Getting to Zero: A Pathway to a Carbon Neutral Seattle

Final Report

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Executive Summary

Cities play a unique role in addressing climate change. Over 80% of Americans live in urban areas, as does over half of the world's population. As a consequence, the design of cities, from their built environment to their transportation systems, has a profound influence on how energy is used, and thus, also on global greenhouse gas (GHG) emissions. Municipal and regional actors, from city planners to business and community groups, as well as the market forces they can influence, will determine whether the form of urban areas will be car-intensive or transit-oriented, how buildings will be built and maintained, and, often, where electricity and heat will be sourced. With one and a half billion new urban dwellers expected in the next two decades, largely in the developing world, it is critical that cities demonstrate how they can dramatically reduce their GHG emissions, while creating more vibrant and prosperous places to live and do business.

Seattle has a long been a world leader in city-level planning and action to address climate change. Seattle already possesses a carbon-neutral electricity supply, and plans to maintain it, along with a strong foundation of existing emission reducing activities in the transportation, buildings, and waste sectors. For these reasons, the city is uniquely positioned to demonstrate how communities can address the climate challenge.

In 2005, Seattle led the effort to convince over 1,000 mayors to commit their cities to reducing their GHG emissions by 7% from 1990 levels by 2012. In February 2010, the Seattle City Council adopted a more profound and ambitious vision for Seattle: to become what could be the nation's first carbon neutral city. Recognizing the extraordinary challenge of carbon neutrality and in preparation for updating its Climate Action Plan by 2012, the Seattle Office of Sustainability and Environment (OSE) commissioned SEI and its partners at Cascadia Consulting Group and ICF International to develop a scenario of how the city might be able to achieve carbon neutrality.

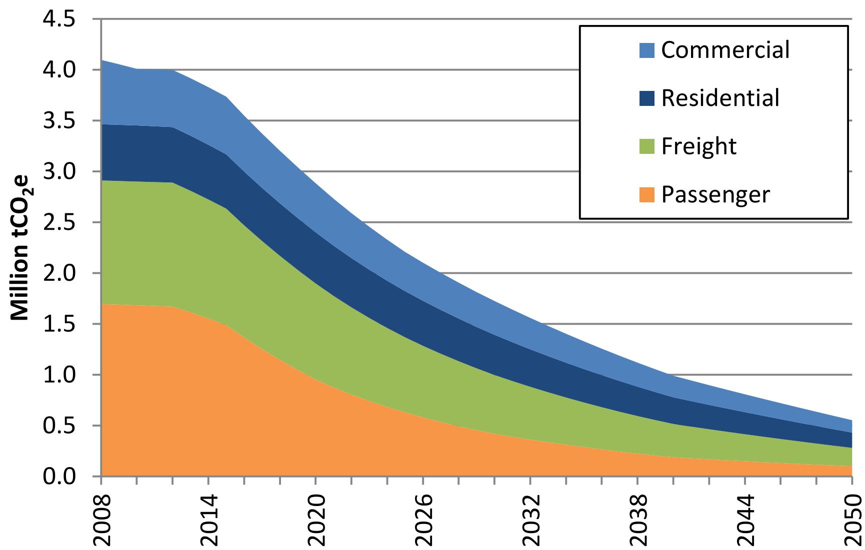
Together, the SEI team and OSE, with guidance from our Technical Review Committee, constructed a Carbon Neutral scenario from the "bottom up" by developing a suite of ambitious strategies based on aggressive deployment at plausible penetration rates of technologies and practices. The Carbon Neutral scenario presented here represents one of many possible pathways to carbon neutrality and serves to illuminate the depth of potential emissions reductions that could move Seattle toward becoming a carbon neutral city.

Results of the Carbon Neutral scenario suggest that implementation of a full suite of emissions-reducing strategies could cut Seattle's per capita GHG emissions by 30% by 2020, 60% by 2030, and 90% by 2050, relative to 2008 levels. Three broad outcomes are central to the rapid pace of emission reductions in the Carbon Neutral scenario:

- Shifts to less GHG-intensive travel modes such as ride sharing, transit, walking and biking lead to 30% less per-capita travel by light duty vehicles in 2030 and 50% less by 2050, relative to 2008 levels.

- Second, dramatic increases in energy efficiency in building design and operations, as well as in vehicle efficiency, result in over 30% energy savings by 2030 (per capita in residential, per square foot in commercial, and per-mile in vehicles) and over 50% by 2050, relative to 2008 levels.
- Finally, homes, businesses, and vehicles transition to lower carbon energy sources: electricity (or possibly hydrogen) in the long run, biofuels as a bridging strategy for transportation until electric vehicles predominate, and to a much lesser extent, sustainable biomass sources (for district energy systems).

Figure ES-1. GHG Emissions in the Carbon Neutral Scenario, by Sector



Many of the strategies considered in the Carbon Neutral scenario can provide benefits well beyond emissions reductions. Building design and retrofits, expanded transit investments, and new infrastructures for district energy and electric vehicles can help to create healthier, more vibrant communities, and provide foundations for new, green jobs and businesses.

The City can do much within its sphere of influence to reduce VMT, develop alternative transportation modes, lower building energy use and emissions, develop district energy and electric vehicle infrastructure, and increase recycling, composting, and waste reduction. That said, federal and international action will be essential for the City's goals to be achievable. Over half of the reductions in this scenario result from improving the efficiency of vehicles and appliances and developing and delivering alternative fuels and the equipment to use them. While cities can pilot and create markets for these technologies, they will require the global market demand and research, development, and deployment support that only national and international actions can provide.

Even with concerted action at federal and international as well as the City level, eliminating every ton of GHG emissions may prove too difficult or costly to achieve, especially in the next few decades. Consequently, reaching the City's carbon neutrality goal, defined as zero net emissions by 2050, may require additional steps to offset remaining emissions such as increased sequestration activities, credit for selling excess renewable energy, or other measures. The City can also use these options to achieve more ambitious goals than these scenario results might suggest.

This report offers a proof of concept that a very low emission future is achievable, even if the implementation challenges are daunting. It is important to stress that the scenario presented here is neither the only possible low emission pathway nor necessarily the most ambitious one. Furthermore, this proof of concept is not a policy recipe; the specific analytic assumptions, e.g. for the vehicle travel pricing or extent of district energy development, are not developed or intended as policy recommendations. The scenario, instead, serves to demonstrate the depth of reductions possible with aggressive and foreseeable deployment of strategies and policies in different sectors. The upcoming planning process will provide the opportunity to translate this vision into discrete policies and actions for implementation.

Finally, this report remarks on two additional perspectives on GHG emissions that go beyond the scope of the Carbon Neutral scenario. One perspective is to consider the life cycle GHG emissions associated with goods, food, and services that Seattle residents consume. About half the emissions associated with Seattle residents' consumption is associated with the production of goods, food, and services, emissions that occur largely outside the city limits. These activities and emissions may be less within the city's sphere of influence than those associated with in-city building energy use, transportation, or waste management. Nonetheless, through complementary efforts, the city may wish to engage the community in efforts to reduce the emissions footprint of their purchasing patterns. The second perspective relates to production activities in Seattle that largely fulfill demands outside the city. Because Seattle's port and industrial activity are driven by external demands for the goods they ship and produce, we exclude them from the scope of our scenario analysis. At the same time, the city can expand its efforts to reduce the emissions intensity of goods produced or transported through the city, for example, through increased port electrification or capture of waste energy at industrial facilities. In the report, we suggest some metrics the city can use to track and manage these emissions.

1 Context

1.1 The Climate Challenge: Urgency, adequacy, and responsibility

For several decades, and with increasing consensus, scientists have recognized that increasing emissions of carbon dioxide and other greenhouse gases (GHGs) -- largely due to the use of fossil fuels -- will, if unabated, dangerously disrupt the earth's climate and the economic, social, and natural systems that depend on it. The earth is already 0.8°C warmer than at the dawn of the industrial age. Absent efforts to curb GHG emissions, the earth's temperature could rise by as much as 5°C by the end of the 21st century, risking significant, unpredictable, and irreversible harm: widespread water shortages, crop and species losses, and extreme weather events, to name a few.[1]

The good news is that, globally, there is still the opportunity not just to avoid the worst such outcomes, but to create more attractive and prosperous communities and economies in the process. Major reductions in GHG emissions will require comprehensive changes not just in how we manage energy supply, forest, and agricultural systems, but in how we live and move in urban areas, where most of world's energy, materials, and products are consumed. As described below, this fundamental point speaks to the unique role that cities like Seattle can and indeed must play to achieve this transformation. The question addressed here is what level of reductions might be adequate to limit dangerous interference with the earth's climate. This in turn can provide context for the pace and extent of reduction in Seattle's emissions that government and community actions might aim to achieve, and signal to the broader world what is possible.

The state of scientific knowledge and discourse has advanced since Seattle, and other communities, adopted their current long-term emission reduction goals – in the case of Seattle, its goal of reducing emissions 80% below 1990 levels by 2050. However, while this goal may be considered very *ambitious* in terms of the required policies, technologies and actions to achieve it, it may no longer represent an *adequate* target in terms of confronting the risks of climate change.

Over the past decade, scientists, governments, and civil society have together articulated a growing consensus that the earth's mean temperature should not exceed 2 degrees C above the pre-industrial level if the earth is to maintain a safe operating space for humanity.[2] More recently, many scientists have suggested that a safe operating space might require staying within a 1.5 degrees C increase, and many climate-vulnerable nations have endorsed such a goal.

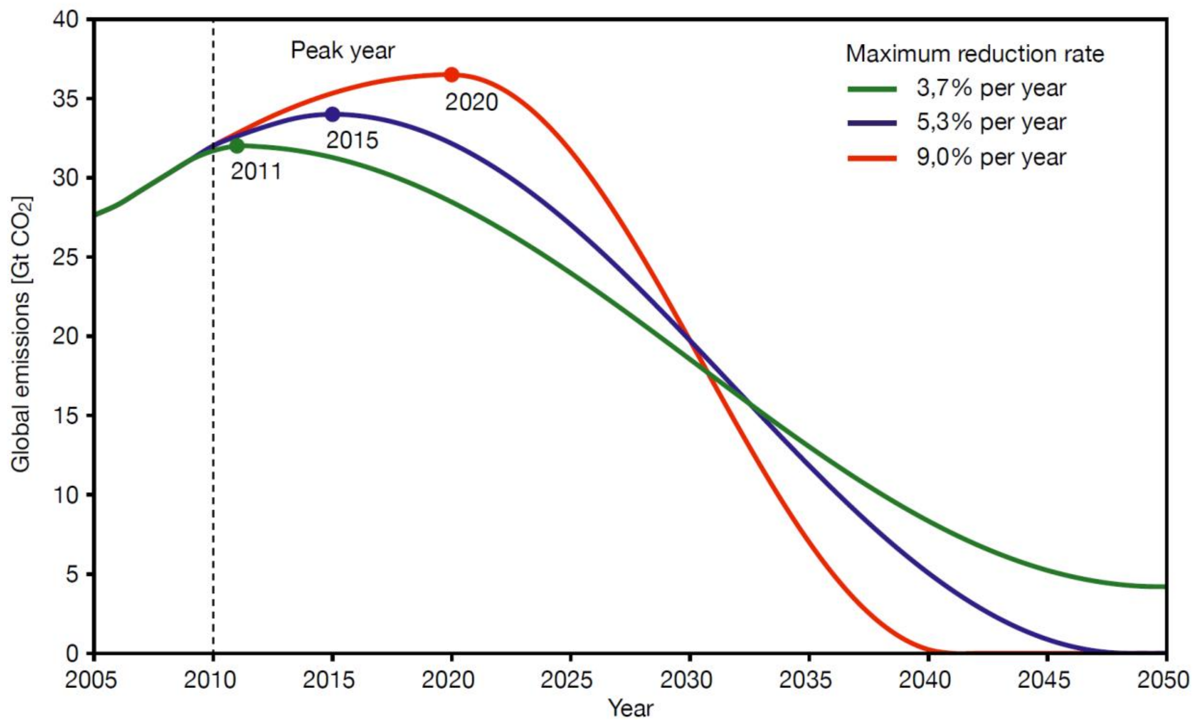
Figure 1 charts three possible global CO_2 emissions pathways that could limit warming to 2 degrees C. The green pathway, for example, suggests that if global emissions were to begin a steady decline at a rather ambitious pace of 3.7% per year, global emissions would need to peak next year in order to

[1] For reference, 4 to 7°C of warming is all that distinguishes the depths of an ice age from the hospitable climate in which human civilization has flourished (IPCC, 2007).

