option. This may be a more complex calculation than calculating volumes of concrete needed for roadways or sidewalks if the item has an odd or curved shape—perhaps involving calculus. However, in many cases, computer design programs such as AutoCAD could perform these calculations.

Number of items is the next variable. When multiplied by CY of concrete/item, it will give the total volume of concrete for that item class.

The output of the above calculation would then be multiplied by the *Pounds of Cement per Cubic Yard of Concrete* in order to obtain the total weight of cement used for that item class.

In order to determine *Emissions* for each line item, the following formula is used:

(# of items x CY/item x Lbs. Cement/CY x (1-%fly ash and slag) x .9)/2204.62

With .9 being the industry average emissions factor and 2204.62 being the conversion from Lbs. to metric tons.

Asphalt Concrete

Asphalt concrete is the final table in the form, and has a variety of variables that are distinct from the previous two tables, each of which is discussed below.

The first variable is *Weight in tons*. Unlike cast-in-place cement concrete, which is almost always specified in amounts of cubic yards, asphalt is nearly always specified in tons (City of Seattle, 2014, 5-21 and 5-43).

Next, project staff are asked to specify whether this asphalt mix is *Hot Mix Asphalt (HMA)* or *Warm Mix Asphalt (WMA)*. This will provide the city with data on percentages of HMA and WMA being used in city projects.

Temperature is the next variable, and a very important one. The temperature to which the asphalt in heated determines the amount of fuel used, and thus the emissions that result. One could leave this variable out and assume all HMA to be 350 degrees Fahrenheit and all WMA to be 250 degrees Fahrenheit, but this leaves out a great deal of the potential variability in temperature of the mixes.

Project Staff are also asked to list the *Warm Mix Method* used, if applicable. Examples of warm mix methods to be entered here include “foaming,” “wax,” or “chemical.”

The final two variables for asphalt concrete are *Percentage of Recycled Asphalt Pavement* and *Percentage of Recycled Asphalt Shingles*. Unlike cement concrete, where use of recycled materials has a negligible impact on emissions, RAP and RAS have the potential to reduce a significant proportion of emissions. Though these variables are not currently defined in project documents or tracked in any meaningful way, this is information the project team or contractor would have, and is key to establishing a baseline of emissions for each asphalt mix.

Emissions are then calculated using the following equation:

$$\text{Weight x ((Temperature x .0003) – (.08 x \%RAP + .08 x \%RAS))}$$

With .003 being the average emissions factor per degree of temperature, and .008 being the emissions reduction factor for each percentage of RAP or RAS.

Total Emissions for the project are then calculated by adding the emissions from each line item in the form.

Supplier and Notes

Each row in the reporting form has a *Supplier* cell to name the supplier of that particular mix. This is important for obtaining supplier specific emissions factors (though EPDs or other methods). When this form is used during the design phase of the project, in conjunction with the alternatives evaluation form, it is likely that the supplier will not yet be chosen. However, in many areas there are only a small number of potential suppliers, and so local governments may choose one supplier as the expected supplier, rather than using averages, to determine the total emissions from that mix. This is at the discretion of those completing the form, but should be clearly specified.

Finally, every row in each table has a *Notes* section, in addition to one overall section at the bottom of the form. These cells provide the opportunity for staff using the form to record any problems, issues, or special conditions that would be relevant for GHG accountants to know when using the form to calculate GHG emissions.

Recommendation of Strategies for Emissions Reductions

Once city officials determine a baseline of greenhouse gas emissions from cement and asphalt purchasing using the reporting practices above, the next steps towards mitigation are to set a reduction target and develop a climate action plan that detail strategies that the City should take to reduce those emissions. Building on the information in literature review, this section recommends those strategies which would be most effective.

The strategies recommended here are a result not only of review of the literature but also of several months of work with professionals with officials from the City of Seattle and other relevant institutions. This work involved dozens of meetings, emails, and telephone calls to gain a better understanding of the institutional context and determine what a cement- and asphalt focused climate action plan (or climate action plan section) would look. A few of the departments/organizations that contributed to this understanding include:

- City of Seattle Office of Sustainability;
- Seattle City Light;
- Seattle Public Utilities;
- Seattle Department of Transportation;
- Seattle Office of Finance and Administrative Services;
- King County;
- Lafarge USA, and;
- University of Washington.

The four relevant questions for the climate action planning process are:

- How much actions will reduce emissions;
- How progress will be monitored;
- The overall vision for the sector, and;
- What actions to implement to get there (City of Seattle OSE, 2013).

Encouraging Use of Low-GHG Concrete Alternatives

All of the strategies for encouraging the use of low-GHG concrete alternatives are of potential use. However, some may be more effective than others, and some may be more politically feasible than others, as discussed below.

Setting mandatory minimums is perhaps the most effective way to ensure that SCMs, WMA, RAP, and RAS are used in city construction projects, because it leaves no choice but to use these materials. However, as discussed in the literature review, this approach is the most unpopular with engineers, who balk at the idea of being told how to specify their concrete mixes. Additionally, legal issues may crop up due to liability being shifted to the city. However, because this strategy has been successful for SDOT, it is worth recommending. One potential solution, at least to the legal argument, is to set minimums but allow exceptions if the contractor has a compelling technical reason why the minimum SCM replacement cannot be met for a particular mix. This would transfer liability away from the local government. Additionally, mandatory minimums can be set only for low-risk applications, as SDOT does by only setting mandatory minimums for sidewalks.

Raising allowable maximums to be in line with ASTM standards should be neither difficult nor controversial—unnecessarily low ceilings on use of technologies which have proven safe at higher levels serves no useful purpose. Raising allowable maximums will not necessarily lead to an increase in usage, as discussed in Chapter 2, but provides the opportunity for increased usage nonetheless.

Economic incentives are one strategy that any local government who wishes to encourage use of low-GHG technologies should pursue. It is important, however, that the economic incentive is set at a high enough level to encourage maximum usage. As Sound Transit (2014) reported, the $0.07/lb. incentive employed by SDOT has only been marginally successful. Increasing the amount of money contractors receive back for reducing cement content, increasing use of recycled material, etc. will have a positive correlation with increased use of the desired technologies.

Cities should implement environmental reporting requirements in the form of environmental product declarations. EPDs ensure that emissions factors are accurate and specific to individual suppliers. This allows the local government to choose to work with suppliers who have more efficient processes that reduce the level of emissions per unit of material. Because the cost of environmental product declarations can be high, local governments can make the choice to require only one EPD per supplier, for the suppliers “standard” mix (portland cement concrete or hot mix asphalt), as long as information on the amounts of GHG-reducing technologies used is made available.

Another useful type of reporting would be a “carbon control plan,” similar to an erosion control plan, that could be required of contractors. This plan would require them to at least consider options to reduce the GHGs from within the project (not just from materials, but from fuel use as well). While this plan would be required, there would not need to be an absolute target, such as reducing emissions by 50% over a baseline. Instead the reductions could represent a target, as they do in the City of Seattle WMBE (Women & Minority Owned Businesses) requirements. When a project is required to fulfill a WMBE plan, they have to state their target percentage of WMBEs that they will include in their project, but the contractor is not punished for not meeting this target (City of Seattle, 2015). In this way, contractors could be required to set a target percentage of GHG reductions beyond what is required by law and design documents, and strive to meet this goal. This is just one more opportunity to achieve reductions beyond what the local government itself is able/willing to require.

Reducing Overall Concrete

Local governments should consider changes to specifications in order to encourage greater use of low-GHG concrete alternatives, but should also create plans for coordinating their efforts to reduce overall concrete in the built environment. This involves the coordination of transportation planners, water planners, landscape architects, and urban designers to ensure that construction projects incorporate as much landscaped area as possible. Local governments cannot afford to invest in single-purpose infrastructure; all infrastructure investments should serve multiple purposes simultaneously.

For instance, transportation planners who wish to decrease the number of lanes on a road in order to increase pedestrian safety should work closely with planners in other departments to incorporate GSI into the new design in order to decrease runoff and increase permeable surface, and planners, designers and architects who are designing a new government building should work with water planners and architects to make sure its plaza mitigates runoff, heat island effect and concrete-related GHG emissions through maximum coverage by native plantings.

An effective climate action plan should recommend the use of an executive or legislative requirement that all large capital projects evaluate alternatives for reducing the total quantity of concrete used in the project, in order to determine the extent of GHG and cost savings that could be achieved.

Additionally, local governments could set minimum permeable surface requirements for different types of projects. For instance, any new road construction might be required to include a certain percentage of street trees or plantings, or any new government buildings be required to dedicate a certain percentage of the site to green space.

Alternatives Evaluation Table

Using the methodology described in this thesis, a local government, city department or utility can evaluate alternatives using information gathered using the Materials Reporting Form & GHG Calculator, as well as the emissions reduction target and climate action strategies discussed above. The purpose of the alternatives evaluation is to execute the next step in the Climate Milestones process—implementing the policies and measures identified in the action plan (ICLEI, 2015).

In order for the climate action plan to be successful, politicians and/or department heads must commit to making the recommended changes. Strategies for getting these recommended policies onto the books are beyond the scope of this thesis, but one thing it can do is show what the result of implementing these policies might look like.

The methodology for this portion of the project is based on the Climate Smart Capital Investment Process put forth by the World Bank in Whittington and Lynch (2014), the alternatives evaluation recommended in WRI and WBCSD (2003), and the suggestion by Sound Transit (2014) that environmental product declarations be used to evaluate emissions and costs from low-GHG cement alternatives. Additionally, alternatives evaluation is a hallmark of the rational planning process and has been used for decades.

In order to show how application of the cement and asphalt purchasing climate action plan might play out in the real world, the "alternatives evaluation" recommendation is applied to hypothetical projects that are typical of ones undertaken by a local government. Though large city like Seattle or Portland undertakes dozens of large construction projects each year, running ~50 hypothetical projects through this methodology would be both unwieldy for the scope of this thesis as well as unnecessary for showing how the alternatives evaluation would work. Thus this effort is downscaled to a very small hypothetical city to demonstrate the methodology (discussed in depth in Chapter 4).

The alternatives evaluation table used here is adapted from the one used to evaluate project-level GHG emissions in the Whittington (2014) Climate Smart Capital Investment Planning methodology. However, instead of evaluating emissions from scopes 1 and 2 emissions based on source of energy and energy saving technologies, this alternatives evaluation table evaluates scope 3 emissions resulting from the manufacture of purchased cement and asphalt.

Project Title				
Criteria	**Units**	**Alternative 1**	**Alternative 2**	**Alternative 3**
Scale	Total Cast-in-Place Cement Concrete (CY)			
	Total Precast Cement Concrete (CY)			
	Total Asphalt (tons)			
	Design Descriptor			
GHG-Reducing Technologies - Cement Concrete	Cement/CY			
	MTCO2e/CY			
GHG-Reducing Technologies - Asphalt Concrete	Percentage HMA			
	Percentage Virgin Materials			
	MTCO2e/ton			
Total GHG Emissions	%MTCO2 Compared to Alt One			
	MTCO2e			
Cost of Materials	Percent compared to Alt One			
	Cost			

Alternatives Evaluation Form Source: Author

Three types of information are required to complete this form:

- **Quantities of materials** and **usage of low-GHG technologies** from the Materials Reporting Form;
- **Emissions factors** from industry averages, environmental product declarations or other plant-level data, and;
- **Cost estimates** from project engineers

Three alternative scenarios are evaluated for each project using this methodology. The first, **Alternative One** is the project without any additional GHG-reducing measures beyond what is required. This “conventional” or “baseline” option is in line both with the methodology laid out by the Whittington (2014), as well as WRI and WBCSD (2003) with the concept of “additionalities.” Therefore, if a city had adopted a mandatory minimum of 10% SCMs to be included in any given mix, the conventional mix would have to include 10% SCMs, because that measure was required by law, not a choice of the project designers/engineers.

Alternatives Two and **Three** are proposals for the same project, but with increased amounts of low-GHG technologies used, so that Alternative Two has lower emissions than the Alternative One, and Alternative Three has the lowest emissions of all.

In order to complete the alternatives evaluation, the materials reporting form should be filled out three times, each considering feasible changes in scale and technology to reduce emissions. Once the three reporting forms are filled out, much of the alternatives evaluation table will auto-populate with the correct numbers.