[2] For an assessment of the "reasons for concern" associated with warming of 2 degrees, see Smith et al (2009), http://www.pnas.org.ezproxy.library.tufts.edu/content/106/11/4133.abstract. The 2 degree target was also noted by signers of the Copenhagen Accord.

satisfy the 2 degree C limit. The longer global action is delayed and emissions continue to rise – as shown in the other two pathways that peak in 2015 and 2020 – the faster and deeper the ultimate reduction pathway must be to limit warming to no more than 2 degrees C. Given that global emissions are unlikely to peak and begin a swift descent next year, it appears unlikely that a goal of 80% below 1990 levels by 2050 (close to what is shown for the green pathway), would be sufficient to stay within the 2 degree C "guardrail".

Figure 1. Examples of Alternative Global CO_2Emissions Pathways to Meet 2° C "Guardrail" (WBGU 2009)[3]



Furthermore, while Figure 1 illustrates *global* emissions pathways for achieving a 2 degree target, it does not speak to "common but differentiated responsibilities", a guiding principle of the UN Framework Convention on Climate Change, signed by 180 countries in 1992, that places greater burden on wealthier countries to finance and deliver emission reductions. From a pragmatic as well as moral perspective, the emissions pathway for wealthier regions will likely need to be even more ambitious than shown above.

Therefore, while the goal of 80% below 1990 levels by 2050 may be considered very *ambitious* in terms of the required policies, technologies and actions to achieve it, it may no longer represent an *adequate* target in terms of Seattle doing its part, and setting an example, in confronting the risks of climate change. An "adequate" reduction goal for 2050 is more likely to involve reductions of at least 90-95% below 1990 levels, if not achieving net zero emissions, which might involve sequestering carbon (in

[3] These scenarios were constructed to limit global CO2 emissions to 750 Gt between 2010 and 2050, a level that is believed to yield a 67% chance of averting warming of 2 degrees over pre-industrial levels.

forests, soils, or underground) to compensate for the remaining GHG emissions that are simply too difficult or costly to eliminate.[4]

1.2 The Role of Cities in Addressing Climate Change

Cities play a unique role in addressing climate change. Over 80% of Americans live in urban areas, as does over half of the world's population.[5] As a consequence, the design of cities, from their built environment to their transportation systems, has a profound influence on how much of the world's energy is used, and thus, on global greenhouse gas emissions. Municipal and regional actors, from city planners to business and community groups, and the market forces they can influence, determine whether the form of urban areas will be car-intensive or transit-oriented, how buildings will be built and maintained, and, often, where electricity and heat will be sourced. With one and half billion new urban dwellers expected in the next two decades, largely in the developing world, it is therefore critical to demonstrate how cities can make the decisions and take the actions that will dramatically reduce their GHG emissions, while also render them more vibrant, prosperous, and livable.

Around the world, hundreds of cities have already pledged to cut GHG emissions aggressively over the next 40 years. Like Seattle, many of these communities have developed visions for a low-carbon economy and adopted specific policies as part of their overall municipal plans. For example, Copenhagen, Denmark, is pursuing 50 initiatives, ranging from conversion of power stations from coal to biomass to expanding its world-leading bike infrastructure, in order to reduce its emissions by 20% by 2015. Closer to home, Vancouver, Canada, launched a detailed plan of emission reduction actions in its quest to become the world's greenest city. Nonetheless, in general, while many cities have adopted ambitious, longer-term emissions reduction goals, few have articulated how to reach them, much less taken significant action to reduce those emissions.

1.3 About this study

Seattle has a long been among the leaders in planning and action to address climate change. In 2005, Seattle led the effort to convince over 1,000 mayors to commit their cities to reducing their GHG emissions by 7% from 1990 levels by 2012. The same year, the City convened a Green Ribbon Commission on Climate Protection, with leaders from across Seattle's business, labor, non-profit, government and academic communities participating. Their work formed the basis for Seattle's current Climate Action Plan. In February 2010, the Seattle City Council adopted a more profound and ambitious vision for Seattle: to become (what could be the nation's first) carbon neutral city.

Recognizing the extraordinary challenge of carbon neutrality and in preparation for updating its Climate Action Plan by 2012, the Seattle Office of Sustainability and Environment commissioned SEI and its partners at Cascadia Consulting Group and ICF International to develop a scenario of how the City might be able to achieve carbon neutrality. Carbon neutrality is still a relatively novel concept, and lacks a

[4] In fact, the relative wealth and historic emissions of wealthier communities such as Seattle suggest that to contribute equitably to global emissions reductions may require a goal that ultimately goes beyond those required to achieve carbon neutrality (Erickson, Chandler, and Lazarus 2010).

[5] http://earthtrends.wri.org/

universal definition. Therefore, the first step in this effort was to review how other communities and institutions have approached the definition and achievement of carbon neutrality, which Box 1 summarizes below.

The City has since elected to define carbon neutrality as net zero greenhouse gas emissions by 2050. This goal definition means that whatever GHG emissions remain in 2050 would need to be "netted out", either through the purchase of "GHG offsets" from activities outside the City or other measures, such carbon sequestration or provision of excess "green electricity" as discussed further below.

By presenting a Carbon Neutral scenario built up from specific emission reducing opportunities, largely based on already-proven technologies and implementation strategies, this report offers a proof of concept that a very low emission future is achievable, even if the implementation challenges are daunting. It is important to stress that **the scenario presented here is neither the only possible low emission pathway nor necessarily the most ambitious one**.[6] Furthermore, this proof of concept is not a policy recipe; the specific analytic assumptions, e.g. for the vehicle travel pricing or extent of district energy development, are not developed or intended as policy recommendations. **The scenario**, instead, **serves to demonstrate the depth of reductions possible with aggressive and foreseeable deployment of strategies and policies in different sectors**. The upcoming planning process will provide the opportunity to translate this vision into discrete policies and actions for implementation.

1.4 Roadmap of the report

This report provides a general outline of the Carbon Neutral scenario and its key findings and implications. Section 2 begins by laying out the "core" sectors and emissions sources that are the focus of our analysis. While there are other elements of the City's emissions, the buildings, transportation, and waste sectors account for the majority of emissions in Seattle, and offer the greatest opportunities for the City to influence GHG emissions through its direct policy, program and investment levers; lobbying for county, state or federal action and legislation; or inspiring community action. Accordingly, we focus on buildings, transportation, and waste as the "core" emissions. Section 3 provides an overview of the Carbon Neutral scenario, the methods used to develop it, and context in which results should be viewed.

Together, the SEI team and OSE, with guidance from the Technical Review Committee (TRC), constructed the Carbon Neutral scenario from the "bottom up" by developing a suite of ambitious strategies based on aggressive deployment at plausible penetration rates of technologies and practices. We describe these strategies in Sections 4 through 6, for the transportation, building energy, and waste sectors, respectively. A separate Technical Appendix provides a fuller explanation of each strategy, as well as the detailed assumptions and their sources.

[6] Other technology pathways may exist to achieve similar goals, such as one more reliant on hydrogen fuel cells than electricity for vehicles. It is also possible that lifestyle and behavior changes (e.g. smaller homes, fewer amenities, less economic activity) could play a greater role in achieving carbon neutrality goals than we articulate in our scenario.

Section 7 presents some additional perspectives on the city's emissions that can guide complementary efforts to address emissions associated with industrial activity in the City and with resident and business consumption. In addition to aiming for carbon neutrality in its "core" emissions, the City is considering how to mobilize the community to address the emissions associated with producing the goods and services it consumes, even if those emissions occur far beyond Seattle's borders. We present a sketch analysis of those emissions, by the category of product or service consumed. In this section, we also touch on how the City may wish to track and influence emissions from in-city industrial production, even as much of this production largely serves regional and international demand for goods and materials (such as glass, cement, and steel) beyond the City's borders. Section 8 offers some general conclusions and suggestions for areas of further work as the City moves towards implementing a carbon neutral vision.

Box 1. How have other communities approached the concept of carbon neutrality?

Even though carbon neutrality is a relatively new concept that lacks a universally accepted definition, various cities in the United States and across the world have begun to craft visions of what carbon neutrality might look like. In addition, many companies and organizations have committed to achieving carbon neutrality, Seattle City Light being a notable local example.

The simplest definition of carbon neutrality is simply zero carbon emissions. For example, imagine a city where no fossil fuels is combusted, and thus no carbon dioxide is emitted. While clear, this definition has several drawbacks. First, it is important to consider emissions other than carbon dioxide emissions from the burning of fossil fuels. While energy-related carbon dioxide emissions pose the greatest challenge for humanity, emissions of other greenhouse gases, such as methane from landfills, nitrous oxide from fertilizer use, and fluorinated gases from industrial processes, among others, can be important to consider, especially where communities can wield major influence, as in the case of waste management. Another such case is land use management, where communities can reduce forest loss associated with development, or otherwise increase the carbon stored in the landscape by supporting increased tree cover. Second, it may prove prohibitively expensive and impractical to eliminate all GHG emissions. Instead, a more cost-effective and practical approach can be to aim for zero *net* carbon emissions. Emissions that cannot be effectively reduced can instead be "netted out" through actions that sequester carbon in trees, plans, soil, or deep underground (what is termed carbon capture and storage) or through the use of GHG offsets or other mechanisms (see discussion in Section 3).

Only two cities that we are aware of, Copenhagen and Melbourne, have committed to achieving net zero emissions for a relatively comprehensive scope of community emissions. (See Annex 1 for a summary table of municipal carbon neutral and similarly ambitious plans.) Other communities have limited the scope of carbon neutrality to a handful of emissions sources such as municipal operations (Austin, Vancouver), new buildings (Vancouver), and new electricity sources (Austin). Växjö, a town of 55,000 in a biomass-resource rich region of Sweden, has set a fossil-fuel (CO_2) free goal for 2030. Other communities aspire to become carbon neutral but lack concrete goals or analysis to support achievement of carbon neutrality goals.

It is perhaps not surprising that nearly all plans that aim for "neutrality" rely on offsets to meet their stated goals; some emission sources are very difficult or costly to reduce, and offsets can be easily invoked to compensate for remaining unabated emissions. In its plan, Copenhagen achieves approximately half of its emission reductions by 2025 through offsets, while Melbourne relies on offsets an even larger fraction of emissions reductions by 2020, its target year for neutrality. In general, these plans leave offsets very loosely defined (in contrast to their more specific definition and requirements in the context of emission trading systems).

2 Seattle's Current GHG emissions

Among US cities, Seattle has a relatively unique emissions profile. Owing to its large city-owned hydroelectric resource, and long-standing City Light policies that favor efficiency and renewable energy, Seattle is the only major US city that can claim net zero carbon electricity. As a result, the use of natural gas in buildings and gasoline and diesel for transportation account for a majority of the city's current GHG emissions. Seattle is also home to the only cement manufacturing plant in Washington State, the Ash Grove facility, which constitutes the other major source of GHG emissions in city. In addition, there are a multitude of other, smaller sources of GHG emissions, from small industrial manufacturing activities to trains and ships moving goods through the Port.

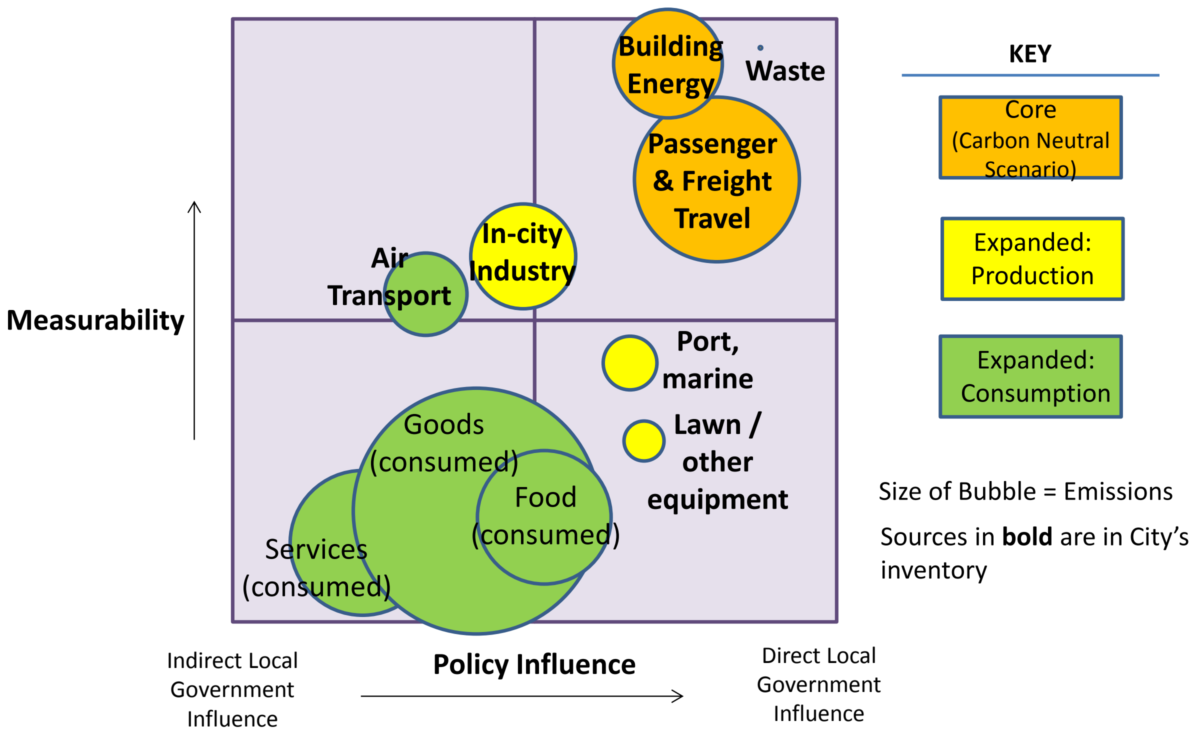
All of these emissions sources are documented in the City's comprehensive GHG emissions inventory, which it has compiled for the years 2005, 2008, and retrospectively, back to 1990. However, the precise scope of emissions sources covered in the City's inventory is not necessarily the appropriate one for the City to use in defining a carbon neutral goal, and in tracking progress towards it. GHG inventory methods used by Seattle and many other communities were designed primarily for use in tracking national level emissions. Cities, in contrast, have different spheres of influence than nations do. Municipal governments and residents can directly affect emissions from homes, commercial establishments, and transportation through actions ranging from transit investments, vehicle and appliance purchases, and building codes and retrofits. In contrast, industrial manufacturing and port activity are driven largely by regional demands outside the city. While local actors can have some influence on the emissions of docked ships (e.g. port electrification) and industrial facilities (e.g. through the Seattle Climate Partnership), progress towards meeting the City's goals should not be strongly determined, for example, by statewide demand for cement or the shipments routed through the Port of Seattle (rather than other ports) and destined for the Midwest. Unfortunately, using the standard inventory method, this would be the case.[7]

To address these concerns, the SEI team worked with city's Office of Sustainability and the Technical Review Committee to establish a policy-relevant and readily-trackable emissions scope for the Carbon Neutral scenario analysis. Together, we adopted a community-scale emissions accounting framework that divides emissions sources into three scopes based on the extent to which these sources can be influenced by government policy and their emissions can be accurately measured and tracked. Depicted in Figure 2, and developed recently under a separate project for King County,[8] this framework identifies three sectors -- residential and commercial energy use, passenger and freight vehicle travel, and waste – as "core" emission sources. These emissions sources combine the greatest capability for government influence with greatest ability for the City to measure and track emissions, and correspond to the

[7] The variance in Seattle's inventory between 1990 and 2008 has been driven in good part by the tons of cement produced. The closure of Lafarge's kiln provides a big drop in Seattle's emissions that does not correspond to a global emissions reduction.
[8] The framework was developed as part of the King County Communities Emission Inventory and Climate Action Assessment project.

majority of emissions reported in the city's official inventory.[9] As shown in Figure 2, we consider in-city industry and port-related emissions separately in an expanded, production scope; we return to a discussion of how the City could address these emission sources in Section 7.

Figure 2. Scope of Seattle's emissions covered in the Carbon Neutral Scenario



The emissions sources shown in green in Figure 2 represent the life-cycle emissions associated with all goods and services consumed by Seattle residents (and government). The majority of these emissions are released far from the city in the course of producing food, manufacturing appliances, or delivering these and other products and services. This consumption category also includes air travel by Seattle residents. In general, emissions associated with consumption are both difficult to track accurately and to influence directly by government action. Nonetheless, while we do not include these emissions sources in our Carbon Neutral scenario analysis, we provide a sketch assessment of the Seattle's per capita consumption-based emissions in Section 7. As we note in that section, there are many actions

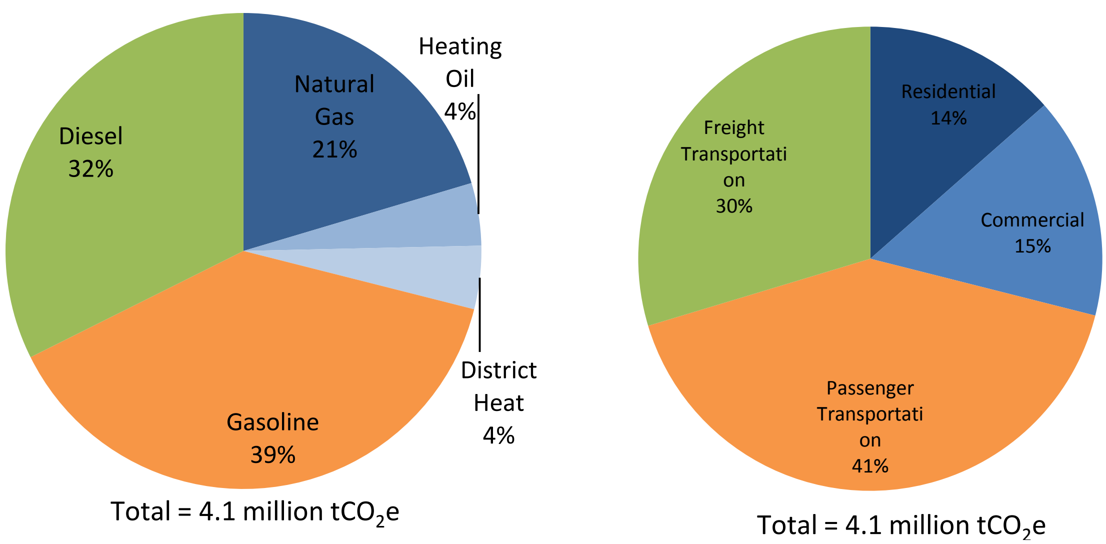
[9] We also depart from the traditional inventory methods in a couple of other ways. First, we adopt the origin-destination method for estimating vehicle miles travelled. This method counts emissions from all trips that occur entirely within Seattle, half of trips that either begin or end in the city, and no trips that both begin and end outside the city (even if they pass through). A number of jurisdictions throughout the country use this methodology. For further discussion of this method, see Ramaswami et al. (2008). Second, we look at waste from a "waste commitment" perspective, which counts emissions associated with all waste generated from within Seattle, regardless of when or where those emissions actually occur. This method better captures the ability of the City or its businesses and residents to affect emissions though waste reduction and diversion to composting and recycling. This approach is increasingly used for community-based inventories; the traditional method considers only the emissions from the city's long-closed landfills, and bears no relationship to current waste generation and management practices.

residents and businesses can take to reduce consumption-based emissions (e.g. improved access to high quality videoconferencing in order to avoid the need for air travel, especially for businesses).

In 2008, total Seattle *core* emissions– i.e. those associated with building energy use, transportation energy use, and waste generated in the City -- amounted to 4.1 million metric tons (or "tonnes") in CO_2 equivalents (CO_2e).[10] Gasoline and diesel use for passenger and freight transportation, respectively, account for the predominant share (≈70%) of current core emissions, as shown in Figure 3. The remaining 30% of emissions are the result of building energy use, largely from the direct use of natural gas for heat and hot water. The direct use of heating oil, while declining in recent decades, still accounted for 4% of core emissions. The Seattle Steam district heat system, fueled by natural gas, also accounted for 4% of emissions in 2008; its GHG emissions declined in 2009 as it switched to partial use of waste wood.

Though among the core emissions, waste management is notably absent from the pie charts in Figure 3. That absence is the result of net waste emissions (from a waste commitment perspective) being approximately zero in 2008. Nonetheless, there are important opportunities to create global emissions reduction from deepening recycling and composting efforts, reducing waste generation, and further reducing methane emissions associated with waste generated in the City. We discuss these strategies, and explain the waste commitment approach, in Section 6.

Figure 3. Seattle's Core GHG Emissions in 2008 by Fuel (left) and Sector (right)



[10] For comparison, the official Seattle inventory estimate for 2008 was 6.8 million tCO2e. The difference is largely accounted for by in-city industrial emissions (1.2 million tCO2e), other non-road fuel use (0.2 million tCO2e), and airport (Boeing Field) and air travel (1.1 million tCO2e), which we include in the expanded production and consumption scopes, respectively.