The first set of variables relate to **Scale.** The first three variables are *total cast-in-place cement concrete, total precast concrete,* and *total asphalt concrete.* To calculate these variables, the planners/designers/engineers developing the project would calculate the total of each type of material needed using the Materials Reporting Form. The variables from the Materials Reporting Form would then auto-populate the “scale” row of the Alternatives Evaluation Table as follows:

Type of Material	Reporting Form Cells used	Equation for Alt. Eval Table
Cast-in Place	CY	Sum
Precast	CY concrete/item; # of items	Sum (CY*#of items)
Asphalt	Weight (tons)	Sum

For instance, for cast-in-place, if a project had three mixes, one requiring 1000 CY, one requiring 500 CY and one requiring 800 CY, the value "2300" would be entered into the *Alternative One Total Cast-in-Place Concrete* cell. Likewise, if a project has two different types of asphalt, the tonnage of each would be summed to produce the total value for the *Total Asphalt Concrete* cells.

The Scale alternatives are where project staff should evaluate the use of various planning techniques to reduce the total amount of concrete in the project. While in some cases the total concrete necessary to build the project will be the same for all alternatives, staff should thoroughly evaluate any opportunity to reduce the total amount of concrete used in the project through site design or planning tools (road diets, replacing parts of a concrete pavilion with landscaping, adding street trees to a sidewalk, efficient use of space, reduction of parking, or using wood-frame rather than concrete construction, to name a few). Reducing the scale of concrete used in a project is very the best way to reduce emissions because it eliminates them outright, rather than reducing a portion of them. The *Design Descriptor* row is where the name of the alternative technique is listed (e.g. "Road Diet + Bioswale").

Next, alternatives are generated for **GHG-Reducing Technologies for Cement Concrete.** The first variable in this section is *Cement/Cubic Yard Compared to Alt One*. This information is brought in automatically from the Materials Reporting Form, and is processed by the following equation:

(sum (all "total pounds cement" cells))/ (sum (all "CY" cells))

For *MTCO2e/CY* the equation used to determine for each alternative is:

Sum (all cement "Emissions" cells)/Sum (all "CY" cells)

At the design stage of the project, it will not be known what cement manufacturer will be producing the cement, so regional industry averages should be used for emissions factors. The cells in this row will auto-populate using the EPA emissions factor of .9 pounds CO2e/pound cement if the emissions factor is not changed in the Materials Reporting Form.

The next set of variables deals with **GHG-Reducing Technologies for Asphalt Concrete**. The first two of these variables are expressed in *Percentage HMA*. Therefore, the Alternative One option (all HMA) will always be listed as 100%. If, for *Alternative Two,* 40% of total tonnage of asphalt used in the project was WMA, "60%" would be entered into the *Percentage HMA* cell for that alternative. Unlike the previous rows that auto-populate from the materials reporting form, this row must be entered manually.

Next, the three project alternatives are compared based on *Percentage of Virgin Materials*. The Alternative One option assumes that no recycled material is used, and so will always read 100%, unless a mandatory minimum percentage of recycled materials in required. This row auto-populates with data from the materials reporting form, using the following equation:

Sum (all asphalt rows "(%RAP + %RAS)* tons)" / Sum all asphalt rows "(tons)"

Next, MTCO2e*/ton* is populated using information from the reporting form. Like with cement concrete, an emissions factor based on the national or regional industry average should be used, as factors such as temperature and warm mix method will likely not be known at this point. In the Materials Reporting Form, temperature for HMA is to be set to 350 degrees Fahrenheit, and temperature for WMA should be set to 250 degrees Fahrenheit. The equation used to populate the cells in the Alternatives Evaluation is:

Sum (all asphalt rows "Emissions") / Sum (all asphalt rows "tons")

The next section, **Total GHG Emissions,** is expressed in *MTCO2e*. These values are imported from the *Total Emissions* box in the Materials Reporting Form. The *% MTCO2e compared to Alternative*

One is calculated by dividing the total MTCO2e for each alternative by the MTCO2e of the Alternative One (which will always be 100%).

The next section is **Cost of Materials,** and like the previous sections, is expressed in both a percentage of Alternative One and actual number (in this case, in dollars). This information can easily be estimated by project engineers using RS Means or another source of cost estimation. By including cost information, the alternatives analysis gives decision-makers the opportunity to evaluate the changes in cost that result from use GHG-reducing techniques and technologies.

Using this methodology in combination with standardized reporting practices, any city can evaluate alternatives for reducing GHG emissions from the cement and asphalt used in its construction projects, as is shown in the hypothetical alternatives evaluation in the next chapter.

Chapter 4: Results

In order to show how a city might make use of the Materials Reporting Form, recommendations for emissions reduction strategies, and Alternatives Evaluation Table, this thesis applies these climate action planning tools to a hypothetical city called "Greenville." Using pulling information from the literature review and a variety of other sources, including the 2014 City of Seattle Standard Specifications and Plans and Seattle's bid website, eBid eXchange, this hypothetical example shows how a real city can use these tools to quantify emissions from cement and asphalt purchasing, set reduction targets and strategies to meet those targets, and implement those strategies on a project-by-project basis, following the ICLEI's Climate Milestones model.

The City

Greenville Overview	
Population	50,000
Past Greenhouse Gas Inventories	2005, 2010
Local Government GHG Reduction Target Year and Level (Base Year=2005)	50% Reduction by 2020 80%Reduction by 2030 Carbon Neutrality by 2050

Application of the Reporting Form

For its 2015 GHG Inventory (released early 2016), Greenville included emissions from cement and asphalt purchasing for the first time. Over the course of the year, it inventoried emissions from 4 capital improvement projects, the cement- and asphalt-related emissions from which totaled 5,310 MTCO2e. In order to achieve this, project managers for each of the four projects were asked to complete the Materials Reporting Form upon completion of the project. The information used in this form came from as-built drawings, quantity takeoff forms and submittals. Emissions were calculated automatically by the form using industry average emissions factors. Below is the completed Materials Reporting Form for the largest of these projects, which resulted in 3, 804 MTCO2e.

Cement and Asphalt Quantities Reporting Sheet		Project Name:	Marcus St Road Replacement Phase 1	Project Manager:	Jane Doe	Phone Number: (206) 555-5555

CAST-IN-PLACE CEMENT CONCRETE	Use (Roadway, Sidewalk, Curb, Structural, etc.)	CY	Lbs of cement/CY	% of fly ash or Slag IN CEMENT MIX	% Recycled Materials	Supplier	Notes	Emissions (MTCO2e)
Concrete Mix 1	Roadway Cement Concrete, Variable Mix- 10 in.	7,141	675	0%	0%	CemCo	Did not take advantage of incentive spec.	1967.76
Concrete Mix 2	Sidewalk Cement Concrete	1,077	505	0%	0%	CemCo		222.03
Concrete Mix 3	Curb, Cement Concrete	98	505	0%	0%	CemCo		20.20
Concrete Mix 4								0.00
Concrete Mix 5								0.00
Concrete Mix 6								0.00
Concrete Mix 7								0.00

PRECAST CEMENT CONCRETE	Item name	CY concrete /item	# of items	Lbs cement/CY	% of fly ash or Slag IN CEMENT MIX	% Recycled Materials	Supplier	Notes	Emissions (MTCO2e)
Item 1	Service Cabinet Footing	0.28	8	564	0%	0%	PrecastNW		0.52
Item 2									0.00
Item 3									0.00
Item 4									0.00
Item 5									0.00

ASPHALT CONCRETE	Use (Roadway, Pavement Patch, etc.)	Weight (Tons)	Hot Mix/Warm Mix?	Temperature	Warm Mix Method (if applicable)	% Recycled Asphalt Pavement	% Recycled Asphalt Shingles	Supplier	Notes	Emissions (MTCO2e)
Asphalt Mix 1	Roadway	15,646	Hot Mix	350	n/a	0%	0%	USAsphalt		1719.47
Asphalt Mix 2										0.00
Asphalt Mix 3										0.00

Please write any additional comments, questions or concerns here:	Total Emissions
1 mile stretch of 4 lane arterial roadway, sidewalks on both sides and service cabinets at each corner.	3929.98

Greenville Materials Reporting Form – Marcus St Road Replacement Phase One Source: Author

GHG Reduction Target and Action Planning Strategies

Greenville updated its Climate Action Plan in the first quarter of 2016. This action plan was the first to include a reduction target specifically for emissions from cement and asphalt purchasing. After reviewing the technologies and strategies available for reducing these emissions, Greenville chose to use align its reduction target for these emissions with its reduction target for scopes 1 and 2 emissions by pursing 50%, 80% and 100% reductions by 2020, 2030, and 2050, respectively. Though these targets are relative to the year 2015, rather than 2005, decision-makers felt that they were able to mitigate these emissions on this accelerated timeframe.

Greenville Reduction Target for GHGs from Cement and Asphalt Purchasing	
Short-Range Reduction Target	50% Reduction over 2015 Levels by 2020
Medium-Range Reduction Target	80% Reduction over 2015 Levels by 2030
Long Range Reduction Target	Carbon Neutrality by 2050 (with offsets)

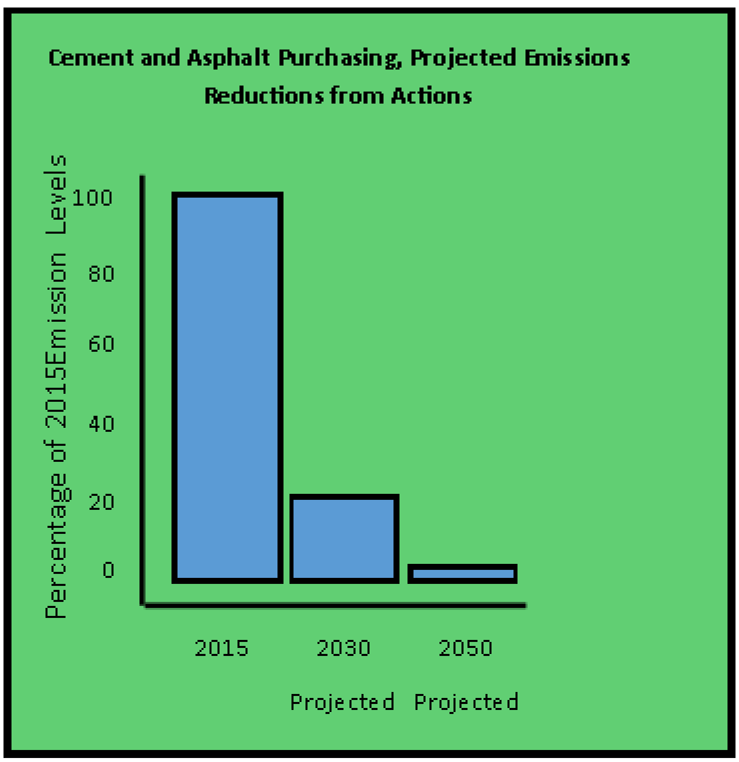
Greenville's Climate Action Plan also for the first time included a subsection within its purchasing section that addressed emissions from cement and asphalt purchasing specifically. This subsection is displayed below.

Cement and Asphalt Purchasing

Purpose:

Cement and Asphalt contribute significantly to Greenville's overall emissions. In 2015 alone, these two materials resulted in nearly 5,310 MTCO2e. In order to become a truly carbon-neutral city, Greenville must find ways to eliminate this source of emissions.

How much will cement and asphalt purchasing actions reduce emissions?



How will we monitor progress?

The City of Greenville will track implementation of identified actions as well as their impact on City construction projects. This will be done by project-level GHG accounting which is already in place. This accounting involves recording the amounts of cement and asphalt that are used in each city construction project, and to what extent GHG-reducing technologies were used. This allows the City to determine the amount of GHGs that are produced by this sector on a yearly basis and track progress toward its reduction target of 50% reduction over 2015 levels by 2030.

Actions

The Cement and Asphalt Purchasing actions are organized as follows:

- Economic Incentives
- Changes to Minimum/Maximum Allowable Materials
- Environmental Reporting Requirements and Alternatives Evaluation

Economic Incentives

2030 Vision: Contractors doing work for the City of Greenville use the maximum possible amounts of low-GHG materials while still finishing projects according to schedule, budget, and quality requirements.

Actions to Implement by 2020:

- Revise standard specifications to add a “Variable Mix” cement reduction incentive spec in which the contractor receives money back for each lb. of cement reduced.
- Revise standard specifications to add an incentive spec in which contractor receives money back for each ton of hot mix asphalt (HMA) replaced with warm mix asphalt (WMA).
- Revise standard specifications to add an incentive spec in which contractor receives money back for each ton of recycled asphalt pavement (RAP) or recycled asphalt shingles (RAS) used in a project.

Changes to Minimum/Maximum Allowable Materials

2030 Vision: 95% of all cement and asphalt concrete used in City of Greenville projects uses at least one GHG-reducing technology.

Actions to Implement by 2020:

- Revise standard specifications in 5-05.3(1) to require a minimum of at least 10% pozzolans (SCMs) in all mixes, unless project engineer has a compelling reason why this is not feasible in a given mix.
- Revise standard specifications so that maximum allowable fly ash or slag in a given mix is raised to the level deemed acceptable by ASTM building codes.
- Raise allowable RAP in 5-04.2(1) to 30%
- Allow RAS in quantities up to 10% (total of 30% RAP+RAS)

Environmental Reporting Requirements

2030 Vision: All City staff and contractors in construction work for the city consider how they can make the construction process more sustainable through fuel efficiency, GHG reductions from materials, etc.

Actions to Implement by 2020:

- Revise standard specs to require a “Carbon Control Plan” from contractors in all projects
- Require any cement concrete supplier working with the city to submit an Environmental Product Declaration for its portland cement concrete
- Require any asphalt supplier working with the city to submit an Environmental Product Declaration for its HMA and/or WMA.
- Require an alternatives evaluation to be carried out before capital projects go to bid, which analyzes the emissions and costs that would result from differing amounts of low-GHG alternatives, as well as from reducing overall concrete use within a project.

Alternatives Evaluation

As Greenville's Climate Action Plan has just been released, most of the recommendations have not yet been implemented. However, with the expectation that they will soon go into effect, the city has begun alternatives evaluation on capital projects in order to begin reducing GHG emissions from the purchasing of cement and asphalt concrete.

The Projects

For the coming year, 2017, Greenville's Capital Improvement Plan has identified **three infrastructure projects** to be built, all of which use cement and/or asphalt in different ways. These three projects are:

Hypothetical Infrastructure Projects	
1	Replacement of a 1 mile stretch of Arterial Roadway
2	Improvements to a City Park
3	Construction of a Combined Sewer Overflow Catchment Basin

Arterial Roadway Project Narrative

Marcus Street is the main arterial through Greenville. One mile of this four-mile road was replaced in 2014, and funding is available to replace an additional mile in 2016. Originally constructed in 1940, the 4 lane cement concrete roadway has surpassed its design life and must be torn out and replaced. Staff from the city's Department of Transportation have decided to use a cement concrete base with an overlay of asphalt concrete in order to provide a smoother ride. The project also includes replacement of sidewalks and curbs. The Alternative One option in this case mirrors what was done in the first phase of this project. In addition to engineering strategies to reduce emissions, city transportation and water planners have proposed reducing this stretch of the arterial by one lane and including a bioswale (a type of GSI) in its place.

City Park Improvements Project Narrative

Green Park is the city's largest park, located a half mile from the city's downtown area. Improvements to the park, in addition to upgraded playground equipment and new landscaping, include replacing the park's parking lot and driveway, and installing cement concrete guardrails along the pedestrian bridge that crosses the Greenville Stream. A recent study found that the parking lot only reaches capacity 1-2 times a year, and additionally, a new bus stop was added in front of the park two years ago, increasing the number of citizens who arrive by bus. City planners have thus decided to evaluate the possibility of eliminating some of the existing parking capacity, either through creation of "compact" spaces or outright elimination of a certain percentage of existing parking spaces. Any parking area reduced would be replaced with native plants and trees.

Combined Sewer Overflow (CSO) Catchment Basin

Greenville has a combined sewer system, meaning that stormwater and sewage travel through the same pipes. During heavy rainfalls, the system becomes overloaded and sewage is dumped into Lake Pleasant, which is a major recreational area for Greenville citizens. This contamination issue is a large concern, and therefore the city has approved funding for an underground CSO catchment basin to store sewage during large storm events until it can be processed by the city's wastewater treatment plant and safely discharged.

Project Alternatives

For each project, project planners and engineers, under the supervision of the project manager, filled out the Materials Reporting Form three times, using information from each project's construction documents, which were at the 20% design phase at the time the alternatives evaluation was carried out. The three reporting form iterations represent the **three alternative** options, as discussed in the Methodology chapter above.

Marcus St. Road Replacement Phase Two - Alternative One

Cement and Asphalt Quantities Reporting Sheet	Project Name:	Marcus St Road Replacement Phase 2 - Alt 1	Project Manager:	Jane Doe	Phone Number: (206) 555-5555

CAST-IN-PLACE CEMENT CONCRETE	Use (Roadway, Sidewalk, Curb, Structural, etc.)	CY	Lbs of cement/CY	% of fly ash or Slag IN CEMENT MIX	% Recycled Materials	Supplier	Notes	Emissions (MTCO2e)
Concrete Mix 1	Roadway Cement Concrete, Variable Mix- 10 in.	7,141	675	0%	0%		Did not take advantage of incentive spec.	1967.76
Concrete Mix 2	Sidewalk Cement Concrete	1,077	505	0%	0%			222.03
Concrete Mix 3	Curb, Cement Concrete	98	505	0%	0%			20.20
Concrete Mix 4								0.00
Concrete Mix 5								0.00
Concrete Mix 6								0.00
Concrete Mix 7								0.00

PRECAST CEMENT CONCRETE	Item name	CY concrete/item	# of items	Lbs cement/CY	% of fly ash or Slag IN CEMENT MIX	% Recycled Materials	Supplier	Notes	Emissions (MTCO2e)
Item 1	Service Cabinet Footing	0.28	8	564	0%				0.52
Item 2									0.00
Item 3									0.00
Item 4									0.00
Item 5									0.00

ASPHALT CONCRETE	Use (Roadway, Pavement Patch, etc.)	Weight (Tons)	Hot Mix/Warm Mix?	Temperature	Warm Mix Method (if applicable)	% Recycled Asphalt Pavement	% Recycled Asphalt Shingles	Supplier	Notes	Emissions (MTCO2e)
Asphalt Mix 1	Roadway	15,646	Hot Mix	350		0%	0%			1719.47
Asphalt Mix 2										0.00
Asphalt Mix 3										0.00

Please write any additional comments, questions or concerns here:	Total Emissions
1 mile stretch of 4 lane arterial roadway, sidewalks on both sides and service cabinets at each corner.	3929.98

Total Emissions: 3,929.98 MTCO2e

Marcus St. Road Replacement Phase Two – Alternative Two

Cement and Asphalt Quantities Reporting Sheet	Project Name: **Marcus St Road Replacement Phase 2 Alt 2**	Project Manager: **Jane Doe**	Phone Number: **(206) 555-5555**

CAST-IN-PLACE CEMENT CONCRETE	Use (Roadway, Sidewalk, Curb, Structural, etc.)	CY	Lbs of cement/CY	% of fly ash or Slag IN CEMENT MIX	% Recycled Materials	Supplier	Notes	Emissions (MTCO2e)
Concrete Mix 1	Roadway Cement Concrete, Variable Mix- 10 in.	7,141	587	0%	10%			1711.22
Concrete Mix 2	Sidewalk Cement Concrete, 25% Pozzolans	1,077	463	0%	0%			203.57
Concrete Mix 3	Curb, Cement Concrete, 25% Pozzolans	98	463	0%	0%			18.52
Concrete Mix 4								0.00
Concrete Mix 5								0.00
Concrete Mix 6								0.00
Concrete Mix 7								0.00

PRECAST CEMENT CONCRETE	Item name	CY concrete/item	# of items	Lbs cement/CY	% of fly ash or Slag IN CEMENT MIX	% Recycled Materials	Supplier	Notes	Emissions (MTCO2e)
Item 1	Service Cabinet Footing	0.28	8	564	0%				0.52
Item 2									0.00
Item 3									0.00
Item 4									0.00
Item 5									0.00

ASPHALT CONCRETE	Use (Roadway, Pavement Patch, etc.)	Weight (Tons)	Hot Mix/Warm Mix?	Temperature	Warm Mix Method (if applicable)	% Recycled Asphalt Pavement	% Recycled Asphalt Shingles	Supplier	Notes	Emissions (MTCO2e)
Asphalt Mix 1	Roadway	15,646	Warm Mix	250		8%	2%			1215.67
Asphalt Mix 2										0.00
Asphalt Mix 3										0.00

Please write any additional comments, questions or concerns here:	Total Emissions
1 mile stretch of 4 lane arterial roadway, sidewalks on both sides and service cabinets at each corner.	3149.50

Total Emissions: 3,149.50 MTCO2e

Marcus St. Road Replacement Phase Two – Alternative Three

Cement and Asphalt Quantities Reporting Sheet	Project Name:	**Marcus St Road Replacement Phase 2 Alt 3**	Project Manager:	**Jane Doe**	Phone Number: **(206) 555-5555**

CAST-IN-PLACE CEMENT CONCRETE	Use (Roadway, Sidewalk, Curb, Structural, etc.)	CY	Lbs of cement/CY	% of fly ash or Slag IN CEMENT MIX	% Recycled Materials	Supplier	Notes	Emissions (MTCO2e)
Concrete Mix 1	Roadway Cement Concrete, Variable Mix- 10 in.	5,356	505	0%	10%	CemCo	Took full advantage of incentive spec. One lane replaced with GSI	1104.13
Concrete Mix 2	Pervious Sidewalk Cement Concrete, 25% Pozzolans	1,077	463	0%	0%	CemCo		203.57
Concrete Mix 3	Curb, Cement Concrete, 25% Pozzolans	98	463	0%	0%	CemCo		18.52
Concrete Mix 4								0.00
Concrete Mix 5								0.00
Concrete Mix 6								0.00
Concrete Mix 7								0.00

PRECAST CEMENT CONCRETE	Item name	CY concrete/item	# of items	Lbs cement/CY	% of fly ash or Slag IN CEMENT MIX	% Recycled Materials	Supplier	Notes	Emissions (MTCO2e)
Item 1	Service Cabinet Footing	0.28	8	564	0%	0%	NWConcrete		0.52
Item 2									0.00
Item 3									0.00
Item 4									0.00
Item 5									0.00

ASPHALT CONCRETE	Use (Roadway, Pavement Patch, etc.)	Weight (Tons)	Hot Mix/Warm Mix?	Temperature	Warm Mix Method (if applicable)	% Recycled Asphalt Pavement	% Recycled Asphalt Shingles	Supplier	Notes	Emissions (MTCO2e)
Asphalt Mix 1	Roadway	11,734	Warm Mix	250	Plant Foaming	15.00%	2%	USAsphalt		905.18
Asphalt Mix 2										0.00
Asphalt Mix 3										0.00

Please write any additional comments, questions or concerns here:	Total Emissions
1 mile stretch of 3 lane arterial roadway, Green stormwater infrastructure replacing fourth lane, pervious sidewalks on both sides and service cabinets at each corner.	2231.92

Total Emissions: 2,231.92 MTCO2e

Green Park Renovation - Alternative One

Cement and Asphalt Quantities Reporting Sheet	Project Name:	**Green Park Renovation Alt 1**	Project Manager:	**Jane Doe**	Phone Number: 555-555-5555

CAST-IN-PLACE CEMENT CONCRETE	Use (Roadway, Sidewalk, Curb, Structural, etc.)	CY	Lbs cement/CY	% of fly ash or Slag IN CEMENT MIX	% Recycled Materials	Supplier	Notes	Emissions (MTCO2e)
Concrete Mix 1	Roadway Cement Concrete, 10 in.	400	550				Parking Lot	89.81
Concrete Mix 2	Driveway Cement Concrete, 8 in.	15	550				Driveway	3.37
Concrete Mix 3	Sidewalk Cement Concrete, 6 in.	14	505					2.89
Concrete Mix 4								0.00
Concrete Mix 5								0.00
Concrete Mix 6								0.00
Concrete Mix 7								0.00

PRECAST CEMENT CONCRETE	Item name	CY concrete/item	# of items	Lbs cement/CY	% of Fly Ash or Slag IN CEMENT MIX	% Recycled Materials	Supplier	Notes	Emissions (MTCO2e)
Item 1	Pedestrian Bridge Railings	5	2	575					2.35
Item 2									0
Item 3									0
Item 4									0
Item 5									0

ASPHALT CONCRETE	Use (Roadway, Pavement Patch etc.)	Weight (Tons)	Hot Mix/Warm Mix?	Temperature	Warm Mix Method (if applicable)	% Recycled Asphalt Pavement	% Recycled Asphalt Shingles	Supplier	Notes	Emissions (MTCO2e)
Asphalt Mix 1										0
Asphalt Mix 2										0
Asphalt Mix 3										0

Please write any additional comments, questions or concerns here:	Total Emissions
	98.41

Total Emissions: 98.41 MTCO2e

Green Park Renovation – Alternative Two

Cement and Asphalt Quantities Reporting Sheet	Project Name:	Green Park Renovation Alt 2		Project Manager:	Jane Doe				Phone Number: 555-555-5555