For most other US cities, electricity use would figure prominently in building emissions. Indeed, across all residential and commercial buildings in the US, the GHG emissions associated with the electricity use exceed the GHG emissions from natural gas use.[11] Indeed in Seattle, electricity accounts for slightly over half of building energy use (53% in 2008), but none of the sector's emissions, because of City Light's ability to provide net zero emissions power. However, simply switching heating systems and appliances from natural gas to electricity doesn't necessarily mean that GHG emissions is the buildings sector will go to zero. City Light's ability to continue providing net zero emissions electricity depends on managing electricity demands over time, as the existing hydroelectric resource is finite and, potentially, could decline due to climate change. The amount of solar electricity that can be generated in the City is limited, and the City will need to compete with other communities for new renewable energy resources. Therefore, switching buildings and vehicles from natural gas and transportation fuels to net zero carbon electricity, a major component of the Carbon Neutral scenario described in the Sections below, would need to be complemented by major investments in electricity efficiency and conservation.

[11] According to the US EPA's national GHG inventory for 2008 (U.S. EPA 2011), about 71% of residential CO2 emissions and 79% of commercial CO2 emissions were associated with electricity production.

3 Envisioning a Carbon Neutral Seattle

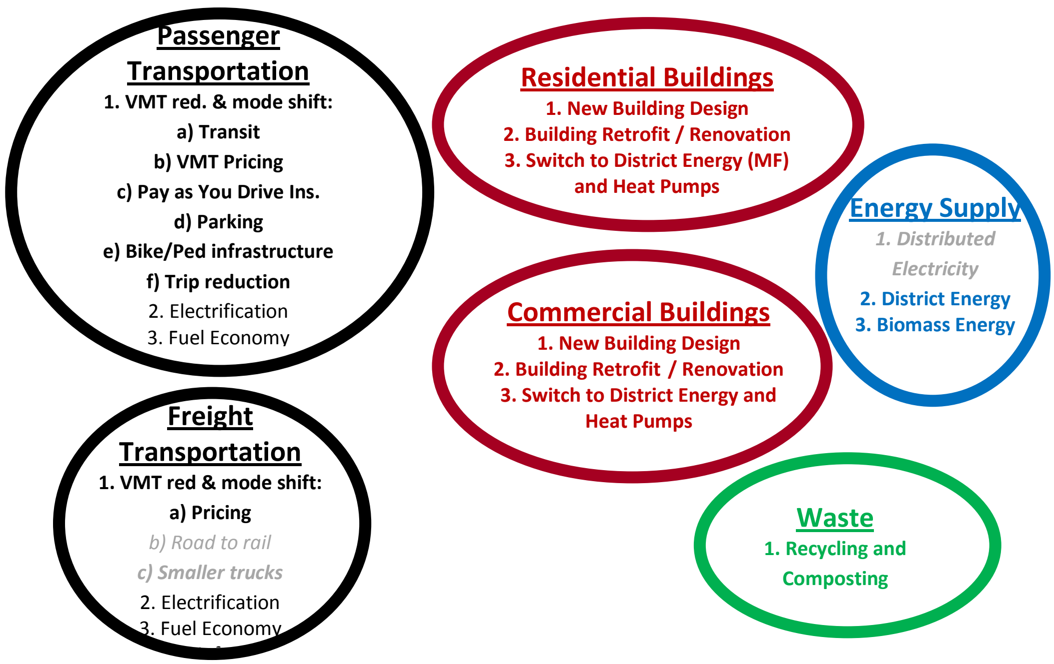
There are many conceivable pathways to a carbon neutral Seattle. One such path might be dominated by renewably-powered smart grids and electric vehicles; another path might rely more heavily on hydrogen fuel cells or next-generation biofuels that pose less competition for agricultural lands. New district energy systems, powered by biomass, could heat and cool the city's homes and businesses, or ultra-high-efficiency electric heat pumps could do the same. Similarly, there are myriad ways the City, businesses, and citizens could design buildings and streetscapes to reduce energy use and to encourage trips taken by foot, bike, or transit rather than car. There is no single recipe or specific pathway to deep emission reductions. Thus, as some have suggested, the challenge of reducing carbon emissions will be tackled not with a silver bullet, but with silver buckshot. To illustrate what is possible, rather than necessarily what is most likely or ultimately desirable, in this section, we articulate one possible pathway to a carbon neutral scenario.

3.1 Identifying Emission Reduction Strategies

The Carbon Neutral scenario presented in this report is based on aggressively implementing a suite of ambitious strategies in the transportation, built environment, energy supply and waste sectors out to the year 2050. For the most part, these strategies, as displayed in Figure 4, represent broad technical options, such as increased vehicle efficiency and electrification, new building design, and district energy rather than the specific policies that might be needed to achieve them, such as carbon pricing, building codes, or financial incentives. The exception is for the strategies to reduce passenger vehicle travel, where we consider policies such as pricing and transit, bike, and pedestrian infrastructure investment.

Many of these strategies build on the foundation of the actions already underway in Seattle. For example, the residential building retrofit strategy can be viewed as an extension of the ambitious effort recently begun through the City's $20 million Energy Efficiency and Conservation Block Grant to retrofit 2000 single family homes in central and south Seattle by 2014.

Figure 4. Strategies Considered in the Seattle Carbon Neutral Scenario.
(Strategies in **bold** are those with greater local control and influence.
Strategies in *grey italics* are not quantified.)



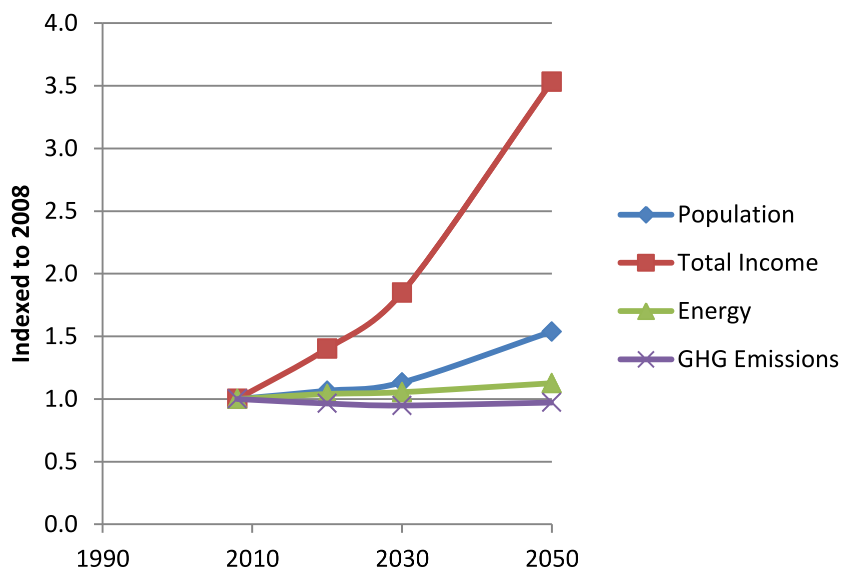
The SEI team identified the suite of strategies shown in Figure 4 by reviewing sectoral trends, other regions climate plans, and collecting input from City staff and the Technical Review Committee. Ultimately, four criteria guided the selection and ambition –achievable penetration rates, technology characteristics, and where relevant, policy parameters – of the strategies:

- ***Significance of emission reductions.*** We sought strategies capable of reducing (or enabling other strategies to reduce) by 1% or more of current core emissions.
- ***Technological maturity.*** For the most part, we relied upon currently-available, market-ready technologies and policy levers. For the transportation sector, where technological challenge in delivering low-carbon solutions is perhaps greatest, we depend on continued technological progress to bring next generation biofuels and enable large-scale penetration of electric (or hydrogen) vehicle systems beyond 2030.
- ***Consistency with carbon neutral imperative.*** While some natural gas technologies, such as combined district heat and power facilities or compressed natural gas vehicles, could significantly reduce emissions relative to current practices, we avoided "locking-in" any major new investments in long-lived fossil fuel based infrastructure.
- ***Cost-effectiveness.*** We focused on technologies and practices that tend to offer net cost savings or lower costs of emissions abatement, especially in the near term. For these reasons, solar technologies, for example, do not play a prominent role in the scenario.

3.2 Projecting Seattle's future emissions under business-as-usual

We assess the emissions implications of these strategies using the LEAP modeling framework.[12] We first use this framework to construct a Baseline scenario out to 2050. Taking a business-as-usual perspective, the Baseline scenario assumes no further action of local policies beyond specific expected developments and existing federal and state policies. We draw population, income, housing, and travel projections from recent Puget Sound Regional Council (PSRC) studies. As shown in Figure 5, population and personal income are expected to continue to rise substantially in Seattle through 2050. Seattle's population grows slightly over 50% from under 570,000 in 2008 to over 900,000 by 2050, while the region becomes significantly wealthier, total income increasing to 3.5 times current levels, resulting in a doubling of average income per capita (in inflation-adjusted, "real" terms). We also capture the US Energy Information Agency's expected changes in fuel and electricity use in response to changes in energy prices, and federal policies in place such as appliance and vehicle standards, and renewable fuel standards.

Figure 5. Historical and projected growth in population, personal income, energy use, and GHG emissions in the baseline scenario, 1990-2050 (indexed to 2008 value)



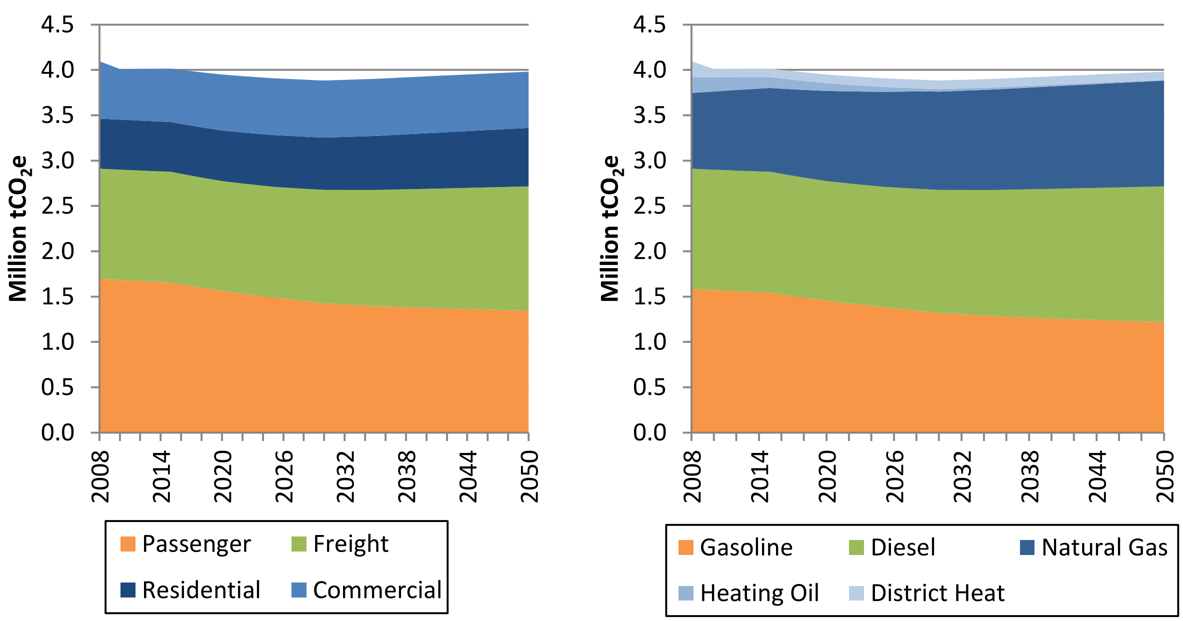
[12] The use of LEAP (the Long-range Energy Alternatives Planning system) facilitates an internally consistent assessment of overlapping strategies (e.g. reducing vehicle travel, increasing vehicle efficiency, and switching vehicle fuels). For further information on LEAP, see http://www.energycommunity.org/.

Despite continued population and income growth, we project that under the baseline scenario, Seattle's total GHG emissions will actually decline slightly for the next two decades, to about 95% of 2008 levels by 2030, before rising slightly out to 2050 (almost back to 2008 levels), as illustrated in Figure 5. This rather surprising projection of relatively flat emissions in fact mirrors the most recent US national projections; the U.S. Energy Information Administration forecasts that US emissions as a whole will not return to 2005 levels until 2027 (U.S. EIA 2010). The lack of expected emissions growth is a reflection of anticipated improvements in vehicle and building efficiency as well as *saturation* in per capita travel and many building energy end uses. (In other words, while ownership and use of vehicles and major energy-using appliance have risen for decades, the room for per capita growth is now limited. In general, there is less scope to spend more hours behind the wheel of a car, or to increase the number of refrigerators or washing machines per household.) The Baseline scenario also includes some recent actions, such as implementing the Light Link rail system and switching from natural gas to biomass for district heating, both of which contribute to flat or declining emissions in Seattle.

We also find under the Baseline scenario that:

- Gasoline use for passenger transportation declines as share of Seattle emissions, but nonetheless remains the major source of GHG emissions throughout almost the entire scenario period, as shown in Figure 6.
- Natural gas use in buildings and diesel use for freight transport are the two major sources of emissions growth over the coming decades, suggesting the importance of targeting these areas for climate action planning.
- In 2050, over 75% of households will reside in housing units that are currently standing today, underscoring the importance of strategies aimed at renovation and retrofit of existing buildings.

Figure 6. GHG Emissions in the Baseline scenario, 2008-2050, by Sector (left) and by Fuel (right)



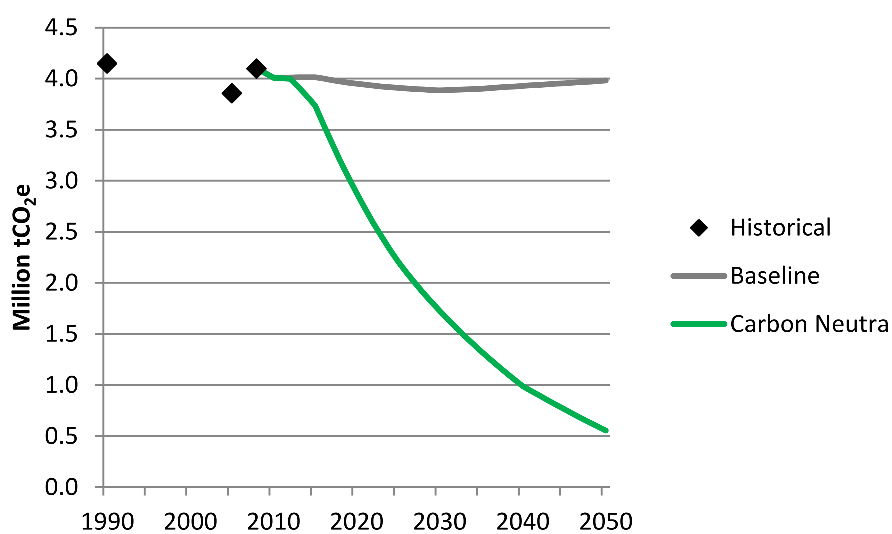
Box 2. What about the efforts the City and other local actors are already undertaking?

As part of the City's Climate Protection Initiative and other regional investments, many activities are planned or underway that will deliver important GHG emission reductions. In some cases, such as the Sound Transit Light Link Rail system and Seattle Steam's partial conversion from natural gas to biomass, activities have already yielded significant emissions savings between 2008 (the analysis base year) and today; these actions are built into the baseline scenario. In contrast, Seattle City Light and PSE conservation programs, retrofit activities under the energy efficiency block grant program, transit and green fleet investments, Seattle Public Utility efforts in waste management, and many others, should also yield emission reductions in coming years. These and other actions serve as a foundation for broader strategies included in the Carbon Neutral scenario and are thus not specifically included in the Baseline scenario.

3.3 Projecting Emissions under the Carbon Neutral Scenario

The strategies of the Carbon Neutral scenario combine to take Seattle's core GHG emissions on a dramatically different course than what is projected in the "business as usual" scenario. As Figure 7 demonstrates, the combined strategies of the Carbon Neutral scenario yield a nearly 90% drop in GHG emissions by 2050, as compared with 2008 levels.

Figure 7. Seattle Core GHG Emissions[13]



[13] For comparability, we adapted historical emissions from the 1990 and 2005 values calculated in the 2008 Seattle inventory, reflecting the "core" scope used in this analysis. Both historical years were scaled to adjust for the use of origin-destination pairs (discussed elsewhere in this report), and emissions associated with electricity were removed in 2005 once offsetting began. However, in 1990, electricity emissions associated with the residential, commercial, and industry sectors are included. (While industry is not included in the "core" emissions in this framework, we included all electricity regardless of sector.)

Three broad elements each contribute significantly to the rapid pace of emission reductions in the Carbon Neutral scenario:

- **Dramatic increases in energy efficiency** in building design and operations, and vehicle efficiency result in over 30% energy savings by 2030 and over 50% by 2050, relative to the Baseline scenario.
- **Shifts to less GHG-intensive travel modes** such as ride sharing, transit, walking and biking lead to almost 30% less travel by light duty vehicles in 2030 and almost 40% less by 2050, relative to the baseline.
- Homes, businesses, and vehicles **transition to lower carbon energy sources.** Much of the vehicle fleet switches to electricity (or hydrogen) over the coming four decades, with biofuels playing a key role in the interim. Homes and businesses rely increasingly on high efficiency heat pumps for heat and hot water, and where available, on district energy systems powered by biomass[14] and waste heat recovery systems. Petroleum product use, which accounts for approximately half of energy use today, is virtually eliminated – for both vehicle and in-building uses – by 2050. While electrification of homes and vehicles increases the share of energy that electricity provides – rising from about 30% today to over 50% by 2050 -- due to efficiency gains, total electricity use remains below Baseline scenario levels.

The assumptions underlying the scenario and its strategies are documented in detail in the Technical Appendix, and discussed by sector in Sections 4 through 6. Some key elements are worth noting:

- The Carbon Neutral scenario is based on the same projections of population and economic activity as the Baseline scenario shown in Figure 5. Deep emissions reductions are achieved, while Seattle's population grows by over 50% and per capita incomes double between now and 2050. In other words, the Climate Neutral scenario is assumed to be consistent with a growing, prosperous Seattle.
- We assume that Seattle City Light can continue to provide net zero GHG electricity through 2050, consistent with internal assessments and policies to date, and its stated plans for new resource acquisition. We assume that this is the case only if electricity demand is kept within levels projected in our baseline scenario, which is consistent with SCL's own planning documents. In fact, we find that overall electricity demand is significantly lower in the Carbon Neutral scenario than in the Baseline scenario.[15] Deep improvements in the efficiency of the

[14] Many concerns have been articulated about the potential impacts of biomass energy use with respect to the timing of carbon emissions, biodiversity, sustainability, among other issues. While we treat biomass energy here as a net zero carbon resource (over a multi-decadal time frame), it will be important to establish clear guidelines for sourcing biomass to ensure that overall impacts are positive, and that claimed net carbon benefits are achieved.

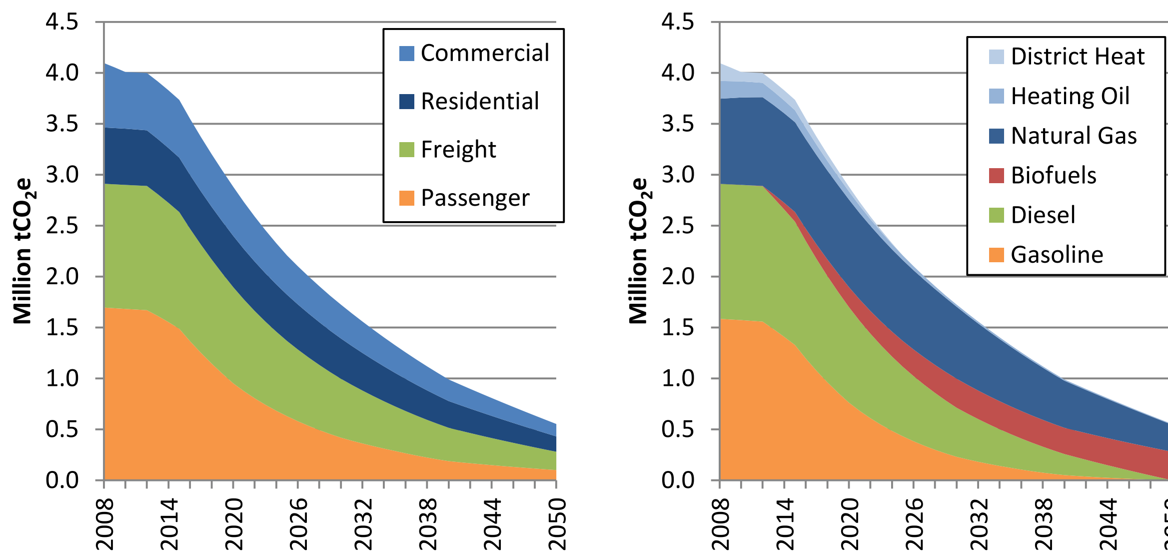
[15] Under the Baseline scenario, electricity use in the City of Seattle (including industrial) increases from 920 aMW in 2008, to 1090 aMW in 2030 and 1250 aMW in 2050. (This pace of growth is similar to that projected in SCL's 2010 load forecast (http://www.seattle.gov/light/news/issues/irp/docs/dbg_538_app_e_4.pdf). In the Climate Neutral scenarios, electricity use increases slightly to 930 aMW in 2030, before dropping to 840 aMW in 2050.

Seattle building stock free up more than enough electricity to power an electrified vehicle fleet and the increased use of heat pumps in buildings.

- We assume that the City is capable of sourcing sufficient biomass with net zero carbon impact to support an expansion of biomass-fired district heat.[16] Since this may prove difficult to ensure, we conducted a sensitivity analysis, replacing biomass-based district energy with heat recovery based heat pumps systems (e.g. using underground geothermal heat, or waste heat from sewage and other sources). This analysis suggests that if district energy systems relied on heat pumps rather than biomass, overall electricity use in the City would increase by only 3.7% by 2050, and remain well below Baseline scenario levels.

Figure 8 shows how emissions evolve by sector and fuel, respectively, in the Carbon Neutral scenario. As illustrated on the left, emissions decline rapidly in all sectors, most steeply in the passenger transportation sector, as a combination of significant efforts on three fronts: reducing single occupancy vehicle use, improving vehicle efficiency, and beginning the transition to low-carbon fuels. Because there are fewer levers to affect freight than passenger vehicle travel, and because of the slower turn-over of freight vehicles, freight emissions decline more slowly. Commercial sector emissions decline somewhat more rapidly than residential emissions because of the greater ability to tap into lower-emissions district energy systems (or switch to independent heat pumps). As shown on the right hand chart in Figure 8, the combined result of these strategies is that virtually all gasoline and diesel use is eliminated by 2050. Natural gas (buildings) and biofuels (especially in freight) are the major remaining emissions sources in 2050.