CAST-IN-PLACE CEMENT CONCRETE	Use (Roadway, Sidewalk, Curb, Structural, etc.)	CY	Lbs cement/CY	% of fly ash or Slag IN CEMENT MIX	% Recycled Materials	Supplier	Notes	Emissions (MTCO2e)
Concrete Mix 1	Roadway Cement	374	550	25%	20%		Parking Lot	62.98
Concrete Mix 2	Driveway Cement	15	550	25%	20%		Driveway	2.53
Concrete Mix 3	Sidewalk Cement	14	505	25%	20%			2.16
Concrete Mix 4								0.00
Concrete Mix 5								0.00
Concrete Mix 6								0.00
Concrete Mix 7								0.00

PRECAST CEMENT CONCRETE	Item name	CY concrete/item	# of items	Lbs cement/CY	% of Fly Ash or Slag IN CEMENT MIX	% Recycled Materials	Supplier	Notes	Emissions (MTCO2e)
Item 1	Pedestrian Bridge Railings	5	2	575	50%				1.174
Item 2									0
Item 3									0
Item 4									0
Item 5									0

ASPHALT CONCRETE	Use (Roadway, Pavement Patch etc.)	Weight (Tons)	Hot Mix/Warm Mix?	Temperature	Warm Mix Method (if applicable)	% Recycled Asphalt Pavement	% Recycled Asphalt Shingles	Supplier	Notes	Emissions (MTCO2e)
Asphalt Mix 1										0
Asphalt Mix 2										0
Asphalt Mix 3										0

Please write any additional comments, questions or concerns here:	Total Emissions
20 of 40 parking spots converted to compact car parking	68.84

Total Emissions: 68.84 MTCO2e

Green Park Renovation – Alternative Three

Cement and Asphalt Quantities Reporting Sheet	Project Name:	**Green Park Renovation Alt 3**	Project Manager:	**Jane Doe**	Phone Number: 555-555-5555

CAST-IN-PLACE CEMENT CONCRETE	Use (Roadway, Sidewalk, Curb, Structural, etc.)	CY	Lbs cement/CY	% of fly ash or Slag IN CEMENT MIX	% Recycled Materials	Supplier	Notes	Emissions (MTCO2e)
Concrete Mix 1	Roadway Cement Concrete, 10 in.	117	550	25%	20%		Parking Lot	19.70
Concrete Mix 2	Driveway Cement Concrete, 8 in.	15	550	25%	20%		Driveway	2.53
Concrete Mix 3	Sidewalk Cement Concrete, 6 in.	14	463	25%	20%			1.98
Concrete Mix 4								0.00
Concrete Mix 5								0.00
Concrete Mix 6								0.00
Concrete Mix 7								0.00

PRECAST CEMENT CONCRETE	Item name	CY concrete/item	# of items	Lbs cement/CY	% of Fly Ash or Slag IN CEMENT MIX	% Recycled Materials	Supplier	Notes	Emissions (MTCO2e)
Item 1	Pedestrian Bridge Railings	5	2	575	60%				0.94
Item 2									0
Item 3									0
Item 4									0
Item 5									0

ASPHALT CONCRETE	Use (Roadway, Pavement Patch etc.)	Weight (Tons)	Hot Mix/Warm Mix?	Temperature	Warm Mix Method (if applicable)	% Recycled Asphalt Pavement	% Recycled Asphalt Shingles	Supplier	Notes	Emissions (MTCO2e)
Asphalt Mix 1										0
Asphalt Mix 2										0
Asphalt Mix 3										0

Please write any additional comments, questions or concerns here:	Total Emissions
Parking reduced by 10 spaces, for a total of 20 compact spaces and 10 regular spaces.	25.15

Total Emissions: 25.15 MTCO2e

CSO Basin - Alternative One

Cement and Asphalt Quantities Reporting Sheet | Project Name: CSO Basin #1 Alt 1 | Project Manager: **Jane Doe** | Phone Number: 555-555-5555

CAST-IN-PLACE CEMENT CONCRETE	Use (Roadway, Sidewalk, Curb, Structural, etc.)	CY	Lbs cement/CY	% of fly ash or Slag IN CEMENT MIX	% Recycled Materials	Supplier	Notes	Emissions (MTCO2e)
Concrete Mix 1	Storage Tank, Facilities Vault and Valve Vault	6750	660					1818.68
Concrete Mix 2	Roadway Cement Concrete, Variable Mix, 10 in.	773	675					213.01
Concrete Mix 3	Sidewalk Cement Concrete	117	505					24.12
Concrete Mix 4	Curb, Cement Concrete	11	505					2.27
Concrete Mix 5		0	0					0.00
Concrete Mix 6		0	0					0.00
Concrete Mix 7		0	0					0.00

PRECAST CEMENT CONCRETE	Item name	CY concrete/item	# of items	Lbs cement/CY	% of Fly ash or Slag IN CEMENT MIX	% Recycled Materials	Supplier	Notes	Emissions (MTCO2e)
Item 1		0	0	0					0
Item 2		0	0	0					0
Item 3		0	0	0					0
Item 4		0	0	0					0
Item 5		0	0	0					0

ASPHALT CONCRETE	Use (Roadway, Pavement Patch etc.)	Weight (Tons)	Hot Mix/Warm Mix?	Temperature	Warm Mix Method (if applicable)	% Recycled Asphalt Pavement	% Recycled Asphalt Shingles	Supplier	Notes	Emissions (MTCO2e)
Asphalt Mix 1	Roadway	1694	Hot Mix	350		0%	0%			177.87
Asphalt Mix 2		0		0		0%	0%			0
Asphalt Mix 3		0		0		0%	0%			0

Please write any additional comments, questions or concerns here:	Total Emissions
	2235.95

Total Emissions: 2235.95 MTCO2e

CSO Basin – Alternative Two

Cement and Asphalt Quantities Reporting Sheet			Project Name:	CSO Basin #1 **Alt 2**		Project Manager:	**Jane Doe**	Phone Number: 555-555-5555	
CAST-IN-PLACE CEMENT CONCRETE	Use (Roadway, Sidewalk, Curb, Structural, etc.)	CY	Lbs cement/CY	% of fly ash or Slag IN CEMENT MIX	% Recycled Materials	Supplier	Notes		Emissions (MTCO2e)
Concrete Mix 1	Storage Tank, Facilities Vault and Valve Vault	6750	660	50%					909.34
Concrete Mix 2	Roadway Cement Concrete, Variable Mix, 10 in.	773	505	0%					159.36
Concrete Mix 3	Sidewalk Cement Concrete	117	463	0%					22.11
Concrete Mix 4	Curb, Cement Concrete	11	463	0%					2.08
Concrete Mix 5		0	0						0.00
Concrete Mix 6		0	0						0.00
Concrete Mix 7		0	0						0.00

PRECAST CEMENT CONCRETE	Item name	CY concrete/item	# of items	Lbs cement/CY	% of fly ash or Slag IN CEMENT MIX	% Recycled Materials	Supplier	Notes	Emissions (MTCO2e)
Item 1		0	0	0					0
Item 2		0	0	0					0
Item 3		0	0	0					0
Item 4		0	0	0					0
Item 5		0	0	0					0

ASPHALT CONCRETE	Use (Roadway, Pavement Patch etc.)	Weight (Tons)	Hot Mix/Warm Mix?	Temperature	Warm Mix Method (if applicable)	% Recycled Asphalt Pavement	% Recycled Asphalt Shingles	Supplier	Notes	Emissions (MTCO2e)
Asphalt Mix 1	Roadway	1694	Hot Mix	350		5%	0%			177.80
Asphalt Mix 2		0		0		0%	0%			0
Asphalt Mix 3		0		0		0%	0%			0

Please write any additional comments, questions or concerns here:	Total Emissions
	1270.70

Total Emissions: 1270.70 MTCO2e

CSO Basin – Alternative Three

Cement and Asphalt Quantities Reporting Sheet	Project Name: CSO Basin #1 **Alt 3**	Project Manager: **Jane Doe**	Phone Number: 555-555-5555

CAST-IN-PLACE CEMENT CONCRETE	Use (Roadway, Sidewalk, Curb, Structural, etc.)	CY	Lbs cement/CY	% of fly ash or Slag IN CEMENT MIX	% Recycled Materials	Supplier	Notes	Emissions (MTCO2e)
Concrete Mix 1	Storage Tank, Facilities Vault and Valve Vault	6750	660	70%	20%		Slag	545.60
Concrete Mix 2	Roadway Cement Concrete, Variable Mix, 10 in.	773	505	10%	15%		Fly Ash	143.42
Concrete Mix 3	Sidewalk Cement Concrete	117	463	10%	26%		Fly Ash	19.90
Concrete Mix 4	Curb, Cement Concrete	11	463	10%	26%		Fly Ash	1.87
Concrete Mix 5		0	0					0.00
Concrete Mix 6		0	0					0.00
Concrete Mix 7		0	0					0.00

PRECAST CEMENT CONCRETE	Item name	CY concrete/item	# of items	Lbs cement/CY	% of Fly Ash or Slag IN CEMENT MIX	% Recycled Materials	Supplier	Notes	Emissions (MTCO2e)
Item 1		0	0	0					0
Item 2		0	0	0					0
Item 3		0	0	0					0
Item 4		0	0	0					0
Item 5		0	0	0					0

ASPHALT CONCRETE	Use (Roadway, Pavement Patch etc.)	Weight (Tons)	Hot Mix/Warm Mix?	Temperature	Warm Mix Method (if applicable)	% Recycled Asphalt Pavement	% Recycled Asphalt Shingles	Supplier	Notes	Emissions (MTCO2e)
Asphalt Mix 1	Roadway	1694	Warm Mix	250		5%	2%			126.10
Asphalt Mix 2		0		0		0%	0%			0
Asphalt Mix 3		0		0		0%	0%			0

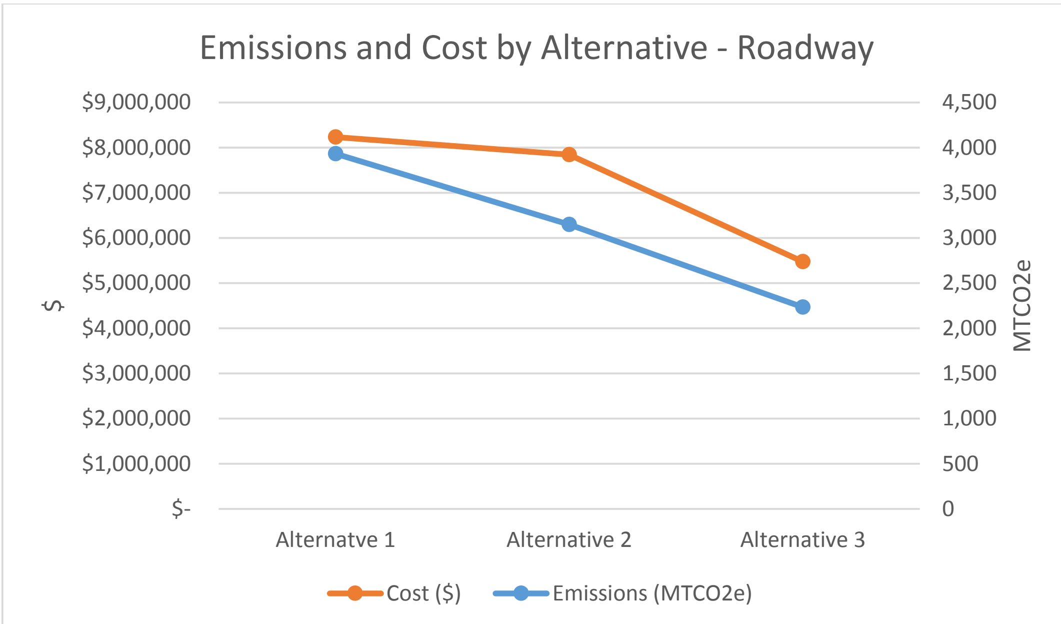
Please write any additional comments, questions or concerns here:	Total Emissions
	836.90

Total Emissions: 836.90 MTCO2e

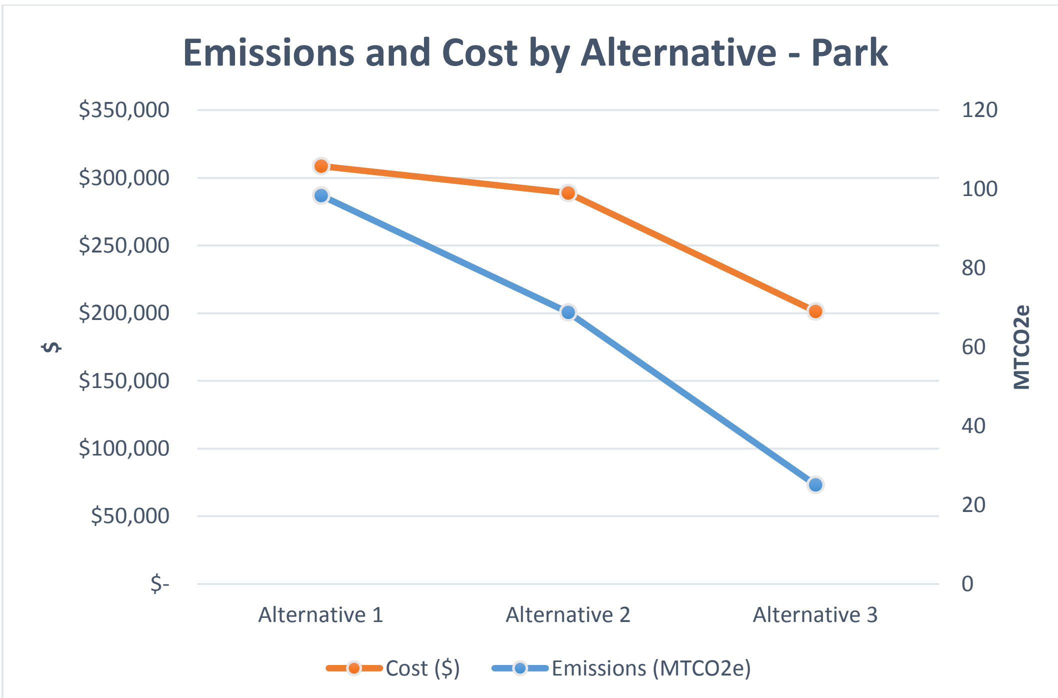
Upon completion of the reporting forms for all three alternatives for each project, the Alternatives Evaluation Tables were automatically filled in, with the exception of cost data, which was entered manually by the project engineer. The Alternatives Evaluation Table for each project is below.

The results of the alternatives evaluation showed that, were the city to pick the Alternative One option for all three projects, 6,264.34 MTCO2e would result. However, if Alternative Three was picked in each case, only 3,093.97 MTCO2e would result—a reduction of just over 50%.

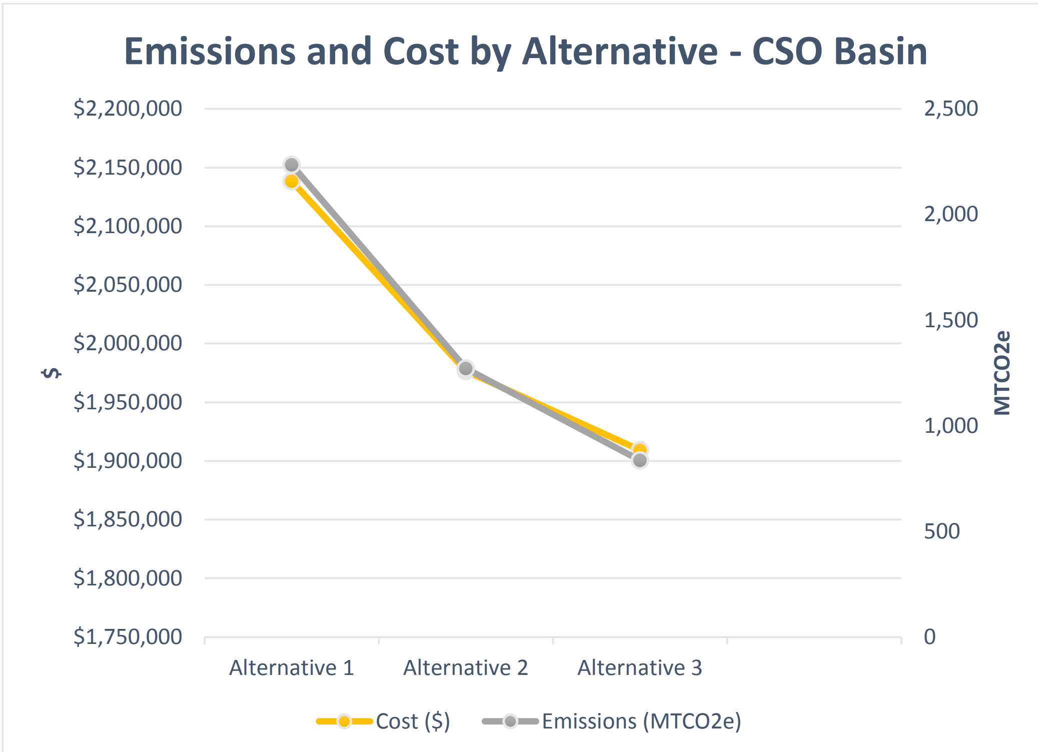
Marcus St Road Replacement Phase 2				
Criteria	**Units**	**Alternatve 1**	**Alternative 2**	**Alternative 3**
Scale	Total Cast-in-Place Cement Concrete (CY)	8316.00	8316.00	6530.75
	Total Precast Cement Concrete (CY)	2.24	2.24	2.24
	Total Asphalt (tons)	15645.74	15645.74	11734.31
	Design Descriptor	none	none	Road diet & bioswale
GHG-Reducing Technologies - Cement Concrete	Cement/CY	650.96	569.48	497.44
	MTCO2e/CY	0.27	0.23	0.20
GHG-Reducing Technologies - Asphalt Concrete	Percentage HMA	100%	0%	0%
	Percentage Virgin Materials	100%	90%	83%
	MTCO2e/ton	0.11	0.08	0.08
Total GHG Emissions	%MTCO2 compared to Alt One	100%	80%	57%
	MTCO2e	3929.98	3149.50	2231.92
Cost of Materials	% Compared to Alt 1	100%	95%	66%
	Cost	$ 8,234,190.00	$ 7,838,966.00	$5,475,014.00


Emissions and Cost by Alternative - Roadway
$9,000,000
$8,000,000
$7,000,000
$6,000,000
$5,000,000
$4,000,000
$3,000,000
$2,000,000
$1,000,000
$-
$
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
MTCO2e
Alternatve 1
Alternative 2
Alternative 3
Cost ($)
Emissions (MTCO2e)

Green Park Renovation				
Criteria	**Units**	**Alternative 1**	**Alternative 2**	**Alternative 3**
Scale	Total Cast-in-Place Cement Concrete (CY)	429.00	403.00	146.00
	Total Precast Cement Concrete (CY)	10.00	10.00	10.00
	Total Asphalt (tons)	0.00	0.00	0.00
	Design Descriptor	none	compact parking spaces	compact parking spaces and reduced parking
GHG-Reducing Technologies - Cement Concrete	Cement/CY	549.13	549.08	541.66
	MTCO2e/CY	0.22	0.17	0.17
GHG-Reducing Technologies - Asphalt Concrete	Percentage HMA	N/A	N/A	N/A
	Percentage Virgin Materials	N/A	N/A	N/A
	MTCO2e/ton	N/A	N/A	N/A
Total GHG Emissions	%MTCO2 Compared to Alt One	100%	70%	26%
	MTCO2e	98.41	68.84	25.15
Cost of Materials	% Compared to Alt One	100%	94%	65%
	Cost	$ 308,780.00	$ 288,843.50	$ 201,468.20


Emissions and Cost by Alternative - Park
$350,000
$300,000
$250,000
$200,000
$150,000
$100,000
$50,000
$-
$
120
100
80
60
40
20
0
MTCO2e
Alternative 1
Alternative 2
Alternative 3
Cost ($)
Emissions (MTCO2e)

CSO Basin #1				
Criteria	**Units**	**Alternative 1**	**Alternative 2**	**Alternative 3**
Scale	Total Cast-in-Place Cement Concrete (CY)	7651.00	7651.00	7651.00
	Total Precast Cement Concrete (CY)	0.00	0.00	0.00
	Total Asphalt (tons)	1694.00	1694.00	1694.00
	Design Descriptor	none	none	none
GHG-Reducing Technologies - Cement Concrete	Cement/CY	658.92	641.04	641.04
	MTCO2e/CY	0.27	0.14	0.09
GHG-Reducing Technologies - Asphalt Concrete	Percentage HMA	100%	100%	0%
	Percentage Virgin Materials	0%	5%	7%
	MTCO2e/ton	0.11	0.10	0.07
Total GHG Emissions	%MTCO2 Compared to Alt One	100%	57%	37%
	MTCO2e	2235.95	1270.70	836.90
Cost of Materials	Percent compared to Alt One	100%	92%	89%
	Cost	$ 2,138,446.00	$ 1,976,770.00	$1,909,174.00



Upon analysis of these options, decision-makers in Greenville chose to pursue Alternative Three on both the Marcus Street project and the CSO Basin. However, due to concerns about loss of parking at Green Park, Alternative Two was chosen in that case. The total emissions from the cement and asphalt used in the three projects would then be 3136.66 MTCO2e—nearly a 40% reduction from 2015 levels. This puts Greenville well on its way to its target of a 50% reduction in emissions from cement and asphalt purchasing by 2020.

Chapter 5: Discussion

The hypothetical exercise above shows how a city might go about implementing an action plan for reducing greenhouse gas emissions from cement and asphalt purchasing following the steps of ICLEI's 5 milestones for climate mitigation. This section discusses the applicability of this exercise to actual cities in the Pacific Northwest and around the country.

Materials Reporting Form

As the hypothetical example of "Greenville" shows, the Materials Reporting Form can serve multiple purposes. Its first and primary purpose is to establish a baseline by quantifying the total emissions from cement and asphalt purchasing in a given year. Information from a recent year on the quantities of materials used in each project, as well as the amount of GHG-reducing alternatives such as SCMs and warm mix asphalt, will be readily available from members of the project team and contractors, if not directly from project documents such as truck ticket data, as-built drawings, quantity takeoffs and submittals.

However, collection of this data will require the time and effort of the project manager, and this is perhaps the biggest barrier to this type of reporting. To the author's knowledge, the only local government agency who has instituted this type of reporting is the Seattle Department of Transportation, though that agency's quantification of GHGs from purchased cement and asphalt, based off of truck ticket data, does not include as many variables as does the materials reporting form developed here. It is interesting to note that SDOT's method does not require staff from individual projects to self-report, as this methodology does. Instead, data is collected by one staff member who compiles an annual report on emissions from cement and asphalt (Healy, 2014). If self-reporting is found to be too burdensome on individual project engineers, this method could be applied to use of the Materials Reporting Form. However, it may be the case that some of the finer details of the project, such as asphalt mix temperature, for example, may have to be estimated. As project managers have a more intimate knowledge of the project, it is likely that data in the Materials Reporting Form would be more complete and accurate if it came directly from them.

Another point of discussion is whether project-level data is really necessary. As discussed in the literature review, many local governments have quantified their emissions from cement and asphalt as part of a larger scope 3 emissions analysis, typically using spend-based methods in which a GHG emissions factor was applied per dollar spend on the material (WCCF, 2014). This method is useful for gaining a rough estimate of emissions from a material, and certainly has the advantage of being very easy to accomplish. However, while it can be used to track emissions reductions from planning techniques that reduce overall use of concrete, it cannot take into account engineering strategies such as SCMs and WMA.

Additionally, the prices of construction materials are constantly changing. The amount asphalt that $1 buys in 2015 may be drastically different than the amount of asphalt $1 buys in 2025. This makes meaningful long-term tracking difficult, if not impossible. By recording actual amounts of materials and use of GHG-reducing technologies, the project-level accounting made possible by the Materials Reporting Form allows local governments not only to gain a snapshot of emissions, but track their progress towards emissions reductions in a meaningful way. As Reporting and Monitoring is a fundamental step of the Climate Milestones process, accurately tracking emissions over time is important to successful climate mitigation strategies.

One potential shortcoming of the Materials Reporting Form is its default reliance on industry-average emissions factors from the EPA, making it an average data method of reporting, as defined by WRI's Scope 3 GHG Protocol. This is problematic because it assumes that all cement and asphalt manufactures are alike. As discussed in chapter two, there are a number of factors that go into the actual amount of GHGs per unit of material, and this can drastically affect the total emissions of a project. For example, if a project uses 500 cubic yards of concrete with 600 lbs. of cement per cubic yard, the *.9 lbs. CO2e/lb. cement* default in the Materials Reporting Form would produce a result of 122.47MTCO2e. However, if that plant were particularly efficient or inefficient, that emissions factor could range from 1 lb. CO2e/lb. cement to .8 lbs. CO2e/lb. cement, meaning the total emissions could range anywhere from 136.07 MTCO2e to 108.86 MTCO2e. By using industry average emissions factors combined with material quantities based on geometry and material/CY or ton, the reporting form is a blunt tool, at best. Therefore, a local government would find this tool most useful and accurate if it customized the emissions factor variable to the plant that provided the material, as suggested in the Strategies and Recommendations portion of this thesis. With this combination, the Materials Reporting Form would become a Supplier-Specific method of accounting as defined by WRI, making it the most accurate form of scope 3 GHG reporting.