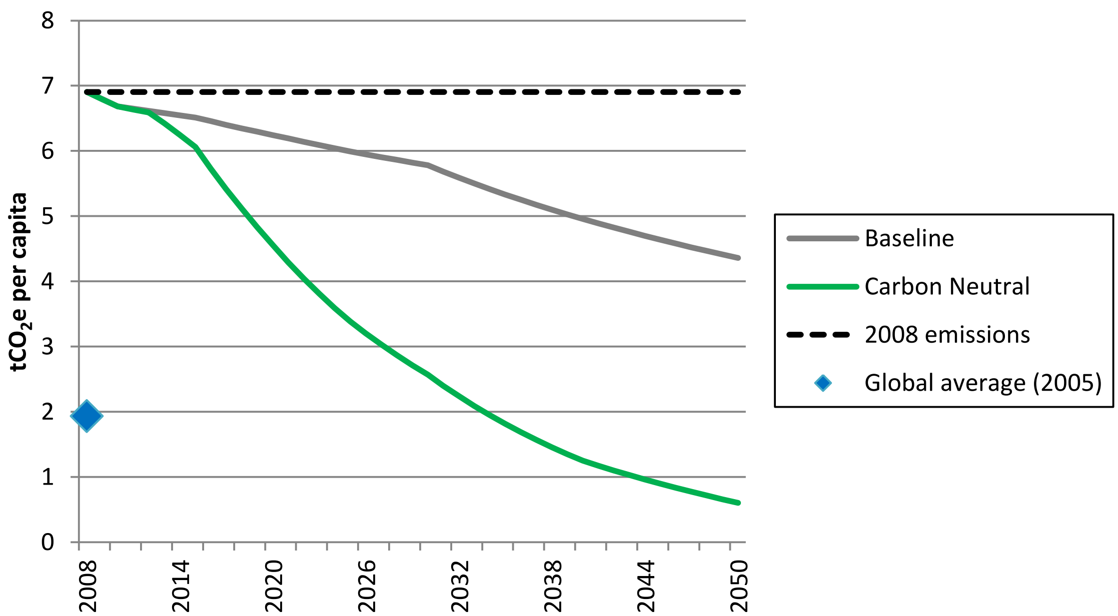
Figure 8. GHG Emissions in the Carbon Neutral Scenario, by Sector (left) and by Fuel (right)



[16] See footnote 14 regarding biomass issues.

Because denser communities are more conducive to lower GHG emissions – by reducing the need for vehicle travel as well as having smaller homes to heat and cool – it could be beneficial from a GHG perspective for Seattle to accommodate more of the region's growth. However, to the extent that Seattle takes on new residents or businesses that might have gone elsewhere in the region, the region's emissions may go down, but the City's may increase. For this reason, it may be appropriate for the City to measure progress in terms of reducing emissions on a per capita (or per unit of commercial activity) basis. Figure 9 illustrates how per capita emissions change both in the Baseline and Carbon Neutral scenarios.

Figure 9. Comparison of Core GHG Emissions per Capita



Seattle GHG emissions in 2008 amounted to 6.9 tCO_2e per capita; this compares with a US average of over 13 tCO_2e and global average of just under 2 tCO_2e, for emissions in the "core" scope. [17] In the Carbon Neutral scenario, emissions drop by 91% to 0.6 tCO_2e per person by 2050. (See Table 1 below.)

[17] For comparability with the sectors comprising our "core" emissions, we calculate U.S. and global averages for only buildings and transport road sectors (including electricity) using McKinsey & Company's (2010) version 2.1 cost curve, as accessed in the online *Climate Desk* application, for the year 2005.

Table 1. Summary of GHG Emissions Results from Baseline and Carbon Neutral Scenarios

	2008	2020	2030	2050
Total GHG Emissions (Core)				
Baseline Scenario (Million tCO2e)	4.1	3.9	3.9	4.0
% change from 2008 levels	--	*-4%*	*-5%*	*-3%*
Carbon Neutral Scenario (Million tCO2e)	4.1	2.9	1.7	0.6
% change from 2008 levels	--	*-30%*	*-58%*	*-87%*
Per Capita GHG Emissions (Core)				
Baseline Scenario (tCO2e/capita)	6.9	6.2	5.8	4.4
% change from 2008 levels	--	*-10%*	*-16%*	*-37%*
Carbon Neutral Scenario (tCO2e/capita)	6.9	4.6	2.6	0.6
% change from 2008 levels	--	*-34%*	*-63%*	*-91%*

Box 3. Limitations of this analysis

The following limitations should be kept in mind when reviewing this study:

- The strategies considered here are far from exhaustive. While we look at a few broad strategies that offer significant emission savings, numerous other strategies are possible.
- We did not conduct an economic analysis of the impact of individual or combined strategies. To the extent some strategies, especially those that reduce energy bills and fuel purchase, reduce consumer costs, re-spending of these energy savings could yield added economic benefits to local businesses, and slightly increase energy use and emissions as a result (rebound effect). Other strategies might increase costs for consumers and businesses, and create corresponding economic losses, and possible knock-on decreases in emissions (reverse of the rebound effect). At the same time, investments in new low-carbon technologies, practices, and businesses could prove to be a key engine of future regional economic growth and employment. Further strategy-specific assessment can help shed light of potential direction and magnitude of these effects.
- We did not consider embedded energy and life-cycle emissions in the Core emissions analysis. We do provide a rough estimate of total emissions associated with goods and services consumed in Seattle in Section 7. However, the life-cycle emissions of all of the materials and services implications of the carbon neutral scenario, while important to reflect upon, are too uncertain and complex to estimate.
- This analysis did not consider the funding or political challenges of, or level the community support for, the strategies.
- Deep uncertainties, and the possibility for surprises and discontinuities, are fundamental to long-term scenarios. For the sake of assessing the impact of discrete strategies, and the challenges of doing otherwise, our analysis presumes continuity in consumption and demographic patterns.

3.4 Getting to Net Zero

Since the carbon neutral goal is net zero greenhouse gas emission by 2050, and the Carbon Neutral scenario gets us only 90% of the way there, how can we address the remaining 10%? In our analysis, we find that about 0.5 million tCO_2e in emissions remain in 2050, a rough estimate that conveys how difficult or impractical it may be to replace all natural gas use in the city's buildings and switch the entire vehicle fleet to emissions-free technologies (electric or hydrogen-powered). There could well be other emission sources that prove hard to eliminate.

One option to achieve net zero emissions, or move closer to it, would be *broaden and deepen the suite of reduction strategies* by increasing ambition, adding a basket of smaller strategies, or waiting for breakthrough technologies which cannot be fully anticipated today. A second option would be to *support and take credit for emissions reductions (or sequestration) occurring outside of the city's Core emissions and use those to "net out" the remaining emissions.* One such source could be counting benefits of recycling or avoided sprawl. Increased sequestration, though urban forestry or watersheds (e.g. Skagit, Cedar River), is another option. Alternatively, the City could generate "excess" low-carbon electricity ("green electrons"), by selling extra hydro or renewable electricity not needed here in the City to others. Such an approach provides a way to count the environmental benefit of generating additional green electricity, say from rooftop solar PV systems. Another more common option for would be simply to purchase GHG offsets, which are widely available in various domestic and international markets. Finally, green procurement strategies could be credited for the emissions benefits they might yield, in most cases, outside the core Seattle boundary.

Table 2 explores the pros and cons of these options for addressing the City's remaining emissions.

Table 2. Pros and Cons of Options for Getting to Zero

Option	How Measured?	Advantages	Disadvantages
Count Benefits Recycling or Avoided Sprawl	Life cycle tools (recycling); Models (sprawl)	GHG benefits of these measures may not otherwise be counted	May double count reductions occurring elsewhere; high quantification uncertainty
Biological Carbon Sequestration (e.g. in trees)	Remote sensing, on ground measurement	Relatively straightforward and widely-accepted	Potential for reversals and emissions leakage; quantification uncertainty
Exported green electricity	Grid (marginal) emission factor	GHG benefit of new renewables and efficiency may not otherwise be counted	May not represent additional effort, especially if based on existing hydro
Offsets	Various offset protocols	Offset units widely available Offset projects may have co-benefits	Offsets can be subject to significant quality concerns (additionality, leakage, verification, etc.); can be costly ($5-20/$tCO_2e$ today)
Consumption/ procurement strategies	Modeling of consumption emissions	Includes benefit of consumption strategies	May double-count reductions; quantification uncertainty

4 Sector Deep Dive: Transportation

The movement of goods and people accounts for over half of Seattle's GHG emissions. Transportation has also been the sector with the greatest absolute emissions growth nationally in the past two decades.[18] However, because of expected improvements in vehicle fuel economy, due to recently enacted federal standards, forecast increases in fuel prices, and the expectation that per capita vehicle travel will no longer be growing[19], passenger vehicle ("light-duty vehicle", or LDV) emissions may actually be stabilizing here in the region and across the US as well.

While these trends are encouraging, achieving deep reductions in transportation emissions remains a major technological, behavioral, and political challenge. Moving to zero carbon vehicles will require widespread deployment of new fueling infrastructures, whether for electricity or hydrogen, and safe and convenient on-board fuel storage options. The multi-decade timescale required for mass uptake of zero emission vehicles means that other complementary strategies will be essential. Over the next two decades, sustainable biofuels could play an important role in providing lower-carbon fuels for internal combustion engines. And moving people and goods to desired destinations with fewer vehicle miles travelled will mean changing travel habits, investing in healthy and convenient alternatives, such as pedestrian, transit, and bicycle networks.

Furthermore, managing freight emissions could, over time, become the increasing focus of energy and climate action planning. Even though the Obama administration recently announced in April 2011 new proposed federal emissions and fuel economy standards for freight vehicles, the scope for efficiency improvement is generally smaller for freight than passenger vehicles. As a result, freight vehicle emissions could easily grow to exceed passenger vehicle emissions by 2050.

Note: In this and following sections, we use codes to reference individual strategies as shown in Figure 4*. For example, Strategy PT2 refers to Passenger Vehicle Electrification. Readers wishing additional context, explanation, and technical specifications can then use these codes to look up more detailed information in the Technical Appendix to this report.*

4.1 Increasing transportation options and reducing vehicle miles travelled

For the Carbon Neutral scenario, we considered several closely linked strategies to reduce reliance on single occupancy vehicles. Aimed at reducing vehicle miles travelled (VMT) by light duty vehicles (LDV), these strategies fall into two groups:[20]

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[18] According to the US EPA's national GHG inventory, emissions in the transportation sector grew by 343 million tonnes CO_2e between 1990 and 2008, greater than the growth in the residential, commercial, or agriculture sectors. Emissions in industry declined between 1990 and 2008. On a relative basis, the growth in residential (27%) and commercial (32%) emissions outpaced transportation (22%).

[19] PSRC projects VMT to grow at approximately the same pace as population for the next two decades.