Additionally, another shortcoming of the calculator is that it fails to take into account the long-range perspective. By focusing on emissions before an up to the construction stage, the fact that GHG reducing materials such as SCMs can have an impact on project lifespan is left out. As noted in chapter two, SCMs can result in greater long-term strength, meaning a roadway or building has the potential to last longer than one built without SCMs. While this is an important thing to acknowledge and consider when making design and engineering decisions, the extent to which a project's lifespan can be extended is ill-defined, and is thus outside the scope of this thesis.

Strategies and Recommendations

The first hurdle to a local government implementing climate action strategies for reducing emissions from cement and asphalt is acknowledging that these emissions are significant and worth mitigating. While this may appear obvious given the evidence presented above, most local governments have not done this, with mitigation actions, if they occur, happening at the departmental level and not being tied to an overall climate action plan or mitigation goal. While mitigation efforts certainly help whether they are part of a larger strategy or not, expressly naming them in the climate action plan and then working towards implementing them in a coordinated fashion, as recommended in this thesis, will likely achieve better results.

As discussed above, Seattle does not have a purchasing-related section in its climate action plan, but King County and Portland, both do. However, the strategies in these focus on things such as using recycled content paper, sustainably sourcing office supplies, and recycling (King County, 2012, 33-34; City of Portland and Multnomah County, 2015, 89-96). There are no references to strategies for reducing construction related emissions as a whole, despite these being the largest source of purchasing-related emissions on the local government scale. Local governments that have purchasing/consumption sections in their climate action plan could easily integrate the "Cement and Asphalt Purchasing" subsection in Chapter 4 into their existing purchasing section. Local governments who have not yet integrated purchasing into their climate action plans, such as the City of Seattle, can could create new section related to construction purchasing. Seattle's Climate Action Plan is due to be updated in 2016 (Seattle OSE, 2013, 7). This update of the Climate Action Plan represents an opportunity to begin focusing strategies for reducing scope 3 emissions the purchasing of cement and asphalt.

While some of the strategies that are named in "Greenville's" Climate Action Plan have been applied in the real world, others have not. While all the strategies listed are technically possible, the political climate of each local government or local government agency will determine which strategies can be implemented.

Of the three wider strategies recommended, economic incentives to reduce cement content and to increase use of WMA, RAP and RAS are perhaps the most feasible. The Seattle Department of Transportation has already used an economic incentive for reducing cement content in roadway concrete for several years, resulting in modest reductions to GHG emissions. However, the economic incentive to reduce emissions ($0.07/lb. cement reduced) is small in comparison to the overall project cost (Sound Transit, 2014, A.12). Therefore greater incentives may be necessary to increase the amount of SCMs in projects. Adopting this incentive spec at the city level, and expanding it to all concrete uses, rather than just roadway concrete, may be an effective way to decrease GHG emissions from City of Seattle projects. Likewise, other local governments could also achieve emissions reductions by adopting this or similar incentive specs.

Setting mandatory minimums, while guaranteed to reduce emissions, will likely be the most difficult strategy for local governments to implement. As discussed in chapter 2, many engineers are averse to being mandated to use a certain type of material, and mandatory minimums may shift responsibility from the contractor to the local government itself if something goes wrong. Even with the added clause *"unless project engineer has a compelling reason why the mandatory minimum is not feasible in a given case,"* it is likely that this strategy will be difficult for many local governments to pursue. It is worth noting that the mandatory minimum strategy has worked well for SDOT, which requires all sidewalks, curbs and curb ramps to contain 25% pozzolans. It may be feasible, therefore, for other departments and local governments to adopt this spec, at least in regards to low-risk uses such as sidewalks. As for other uses such as roadways, structural, etc. a 10% pozzolan minimum could be low enough to encourage its use without having a significant impact on performance.

The final set of reduction strategies, requiring environment reporting standards, should be applicable to any local government, as long as they are willing to bear the extra cost in time and money that these standards will require. As noted in Chapter 2, one potential strategy for reducing emissions from cement purchasing is through Environmental Product Declarations (EPDs), though the drawback was that a declaration for each mix would cost between $1,000 and $5,000 (Sound Transit, 2014, B.21). By recording the percentage of SCMs in each concrete mix, the Materials Reporting Form avoids the necessity for multiple EPDs. If a local government using the Materials Reporting Form were to go implement EPDs, it would simply need to get an EPD for a 100% portland cement concrete mix from each manufacturer it worked with, and could then apply the well-established GHG reduction factor of SCM-use to the emissions factor for portland cement concrete contained in the EPD. In the case of asphalt, however, EPDs might be required on a batch-by-batch basis, as the transportation-related emissions make up larger proportion of emissions.

The decision of whether or not to use EPDs and to what extent to use them, in the end, comes down to whether the extra cost of requiring them of the supplier is outweighed by the cost of having the project manager or other staff take the time to gather the necessary information to achieve the same level of accuracy in the emissions factor applied to each mix.

Finally, reduction in overall concrete in the built environment may be more difficult in some cases than others. Seattle, Portland, King County, and a number of other cities around the country require all government buildings over a certain square footage to achieve LEED gold status (King County, 2015). This does not necessarily mean that they will take advantage of credits relating to reducing impermeable surfaces, but it leaves the option open. In the case of roadways, space for cars, bikes and pedestrians is the main priority. In many cases all available space will be needed to move citizens. However, over-designed roads and parking lots are prime spaces for replacement of concrete with vegetation. Again, this would require cooperation between multiple departments, which may be difficult. One example of inter-departmental cooperation that gives hope to such collaboration is the park street that recently opened in Seattle. A collaboration between SDOT and Seattle Parks and Rec, the street intermingles pedestrians, bikes, cars and transit in the same space (Seattle Parks and Rec, 2015).

Bell Street Park Source: DowntownSeattle.com

Though the project did not do much in the way of reducing impermeable surface, it could serve as a model for future collaborations between DOTs and parks agencies, where increased vegetation and reduced use of concrete is a primary goal.

Determining which strategies are available to a given local government will in turn determine how fast it can mitigate those emissions. A GHG reduction target will depend on the local government's political context, existing reduction targets, and technical capacity. In the hypothetical example of Greenville, political will and knowledge of GHG reducing techniques and technologies allowed that city to set a reduction target in line with its existing local government reduction targets. This is, however, a best-case scenario. Some local governments may not be able to implement the changes to specs and policies recommended in this thesis due to political factors, and this may prevent a swift reduction in emissions. Engineers and planners may also have limited knowledge or experience with technologies such as SCMs or WMA or impervious surface-reducing techniques such as GSI or road diets. This too can slow the process toward emissions reductions.

Regardless of the pace, any local government that successfully implements the reporting practices recommended in this thesis and develops strategies for reducing its emissions can set short-, medium- and long-range targets for reduction and monitor progress toward them.

It should be noted that any sector will likely not achieve carbon neutrality without the use of carbon offsets. For instance, at least with current technologies, it is impossible to eradicate all emissions associated with the production of cement and asphalt, short of ceasing their use. As complete cessation of cement and asphalt use is a very unlikely scenario, the goal should be to reduce emissions as much as possible, and then to purchase local carbon offsets to nullify the remaining ones. Seeing as cement emissions in many cases can be cut in half using SCMs, and that use of a combination of WMA, RAP and RAS can reduce asphalt-related emissions by as much, it is reasonable to expect that emissions from this sector can at least reach the medium range reduction target without any use of carbon offsets.

Purchasing offsets now, in order to neutralize these emissions quickly, is an option as well. While this strategy is quick and effective, it may undermine taking action on reducing the emissions themselves, as it may be seen as easier to continue purchasing offsets than to implement action strategies. Whether the cost of purchasing offsets would outweigh the cost of implementing the climate action strategies described above is a topic for further study, but the surest strategy to save money and reduce emissions would seem to be to pursue neutrality as far as possible before purchasing offsets for the portion that cannot be mitigated. Perhaps by that point additional technologies will exist to further reduce the emissions from cement and asphalt manufacture.

Alternatives Evaluation

The alternatives evaluation brings GHG mitigation from the theoretical stage to actual implementation by giving decision-makers a side-by-side comparison of how different emissions-reduction techniques and technologies within a single project will contribute to the local government's overall emissions from cement and asphalt purchasing, and therefore its total overall emissions. It also affords the opportunity to compare how different choices will affect the cost of materials for the project.

A local government that has already adopted the Materials Reporting Form for post-project reporting should have a simple time implementing the alternatives evaluation, as a majority of the variables in the alternatives evaluation table auto-populate based on entries to the Materials Reporting Form. The biggest barrier to completing the alternatives evaluation is the time it takes to fill out the reporting form three times—once for each alternative. However, because the calculations are completed automatically, even this should not be particularly burdensome. Only the cost information is required to be calculated and entered into the alternatives evaluation table by staff.

Some local governments might choose to only carry out an alternatives evaluation on larger projects, using a minimum threshold of concrete to determine which projects undergo evaluation. While this certainly would afford less opportunity for evaluation of emissions reductions, some local governments may find that the costs of completing an alternatives analysis on small projects outweigh the potential emissions reductions benefits.

It is important to note that, because this evaluation is meant to occur early in the design phase, exact emissions quantities cannot be determined. The usefulness of the alternatives evaluation is to be able to compare planning and engineering strategies for reducing emissions within a project and then select the alternatives that best set the local government on a path towards its emissions reduction target. The reporting form would then need to be filled out again upon completion of the project, in order to take variables into account that were unknown in the design phase, and in order to hone estimates for future alternatives evaluations.

The primary weakness of the alternatives evaluation method presented here is that it does not present a “winning” alternative, but simply gives decision-makers the opportunity to see the three alternatives side-by-side. Even if decision-makers used the alternatives evaluation on every project, they could still choose the highest-GHG alternative in every case. Whittington (2014), on whose alternatives evaluation this one is based, uses multi-criteria analysis in order to select a preferred alternative for each project. If this alternatives evaluation was incorporated into a larger capital investment planning methodology, perhaps multi-criteria analysis could be used to overcome this deficiency.

Another potential weakness of the alternatives evaluation table is the fact that there is nothing stopping project staff from using three very-similar alternatives. If project alternatives are too similar, then the alternatives evaluation does not provide much benefit to the decision-making process. It is only when three meaningfully different alternatives are presented that the alternatives evaluation can aid in reducing emissions. This is a problem of alternatives evaluation generally, not just this particular use of it, but a remedy could perhaps be found in having superiors check the alternatives or having a third-party verify their uniqueness.

Chapter 6: Conclusions

As local governments in the northwest, across the country, and around the world seek to mitigate the greenhouse gas emissions that are driving anthropogenic climate change, it is important that they take into account not only the direct emissions from their assets, but also the indirect emissions that occur as a result of their purchasing. Construction materials such as cement and asphalt are very GHG-intensive, and their heavy use in local government projects results in significant releases of greenhouse gas emissions—in many cases dwarfing emissions from all other sectors. In order for local governments to truly become carbon neutral, these emissions must be mitigated.

As shown in this thesis, a multitude of techniques and technologies from the planning and engineering disciplines exist that have the potential to eliminate a significant fraction of these emissions. The barrier to reducing these emissions lies in a lack of coordination among disciplines and departments. In order to overcome this barrier, local governments should look to expand their climate action planning processes to include these emissions. By instituting standard reporting practices, making changes to policies and specifications, and evaluating alternatives for reducing GHGs at the project level, local governments can set and meet GHG reduction targets that put them on a track toward true carbon neutrality.

Cement and asphalt concrete are not the only purchased materials that contribute to a local government's scope 3 inventory, however. The methodology proposed here should be expanded to include other construction materials such as steel, iron, and wood, and local governments should strive to reduce other sources of scope 3 emissions as well. It is only when *all* sources of emissions are accounted for that a plan for true carbon neutrality can be achieved.

Bibliography

All States Materials Group (ASMG). 2015. "Cold Mix Asphalt (CMA) Paving." Last updated 2015. http://www.asmg.com/services_mixes_cma.html.

American Coal Ash Association (ACAA). 2009. "Coal Combustion Products: Beneficial Use – Simply Recycling by Another Name." http://www.coalashfacts.org/documents/CCP%20Fact%20Sheet%206%20-%20Recycling%20by%20another%20name.pdf

American Coal Ash Association (ACAA). 2014. "2013 Coal Combustion Product Production & Use Survey Report." http://www.acaa-usa.org/Portals/9/Files/PDFs/2013ReportFINAL.pdf

American Concrete Institute (ACI). 1980. *Manual of Concrete Practice: Part 1*. Detroit, MI: American Concrete Institute. https://law.resource.org/pub/us/cfr/ibr/001/aci.manual.1.1980.pdf

American Concrete Institute (ACI) Committee 232. 2000. "Use of Raw or Processed Natural Pozzolans in Concrete." Farmington Hills, MI: American Concrete Institute. ACI 232.1R-00.

American Society of Landscape Architects (ASLA). 2013. "From Industrial Wasteland to Community Park." Accessed May 30, 2015. http://www.asla.org/sustainablelandscapes/Vid_Brownfields.html.

Arnold, Chester L. and C. James Gibbons. 1996. "Impervious Surface Coverage: The Emergence of a Key Environmental Indicator." *Journal of the American Planning Association* 62(2): 243-258. DOI: 10.1080/01944369608975688.

Asphalt Pavement Association of Michigan. 2008. "What is Hot Mix Asphalt Pavement?" http://www.apa-mi.org/what_is_hot_mix_asphalt_paveme.php.

Athena Institute. 2006. "A Life Cycle Perspective on Concrete and Asphalt Roadways; Embodied Primary Energy and Global Warming Potential." Accessed October 22, 2014. http://www.cement.ca/images/stories/athena%20report%20Feb.%202%202007.pdf

Barnes, Kent B., John M. Morgan III, and Martin C. Roberge. 2012. *Impervious Surfaces and the Quality of Natural and Built Environments*. Baltimore, MD: Towson University. http://pages.towson.edu/morgan/files/Impervious_Surfaces.pdf

Bassett, Ellen, and Vivek Shandas. 2010. "Innovation and Climate Action Planning." *Journal of the American Planning Association*. 76(4): 435-450. Academic Search Complete, EBSCOhost (accessed October 22, 2014).

Boswell, Michael R., Adrienne I. Greve, and Tammy L. Seale. 2010. "An Assessment of the Link Between Greenhouse Gas Emissions Inventories and Climate Action Plans." *Journal of the American Planning Association* 76(4): 451-462. Academic Search Complete, EBSCOhost (accessed October 22, 2014).

Bower, Nathan, Haifang Wen, Kim Willoughby, Jim Weston, and Joe DeVol. 2012. "Evaluation of the Performance of Warm Mix Asphalt in Washington State." Washington State Department of

Transportation Research Paper WA-RD789.1. http://www.wsdot.wa.gov/research/reports/fullreports/789.1.pdf.

Brabec, Elizabeth, Stacey Schulte and Paul L. Richards. 2002. "Impervious Surfaces and Water Quality: A Review of Current Literature and its Implications for Watershed Planning." *Journal of Planning Literature* 16(4): 499-514. http://m.jpl.sagepub.com/content/16/4/499.full.pdf

Buss, Ashley, R. Christopher Williams and Scott Schram. 2015. "The Influence of Warm Mix Asphalt on Binders in Mixes that Contain Recycled Asphalt Materials." *Construction and Building Materials* 77: 50-58. doi:10.1016/j.conbuildmat.2014.12.023.

C40 Cities Climate Leadership Group. 2015. "C40 Cities Make a Difference." Accessed April 21, 2015. http://www.c40.org/cities.

Carnegie Mellon University Green Design Institute. 2015. "EIO-LCA: Free, Fast, Easy Life Cycle Assessment." Accessed Feb 6, 2015. http://www.eiolca.net/.

City of Chicago. 2008. *Adding Green to Urban Design: A City for Us and Future Generations*. Chicago, IL: City of Chicago.

City of Portland. 2005. "Oregon Museum of Science and Industry Parking Lot Swales." https://www.portlandoregon.gov/bes/article/78489.

City of Portland. 2013. "City of Portland Green Purchasing Case Study: Warm Mix Asphalt." http://www.portlandoregon.gov/brfs/article/368274?.

City of Portland and Multnomah County. 2015. "Climate Action Plan Public Comment Draft." Accessed May 1, 2015. https://www.portlandoregon.gov/bps/49989.

City of Seattle. 2015. "Women and Minority Owned Businesses." http://www.seattle.gov/city-purchasing-and-contracting/social-equity/wmbe.

City of Seattle Office of Sustainability and Environment (OSE). 2008. "2005 Inventory of Seattle Greenhouse Gas Emissions: Community & Corporate." Accessed October 22, 2014. http://www.seattle.gov/Documents/Departments/OSE/2005%20Seattle%20Inventory%20Full%20Report.pdf.

City of Seattle Office of Sustainability and Environment (OSE). 2011. "City of Seattle Municipal Greenhouse Gas Inventory: 2008/2009." Accessed October 22, 2014. http://www.seattle.gov/Documents/Departments/OSE/Seattle-CorporateGHG-2008-2009-Report.pdf.

City of Seattle Office of Sustainability and Environment (OSE). 2011. "City of Seattle Municipal Greenhouse Gas Inventory: 2010." Accessed October 22, 2014. http://www.seattle.gov/Documents/Departments/OSE/Muni-GHGInventory_2010.pdf.

City of Seattle Office of Sustainability and Environment (OSE). 2013. "Seattle Climate Action Plan." Accessed October 22, 2014. http://www.seattle.gov/Documents/Departments/OSE/2013_CAP_20130612.pdf.

City of Seattle Office of Sustainability and Environment (OSE). 2014. “2012 Seattle Community Greenhouse Gas Emissions Inventory.” Accessed April 21, 2015. http://www.seattle.gov/Documents/Departments/OSE/2012%20GHG%20inventory%20report_final.pdf.

City of Seattle Procurement. 2014. “Ebid eXchange.”Last modified October 22, 2014. https://www.ebidexchange.com/Default.aspx?cid=eb31bf6e-250d-4d1d-abfb-37cb20108045.

Climate Registry, The. 2010. “Local Government Operations Protocol for the Quantification and Reporting of Greenhouse Gas Emissions Inventories.” Accessed October 22, 2014. http://www.theclimateregistry.org/downloads/2010/05/2010-05-06-LGO-1.1.pdf.

European Commission. 2014. “100 European Cities Sign up to Action on Climate Change.” http://europa.eu/rapid/press-release_IP-14-1138_en.htm

Flynn, Kevin M. and Robert G. Traver. “Green Infrastructure Life Cycle Assessment: A Bio-Infilitration Case Study.” *Ecological Engineering* 55: 9-22. doi:10.1016/j.ecoleng.2013.01.004.

Gomez-Meijide, Breixo and Ignacio Perez. 2014. “A Proposed Methodology for the Global Study of the Mechanical Properties of Cold Asphalt Mixtures.” *Materials and Design* 57: 520-527. doi:10.1016/j.matdes.2013.12.079

Good Company. 2015. “Supply Chain Greenhouse Gas Inventory Meta-Analysis.” Created for Alameda County. http://www.acgov.org/sustain/documents/Meta-Analysis_Study_04302015.pdf

Hanle, Lisa J. 2004. “Co2 Emissions Profile of the U.S. Cement Industry. *US Environmental Protection Agency*. http://www.epa.gov/ttnchie1/conference/ei13/ghg/hanle.pdf

Heinrichs, Dirk, Kerstin Krellenberg, and Michail Fragkias. 2013. "Urban Responses to Climate Change: Theories and Governance Practice in Cities of the Global South." *International Journal of Urban & Regional Research* 37(6): 1865-1878. Academic Search Complete, EBSCOhost (accessed October 22, 2014).

Healy, Denise (Seattle Department of Transportation) in conversation with the author. August 10, 2014.

Hoffman, Ray (Director, Seattle Public Utilities) in conversation with the author. January 21, 2015.

House, Kelly. 2014. “Portland Wins Presidential Award for Climate Change Work.” *The Oregonian*. December 3, 2014. http://www.oregonlive.com/portland/index.ssf/2014/12/portland_wins_presidential_awa.html.

Hurley, Graham C. and Brian D. Prowell. 2005. “Evaluation of Sasobit for Use in Warm Mix Asphalt.” National Center for Asphalt Technology Report 05-06. http://www.warmmixasphalt.com/submissions/11_20071127_EVALUATION_OF_SASOBIT.pdf.

International Energy Agency (IEA) 2011. "Technology Roadmap: Carbon Capture and Storage in Industrial Applications." https://www.iea.org/publications/freepublications/publication/ccs_industry_foldout.pdf.

International Energy Agency (IEA). 2014. "Carbon Capture and Storage." Last updated 2014. http://www.iea.org/topics/ccs/.

https://www.iea.org/publications/freepublications/

ICLEI (Local Governments for Sustainability) and the City of Seattle. 2005. "US Mayor's Climate Action Handbook." Accessed October 22, 2014. http://www.icleiusa.org/action-center/planning/climate-action-handbook.

ICLEI (Local Governments for Sustainability). 2015. ICLEI's Five Milestones for Climate Mitigation. Accessed April 21, 2015. http://www.icleiusa.org/action-center/getting-started/iclei2019s-five-milestones-for-climate-protection.

Intergovernmental Panel on Climate Change (IPCC). 2000. "CO2 Emissions from Cement Production." In *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories,* 175-182. Paris: IPCC.

Intergovernmental Panel on Climate Change (IPCC). 2013. "Summary for Policymakers." in *Climate Change 2013: The Physical Science Basis.* Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge, UK and New York, NY: Cambridge University Press.

Intergovernmental Panel on Climate Change (IPCC). 2014. *Climate Change 2014: Mitigation of Climate Change*. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge, United Kingdom and New York, NY: Cambridge University Press

Keches, Christine and Amy LeBlanc. 2007. "Reducing Greenhouse Gas Emissions from Asphalt Materials." Undergraduate thesis, Worchester Polytechnic Institute. https://www.wpi.edu/Pubs/E-project/Available/E-project-022807-143808/unrestricted/Keches_LeBlanc_MQP_2007.pdf.

Kim, Byungil, Hyounkyu Lee, Hyungbae Park, and Hyoungkwan Kim. 2012. "Framework for Estimating Greenhouse Gas Emissions Due to Asphalt Pavement Construction." Journal of Construction Engineering & Management 138(11): 1312-1321. Academic Search Complete, EBSCOhost (accessed October 22, 2014).

Kumar, Binod, G.K. Tike and P.K. Nanda. 2007. "Evaluation of Properties of High-Volume Fly-Ash Concrete for Pavements. *Journal of Materials in Civil Engineering* 19(10): 206-911. http://dx.doi.org/10.1061/(ASCE)0899-1561(2007)19:10(906)

Larsen, Hogne N., and Edgar G. Hertwich. 2010. "Implementing Carbon-Footprint-Based Calculation Tools in Municipal Greenhouse Gas Inventories." *Journal of Industrial Ecology* 14(6): 965-977. Academic Search Complete, EBSCOhost (accessed October 22, 2014).

Loreti Group, The. 2009. “Cement Sector Greenhouse Gas Emissions Reduction Case Studies.” Prepared for the California Energy Commission. Accessed October 22, 2014. http://www.energy.ca.gov/2009publications/CEC-600-2009-005/CEC-600-2009-005.PDF.

Madlool, N.A., R. Saidur, M.S. Hossian, and N.A. Rahim. 2011. “A Critical Review on Energy Use and Savings in the Cement Industries.” *Renewable and Sustainable Energy Reviews* 15: 2042-2060. doi:10.1016/j.rser.2011.01.005

Mallory, Sandra (Program Manager, Seattle Office of Sustainability and Energy) in conversation with the author. August 23, 2014.

Mehta, P. Kumar. 2004. “High-Performance, High-Volume Fly Ash Concrete for Sustainable Development.” Keynote Paper, *International Workshop on Sustainable Development and Concrete Technology*. http://www.ctre.iastate.edu/pubs/sustainable/mehtasustainable.pdf

Meinhold, Bridgette. 2013. “Spring Street Park: Downtown LA Parking Lot Transformed into Green Public Park.” *Inhabitat*. http://inhabitat.com/spring-street-park-parking-lot-transformed-into-public-park-in-downtown-la/.

Miller, Nicholas W., Dillip Guru and Kara Clark. 2008. “Wind Generation Applications for the Cement Industry.” *Cement Industry Technical Conference Record* May 2008: 103-112.