[20] As noted in Section 3, for VMT reduction options, these strategies consist of policy rather than broad technical options. There are two principal reasons for this. First, when addressing mobility and VMT, strategies are inherently more of a policy nature (i.e. pricing, urban development, and behavioral changes), rather than a

- **Investment in transit, bike, and pedestrian infrastructure** in order to provide fast, convenient, and enjoyable alternatives to car travel. These strategies include:
  - Transit. The Carbon Neutral scenario targets expansion in transit infrastructure and service sufficient to increase the fraction of passenger miles travelled by transit from 8% today to 25% by 2050 (a level already achieved in other cities, such as San Francisco).[21] Achieving this goal will require investments in broader geographic coverage, increasing frequency and reliability, reducing travel times to make transit fast, reliable, comfortable, and affordable, and thus dramatically increase ridership. *[Strategy PT1a]*
  - Pedestrian and bicycle infrastructure. In the Carbon Neutral scenario, "Complete streets", which provide equal access to motorized vehicles, bicyclists, and pedestrians of all ages, are built in all new developments. Building on Seattle's Pedestrian and Bicycle Master Plans, the Carbon Neutral scenario assumes, among other investments, major increases in dedicated bike lanes, boulevards, and trails, wider sidewalks, narrower pedestrian crossings, convenient transit stops, and traffic signals that allow for safe and efficient movement by all modes of travel. *[Strategy PT1e]*

- **Incentive-based, programmatic, regulatory, and pricing mechanisms that can provide direct incentives for travelers** to reduce single occupancy vehicle travel, while generating new revenue for transportation projects and programs. These strategies include:
  - Roadway pricing, which can take a number of forms. These include charging tolls for vehicles to use particular facilities; cordon pricing – a charge to pass into (and sometimes out of) a central city; and per mile VMT charges. Any of these pricing approaches can also include a congestion charging element – that is, a higher fee to use facilities during peak travel hours.[22] For this analysis, we consider a combination of VMT and congestion charges. *[Strategy PT1b]*
  - Pay as You Drive (PAYD) insurance. Traditional insurance policies are priced at a fixed rate per year. Even though higher levels of driving clearly increase a driver's risk for an

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technical one (e.g.. the penetration of specific technologies such as battery electric vehicles, ground source heat pumps, low-e windows, or distributed solar PV, which we explore in other sets of strategies). Second, the City of Seattle Office of Sustainability and Environment recognizes that VMT and mobility policies are ones where a municipality has significant influence and leverage; therefore, at their suggestion, we analyze a more policy-oriented suite of strategies here.

[21] According to the U.S. Census American Community Survey for 2009, current transit mode shares currently exceed 25% in a number of cities: San Francisco (32%), Boston (35%), Chicago (27%), New York (54%), and Washington DC (37%), as reported at http://chartingtransport.wordpress.com/2010/01/16/urban-density-and-public-transport-mode-share/.

[22] An alternative or complementary measure would be to price carbon directly, through a cap and trade program, a carbon tax, or a fee assessed proportional to a vehicle's estimated carbon emissions. Unlike a VMT fee, a carbon price would also directly incentivize shifting to higher fuel efficiency vehicles and lower carbon fuels to offset higher travel prices. For a given fee level, carbon pricing would have less impact on VMT. We include a VMT pricing strategy in this scenario because it complements the strong efficiency and fuel switching strategies outlined below, and because it is perhaps more within the sphere of influence of local actors. As noted elsewhere, while we do not model a carbon pricing strategy here, it is an essential element of national and regional climate policy.

accident, these policies offer no incentive to drive less. By converting policies to a pay per mile basis, PAYD offers an incentive to drive less. *[Strategy PT1c]*

- Parking pricing. Increasing the price of parking can provide a strong incentive to us alternative transportation modes, reduce single-occupancy vehicle use, and encourage more efficient use of land. For the Carbon Neutral scenario, we consider an increase in on- and off-street prices both downtown and in urban villages, and eventual implementation of a policy of no net growth in parking spaces. *[Strategy PT1d]*
- Trip reduction programs. Such programs have generally focused on commute trips, with such as rideshare assistance, transit pass sales and transit subsidies, employee shuttles, alternative work schedules and telecommuting programs, and marketing and personalized assistance for use of alternative modes. Such programs can be expanded to reach all employers and to target the growing share of trips for purposes other than commuting. *[Strategy PT1f]*

As a result of these combined strategies, per capita LDV VMT could decline on the order of 11% by 2020, and 34% by 2050 from 2008 levels as shown in Table 3. While VMT reductions are driven strongly by pricing strategies, transit, walk, and bike infrastructure investments are fundamental to maintaining or enhancing mobility, by providing affordable and convenient alternatives. Freight VMT decreases in response to pricing to a lesser degree. (Our results for the pricing strategies were verified through the separate application of a transportation model.[23])

Note that while direct carbon pricing could be the most efficient pricing approach from a purely GHG reduction perspective, we focus on complementary pricing strategies that are more within the authority of urban jurisdictions to implement, and are often motivated by other objectives. In theory, the same results could be obtained with a sufficiently high carbon price.

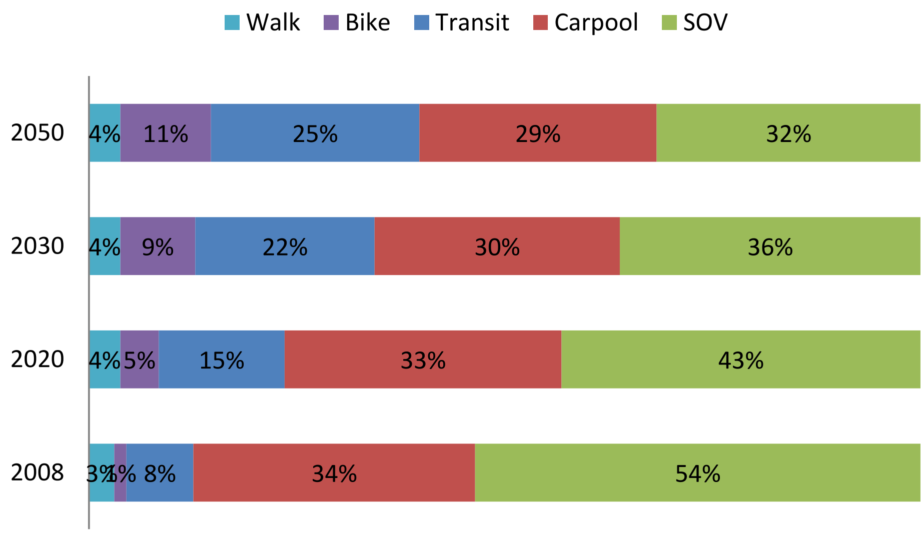
Figure 10 illustrates the major shift in how people move under the Carbon Neutral scenario. Biking, walking, and transit shares nearly double by 2020 and triple by 2050. It is important to note that the shares shown here in this figure are in in terms of passenger-miles traveled (PMT), where a passenger-mile is one mile travelled by one passenger in a given mode.[24] Bike and walk *trip* shares are actually much higher than shown, as shorter average trip lengths for these modes means more trips per passenger-mile. The switch from single occupancy vehicles (SOV) to carpools is important in early years

[23] With the support from King County, ECONorthwest developed and applied their Carbon Sketch Planning Tool to examine the impact of carbon neutral pricing and transit strategies, adapting PSRC data from the T2040 study. Like regional travel demand models, this tool captures land use and travel interactions. When modeling the same pricing policies, the sketch tool yielded results very similar to those from the simpler, elasticity-based analysis used for the Carbon Neutral scenario analysis. Both approaches found 29% reduction in LDV CO2 emissions in 2050. While in the Carbon Neutral scenario analysis, these reductions corresponded directly to a projected 29% reduction in LDV VMT, in the sketch tool, LDV VMT declined by 24%, with the remaining CO2 emission savings due to increased vehicle speeds and efficiency from less congested roadways.

[24] For example, a bike rider riding one mile would be one passenger-mile travelled in the “bike” mode. A car trip of one mile with four passengers would yield four passenger-miles travelled.

(e.g., through 2020) as transit, bike, and pedestrian infrastructure are under development, in order to begin achieving reductions early while maintaining mobility.

Figure 10. Mode Share of Passenger-Miles Travelled



4.2 Developing denser, transit-oriented neighborhoods

Denser urban development can facilitate achievement of travel reduction strategies and the carbon neutral goal. An extensive body of literature finds that people living in compact developments drive less – and walk, bike, and take transit more – than their counterparts living in low density "sprawl" developments.[25] A number of recent efforts have described some of the possible benefits of transit- and pedestrian-oriented developments for Seattle and the region,[26] including reduced greenhouse gas emissions per capita, freeing land for conservation areas and farming, lower overall household costs with less dependency on cars, improved public health through a more active daily routine, and enhanced local business districts and cultural centers (Seattle Planning Commission 2010).

Since our scenario relies in part on population forecasts and associated transportation modeling by the Puget Sound Regional Council for their Transportation 2040 (T2040) effort, the GHG benefits of (already expected) increases in Seattle's density are included by default in our Carbon Neutral Seattle scenario. For example, in the Baseline scenario (from which our Carbon Neutral Scenario departs) and where population increases 54%, per-capita vehicle travel declines more than 20% between 2008 and 2050, and much of this reduction can be attributed to denser communities. We do not model the possible effects of additional densification – either by directing a greater share of the region's population growth to Seattle or redistributing population within Seattle – beyond that already forecast in PSRC's T2040

[25] For example, for a recent meta-analysis of the relationships between the built environment and VMT, see Ewing and Cervero (2010)

[26] For example, see Futurewise et al (2009), Seattle Planning Commission (2010), and the "Metropolitan Cities" alternative of PSRC's Vision 2040 effort (http://www.psrc.org/growth/vision2040/background/vision2040-deis/)..

plan. Further increases in density could facilitate deeper per-capita GHG reductions, especially if additional population growth is matched with increasing employment opportunities.[27]

4.3 Transitioning to clean and efficient vehicle technologies

In addition to shifting travel patterns, increasing vehicle efficiencies and shifting to cleaner fuels further decreases GHG emissions in transportation. For the Carbon Neutral scenario, we considered and quantified the impact of several strategies:

- **Decreasing the energy intensity, or increasing the efficiency, of vehicles** to reduce overall fuel consumption.
    - We assume that a combination of purchasing strategies by Seattle residents, consumers, and government together with aggressive action at the state and federal levels, supported by Seattle, achieve significant fuel economy improvements in the Seattle fleet. The fleet average for liquid-fueled light-duty vehicles reaches 53 mpg by 2050, while buses and freight improve more modestly. In addition, a widespread conversion to electric vehicles (which use significantly less energy per mile), described below, further contributes to a reduction in vehicle energy intensity. *[Strategies PT3, FT3]*
- **Expanding the commitment to cleaner fuels**, through local infrastructure investments (e.g. charging stations), purchasing strategies (e.g. for biofuels), and lobbying for federal action to create markets and innovation.
    - Widespread adoption of electric vehicles (EV) and build-out of electric vehicle infrastructure represents a key option for achieving a zero-carbon transportation system. Seattle is particularly well poised to lead an electric vehicle transition given SCL's commitment to maintain a carbon neutral electricity supply. Based on review of available studies, we assume that share of electric (or hydrogen fuel cell) light-duty vehicles could reach 80% by 2050. Medium- and heavy-duty trucks reach two-thirds and one-third of that penetration, respectively, given the greater technical challenges involved, and slower stock turnover. (Note that while we focus in this analysis on electric vehicles, it is important to recognize that other technologies under development that could achieve a similar low carbon transportation outcome, most notably hydrogen fuel cells.) *[Strategies PT2, FT2]*
    - Biofuels provide an important bridging strategy to reduce life-cycle GHG emission while new electric (and/or hydrogen) vehicle technologies and infrastructure are under development. Unlike electricity, ethanol and biodiesel can be used with current internal combustion engine technology. Generally produced from food crops (e.g., corn, soy, oil seeds), they are limited in their ability to reduce greenhouse gases, and can present