MIT Energy Initiative (MITei). 2015. “Non-Power Plant Carbon Dioxide Capture and Storage Projects.” Last Updated Jan 7, 2015. http://sequestration.mit.edu/tools/projects/storage_only.html

Moen, Wayne S. and Glennda B. McLucas. 1981. “Mount St. Helens Ash: Properties and Possible Uses.” Washington Department of Natural Resources Division of Geology and Earth Resources. http://digitalarchives.wa.gov/WA.Media/do/89F99372069BB3535CEF707EA7924DD1.pdf

Naik, Tarun R. 2005. “Sustainability of Cement and Concrete Industries.” *Center for By-Products Utilization* 2004-15: 1-10. https://www4.uwm.edu/cbu/Papers/2004%20CBU%20Reports/CBU-2004-15.pdf.

National Asphalt Pavement Association (NAPA). 2014. *Annual Asphalt Pavement Industry Survey in Recycled Materials and Warm-Mix Asphalt Usage: 2009-2013*. Lanham, MD: NAPA. http://www.asphaltpavement.org/PDFs/IS138/IS138-2013_RAP-RAS-WMA_Survey_Final.pdf.

National Asphalt Pavement Association (NAPA). 2015a. “Engineering Overview.” http://www.asphaltpavement.org/index.php?option=com_content&view=article&id=14&Itemid=33.

National Asphalt Pavement Association (NAPA). 2015b. “History of Asphalt.” http://www.asphaltpavement.org/index.php?option=com_content&view=article&id=21&Itemid=41.

National Slag Association. 2013. “Blast Furnace Slag.” http://www.nationalslag.org/blast-furnace-slag

North Dakota Department of Transportation (NDDOT). 2014. “Cold Weather Paving.” Powerpoint presentation by Jaqueline Aucker and Greg Olson. https://www.dot.nd.gov/conferences/construction/presentations/2014/Cold%20Weather%20Paving-Aucker%20&%20Olson.pdf.

Onishi, Akio, Xin Cao, Takanori Ito, Feng Shi and Hidefumi Imura. 2010. “Evaluating the Potential for Urban Heat-Island Mitigation by Greening Parking Lots.” *Urban Forestry and Urban Greening* 9(4): 323-332. doi:10.1016/j.ufug.2010.06.002.

Ozawa-Meida, Leticia, et al. 2013. "Measuring Carbon Performance in a UK University Through a Consumption-Based Carbon Footprint: De Montfort University Case Study." *Journal of Cleaner Production* 56: 185-198. Academic Search Complete, EBSCOhost (accessed October 22, 2014).

Portland Cement Association. “How Cement is Made.” Last Updated 2014. http://www.cement.org/cement-concrete-basics/how-cement-is-made.

Provis, John, Peter Duxson, and Jannie Van Deventer. 2008. "Concrete Evidence." *The Chemical Engineer* 809: 28-30. Academic Search Complete, EBSCOhost (accessed October 22, 2014).

Ramaswaini, Anu, Meghan Bemard, Abel Chavez, Tim Hillman, Michael Whitaker, Gregg Thomas, and Matthew Marshall. 2012. "Quantifying Carbon Mitigation Wedges in U.S. Cities: Near-Term Strategy Analysis and Critical Review." *Environmental Science & Technology* 46(7): 3629-3642. Academic Search Complete, EBSCOhost (accessed October 22, 2014).

Read, Steven (Materials Engineer, Seattle Public Utilities), in discussion with the author, March 10, 2015.

Seattle Department of Transportation (SDOT). 2015. “Traffic Calming Program: Physical Traffic Calming Devices.” Accessed May 30, 2015. http://www.seattle.gov/transportation/ntcp_physical.htm.

Seattle Parks and Recreation. 2015. “Bell Street Park.” Accessed May 30, 2015. http://www.seattle.gov/parks/park_detail.asp?ID=4472.

Seattle Public Utilities. 2014a. “Green Stormwater Infrastructure (GSI). Program Overview and Annual Report 2013.” http://www.seattle.gov/util/cs/groups/public/@spu/@drainsew/documents/webcontent/01_028743.pdf

Seattle Public Utiltites. 2014b. “Seattle Requirements for Construction and Demolition Materials Reuse and Recycling: Seattle Recycling Requirements and Shingles Disposal Ban. Powerpoint presentation, August 5, 2014. http://your.kingcounty.gov/solidwaste/linkup/documents/shingles-august-2014-event-presentation-uhlar-heffner.pdf.

Seattle Public Utilities. 2015. “Street Edge Alternatives.” Accessed May 30, 2015. http://www.seattle.gov/util/EnvironmentConservation/Projects/GreenStormwaterInfrastructure/CompletedGSIProjects/StreetEdgeAlternatives/index.htm.

Silica Fume Association. 2014. “What is Silica Fume?” http://www.silicafume.org/general-silicafume.html

Shehata, Medhat H. and Michael D.A. Thomas. 2002. “Use of Ternary Blends Containing Silica Fume and Fly Ash to Suppress Expanision due to Alkali-Silica Reaction in Concrete.” *Cement and Concrete Research* 32(3): 341-349. doi:10.1016/S0008-8846(01)00680-9.

Shogren, Elizabeth and Steve Inskeep. 2005. “Seattle Tackles Greenhouse Gases.” *National Public Radio Broadcast* November 28th, 2005. http://www.npr.org/templates/story/story.php?storyId=5028946

Shogren, Rob (Techinical Director, Lafarge North America), in discussion with the author, January 30, 2015.

King County. 2012. *Greenhouse Gas Emissions in King County*. Prepared by Stockholm Environmental Institute. Seattle, WA: King County. http://your.kingcounty.gov/dnrp/library/dnrp-directors-office/climate/2008-emissions-inventory/ghg-inventory-summary.pdf.

Tang, Zhenghong et al. “Moving from Agenda to Action: Evaluating Local Climate Change Action Plans.” *Journal of Environmental Planning and Management* 53(1): 41-52.

Thomas, Michael D.A., M.H. Shehata, S.G. Shahiprakash, D.S. Hopkins and K. Cail. 1999. “Use of Ternarty Cementious Systems Containing Silica Fume and Fly Ash in Concrete.” *Cement and Concrete Research* 29(8):1207-1214). doi:10.1016/S0008-8846(99)00096-4.

Thomas, Michael. 2007. *Optimizing the Use of Fly Ash in Concrete*. Skokie, IL: Portland Cement Association. IS548. http://www.cement.org/docs/default-source/fc_concrete_technology/is548-optimizing-the-use-of-fly-ash-concrete.pdf?sfvrsn=4

Tracy, Jacob. 2015. Reducing GHG Emissions from Cement Concrete in SPU Construction Projects.” Seattle Public Utilities internal memo.

Tracy, Jacob and Shirli Axelrod. 2014. “Quantifying and Reducing Greenhouse Gas Emissions from City of Seattle Cement and Asphalt Purchasing.” Seattle Public Utilities internal report.

United Nations Framework Convention on Climate Change (UNFCCC). 2014. “Kyoto Protocol.” http://unfccc.int/kyoto_protocol/items/2830.php.

US Conference of Mayors. 2008. “U.S. Conference of Mayors Climate Protection Agreement.” http://www.usmayors.org/climateprotection/agreement.htm.

US Department of Transportation Federal Highway Administration (USDOT). 2011. *Reclaimed Asphalt Pavement in Asphalt Mixtures: State of the Practice*. McLean, VA: USDOT. Publication no. FHWA-HRT-11-021. http://www.fhwa.dot.gov/publications/research/infrastructure/pavements/11021/11021.pdf.

US Department of Transportation Federal Highway Administration (USDOT). 2015a. “Road Diets (Roadway Reconfiguration).” Accessed May 30, 2015. http://www.fhwa.dot.gov/everydaycounts/edc-3/reconfiguration.cfm.

US Department of Transportation Federal Highway Administration (USDOT). 2015b. "Warm Mix Asphalt Technologies." Accessed February 20, 2015. http://www.fhwa.dot.gov/everydaycounts/events/trb/docs/wma/wma_brochure.pdf.

US Environmental Protection Agency (USEPA). 2008a. "Cement Sector Trends in Beneficial Use of Alternative Fuels and Raw Materials: Revised Draft." http://www.epa.gov/sectors/pdf/cement-sector-report.pdf

US Environmental Protection Agency (USEPA). 2008b. *Reducing Urban Heat Islands: Compendium of Strategies—Green Roofs*. Washington, D.C.: USEPA. http://www.epa.gov/heatisland/resources/pdf/GreenRoofsCompendium.pdf

US Environmental Protection Agency (USEPA). 2010a. "Asphalt Concrete." Last modified October 28, 2010. http://www.epa.gov/climatechange/wycd/waste/downloads/asphalt-concrete-chapter10-28-10.pdf

US Environmental Protection Agency (USEPA). 2010b. "Available and Emerging Technologies for Reduction Greenhouse Gas Emissions from the Portland Cement Industry." http://www.epa.gov/nsr/ghgdocs/cement.pdf

US Environmental Protection Agency (USEPA). 2013. *Case Studies Analyzing the Economic Benefits of Low Impact Development and Green Infrastructure Programs*. Washington, D.C.: USEPA).

US Environmental Protection Agency (USEPA). US Environmental Protection Agency (USEPA). 2014a. "Concrete." In *WARM Version 13. http://epa.gov/epawaste/conserve/tools/warm/pdfs/Concrete.pdf*

US Environmental Protection Agency (USEPA). 2014b. "Developing a Greenhouse Gas Inventory." http://www.epa.gov/statelocalclimate/local/activities/ghg-inventory.html

US Environmental Protection Agency (USEPA). 2014c. "Fact Sheet: Final Rule on Coal Combustion Residuals Generated by Electric Utilities." http://www2.epa.gov/sites/production/files/2014-12/documents/factsheet_ccrfinal_2.pdf

US Executive Office of the President. 2013. "The President's Climate Action Plan." Accessed October 22, 2014. http://www.whitehouse.gov/sites/default/files/image/president27sclimateactionplan.pdf.

US Geological Survey. 2014. "Cement." In *2014 Mineral Commodity Summary,* 38-39 http://minerals.usgs.gov/minerals/pubs/commodity/cement/

US Green Building Council (USGBC). 2015. "LEED v4 for Building Design and Construction." http://www.usgbc.org/sites/default/files/LEED%20v4%20BDC_04.01.15_current.pdf.

West Coast Climate and Materials Management Forum (WCCF). 2014a. "Climate Action Toolkit." Accessed October 22, 2014. http://westcoastclimateforum.com/toolkit/homepage.

West Coast Climate and Materials Management Forum (WCCF). 2014b. "GHGI Comparison DRAFT." Excel Spreadsheet. Created by Leslie Cochan.

Whittington, Jan. 2014. *Climate-Smart Capital Investment Planning Handbook*. Washington, D.C.: The World Bank.

Wilson, M.L and S.H. Kosmatka. 2011. *Design and Control of Concrete Mixtures* 15th Edition. Washington, D.C.: Portland Cement Association.

World Bank, The. 2013. *Turn Down the Heat: Climate Extremes, Regional Impacts and the Case for Resilience*. Washington, D.C.: The World Bank. http://www.wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2013/06/14/000445729_20130614145941/Rendered/PDF/784240WP0Full00D0CONF0to0June19090L.pdf.

World Bank, The. 2014. "Asian Cities: Climate Focus Needed in Capital Investment Planning." May 15, 2014. http://www.worldbank.org/en/news/feature/2014/05/15/asian-cities-climate-focus-needed-capital-investment-planning

World Resources Institute. 2011. "Corporate Value Chain (Scope 3) Accounting and Reporting Standard." Accessed October 22, 2014. http://www.wri.org/sites/default/files/pdf/ghgp_corporate_value_chain_scope_3_standard.pdf

World Resources Institute and World Business Council for Sustainable Development. 2003. *The GHG Protocol for Project Accounting*. Washington, D.C.: World Resources Institute

World Resources Institute and World Business Council for Sustainable Development. 2012. *The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard, Revised Edition*. Washington, D.C.: World Resources Institute.

Wu, Zichao and Tarun Naik. 2002. "Properties of Concrete Produced from Multicomponent Blended Cements. *Cement and Concrete Research* 32(12): 1937-1942. doi:10.1016/S0008-8846(02)00907-9

Yang, Jun, Shirley Ddamba, Riyad UL-Islam, Md. Safiuddin, and Susan L. Tighe. 2014. "Investigation on use of recycled asphalt shingles in Ontario hot mix asphalt: a Canadian case study." Canadian Journal Of Civil Engineering 41(2): 136-143. doi: 10.1139/cjce-2013-0022