[27] On the other hand, if job growth was accommodated elsewhere – say, in suburban King County, increasing the share of regional population growth diverted to Seattle could potentially increase Seattle's VMT if Seattle residents undertook more "reverse" commutes to jobs in suburban cities. Such a phenomenon may help explain why PSRC's "Metropolitan Cities" alternative of its Vision 2040 effort, which directed more population to Seattle than any of the other alternatives but which did not include a corresponding increase in Seattle employment, also resulted in the highest forecast VMT.

food supply concerns.[28] Accordingly, we make use of current (i.e., "first generation") biofuels in the next two decades, before phasing them out to next-generation biofuels, which are derived from non-food sources and are generally considered to be less GHG-intensive than first-generation biofuels.[29] *[Strategies PT4, FT4]*

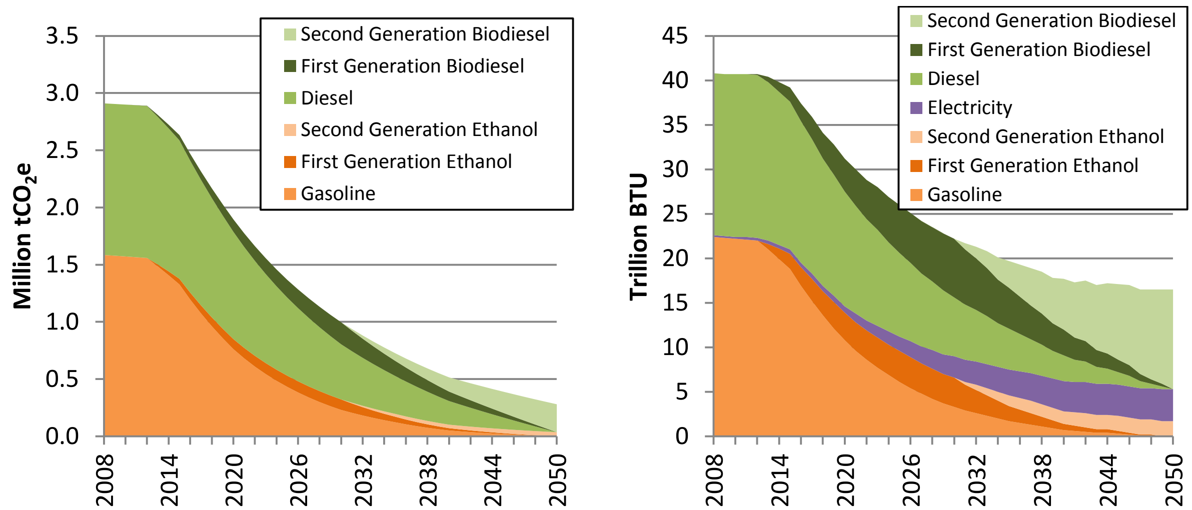
4.4 Overall findings for the transportation sector

The combined effect of strategies in the Carbon Neutral scenario for both the passenger and freight sectors is a 90% reduction in road transportation emissions by 2050. As shown in the left-hand chart in Figure 11, the remaining emissions are associated with the advanced biofuels, which are used in the vehicle stock that could not yet be converted to electricity (or hydrogen). Given that the constraints in converting the freight vehicle fleet are greater than for the passenger fleet, much of the remaining emissions and energy use are associated specifically with biodiesel use, as illustrated in the left-hand chart of Figure 11. It is also interesting to note that despite shifting 80% of light duty vehicles to electricity, and approximately half that fraction of heavy duty freight vehicles, electric energy use for transportation in 2050 is only a small fraction (less than 10%) of energy consumed by current gasoline and diesel vehicles. This outcome is due to the fact that future electric vehicles may be four or more times more energy efficient (in BTU/mile) than current internal combustion engine vehicles (MacKay 2008), in addition to the reductions in vehicle miles travelled, especially in passenger vehicles.

[28] We count emissions from biofuels as a fraction of the standard, tailpipe-based emissions for a comparable petroleum-based fuel. We base our calculation on the ratio of the full life-cycle emissions of the two fuels based on an assessment by the US EPA (2010). For example, the EPA finds that life-cycle emissions of the best first generation ethanol (i.e. sugarcane ethanol or equivalent) are about 40% of life-cycle emissions for gasoline per unit of energy. We apply this ratio to the standard *tailpipe* emissions for gasoline. While this method slightly underestimates the full emissions associated with biofuels in our figures, this method maintains consistency in accounting for petroleum fuels with Seattle's prior GHG inventories. For further information, see this report's Technical Appendix.

[29] Third-generation biofuels (e.g., algae-based fuels), still in early-stage development, may offer the potential to reduce emissions even further and require much less land to produce (IEA 2009).

Figure 11. Transportation GHG Emissions (left) and Energy Use (right) by fuel, Carbon Neutral Scenario, 2008-2050



Indeed, Table 3 shows that among the factors that account for the overall GHG reductions in the transportation sector, improvements in energy efficiency (including improvements in internal combustion and hybrid technologies as well as a significant shift to electric vehicles) and carbon intensity (GHG emissions/unit energy) are most significant.

Table 3. Changes Relative to 2008 in Vehicle Activity, Energy Intensity, and GHG Intensity in the Carbon Neutral Scenario

	2008	2020	2030	2050
Passenger Transport				
LDV VMT/capita	--	-20%	-31%	-53%
LDV Energy per mile	--	-27%	-58%	-80%
LDV GHG Emissions per unit energy	--	-15%	-41%	-88%
Freight Transport				
VMT	--	7%	15%	32%
Energy per mile	--	-16%	-39%	-59%
GHG Emissions per unit energy	--	-13%	-32%	-73%

5 Sector Deep Dive: Built environment

Contributing 30% of total greenhouse gas emissions in Seattle in 2008, buildings represent the other major target for reducing Seattle's core emissions. Aggressive green building designs can reduce energy use per square foot by more than 60% relative to current norms, and can incorporate solar, district energy, or electric technologies that enable them to use low or zero-carbon energy sources. The greatest challenge, however, lies in reducing emissions from existing buildings. The 40-year timeline for reaching a carbon neutral goal for Seattle is less than half the average lifetime of residential buildings, and is also less than the average lifetime of commercial buildings (50-60 years).[30] In fact, given the pace of population growth in Seattle, and limited space for wholly new housing development, over three-fourths of Seattleites in 2050 are likely to be living in buildings already constructed today.

Understanding the critical role of building retrofits in decreasing greenhouse gas emissions, Seattle is already involved in developing extensive retrofit programs and securing funding for such efforts. For example, the City of Seattle has been awarded $20 million through the U.S. Department of Energy Better Buildings grant[31,32] to be used for energy efficiency measures in building retrofits. Both residential (single- and multi-family) and non-residential (municipal, health care, small business, and large commercial) buildings will be addressed, with half of the funds planned for single-family retrofits. In addition, a public-private partnership between property owners and city agencies recently launched the Seattle 2030 District, which is working to create a business district that meets the Architecture 2030 challenge (50% energy savings in existing buildings and carbon neutrality for new buildings, by 2030). Various studies support the feasibility of achieving deep energy savings in existing buildings.[33,34]

As green building design and retrofits can achieve deep reductions in energy use, switching space and water heating from fossil fuels (largely natural gas) to highly efficient electric heat pumps and district energy can help to ensure that remaining energy use is as carbon-free as possible. Electric heat pumps work as air-conditioners-in-reverse by extracting heat from outside air, the ground, ground water, or waste heat sources (such as sewage) to heat and cool a household. District energy systems produce hot water, steam, or chilled water at a central location and distribute this energy to multiple buildings through underground pipes. These systems can offer significant GHG savings by enabling the greater use of renewable energy sources such as biomass, by capturing waste heat from industrial or power facilities, or by increasing system efficiencies through combined heat and power generation.

[30] http://www.eia.doe.gov/oiaf/aeo/assumption/pdf/commercial_tbls.pdf
[31] Funded by the American Recovery and Reinvestment Act of 2009 and awarded by U.S. DOE.
[32] http://www1.eere.energy.gov/wip/eecbg.html
[33] Wigington, Linda. Affordable Comfort Inc. (ACI). "Deep Energy Reductions in Existing Homes: Strategies for Implementation." ACEEE Summer Study 2008. Asilomar, Pacific Grove, CA.
[34] Deep retrofits are achievable and have been demonstrated today, for instance an energy efficiency retrofit of a 1960s federal office building in Denver, which will cut energy use by 70%. Rocky Mountain Institute. 2011. "An Energy Efficiency Poster Child: RMI helping GSA retrofit federal office building in downtown Denver." *Spark: the RMI eNewsletter*. January 25.

While we introduce highly energy efficient building design early in the Carbon Neutral scenario timeline, there is a limit to how quickly and widespread these can be achieved, due technical and financial constraints. Accordingly, as green buildings initiatives are strengthened, and builders ramp up their adoption of these practices over the next ten years, many new buildings are still built at baseline (current) efficiency levels until 2020, which locks in building stock with current standard building technologies. To address this near-term "lost opportunity", we assume that these buildings can switch to district energy or electric heat pump space heating systems, approximately 20 years after construction. Equipping buildings today with hydronic or forced air heating systems, which can more readily accommodate the future application of district energy and heat pumps than other heating systems (e.g., less-efficient electric resistance heat), could help open the door to more efficient or lower-carbon heat sources in the future.

Throughout our assessment of GHG reductions in the buildings sector, we assume, as described in Section 3, that Seattle City Light continues to provide net zero GHG electricity through 2050. Since total electricity use in the Carbon Neutral scenario remains below baseline levels, this assumption is consistent with existing Seattle City Light policy.

Note: As in the Transportation section, we use codes to reference individual strategies. Readers wishing additional context, explanation, and technical specifications can then use these codes to look up more detailed information in the Technical Appendix to this report.

Box 4. Distributed electricity production in Seattle

While distributed electricity production through rooftop PV systems could be a key feature of a Carbon Neutral Seattle, we do not specifically model this strategy, since as noted, the City's electricity will already be net zero carbon. However, the transition to a low-carbon future may require tapping all such resources. Integrating distributed energy production into community design will allow Seattle to meet more of its own energy needs, freeing up more remote renewable plants, like the Stateline wind project on the OR-WA border (which comprises the majority of SCL's non-hydro renewable resource), to serve other loads. Furthermore, distributed energy production is fundamental to zero carbon building design and initiatives such as the Living Building Challenge.[35] Programs in Germany and California are already achieving significant penetration of smaller solar rooftop systems on homes as well as larger ones on commercial and industrial structures. In California, the capacity of net metered solar systems already represents 2% of total peak demand in two of the major utility service districts.[36] Rooftop PV potential can be estimated based on regional solar radiation as well as building characteristics (e.g., rooftop availability, shading, etc.) using remote sensing and GIS technology. Draft results from one study of the City of Seattle estimate the City has a *technical* potential from rooftop PV of 210 aMW[37], a figure that represents nearly a quarter of Seattle's electricity demand in 2008.

5.1 Reducing GHG emissions in Seattle homes

Residential building operations account for about one-fifth of the primary energy used in the U.S. Innovations in building technology over recent decades offer a tremendous opportunity to introduce highly energy-efficient residences to Seattle's built environment, using appropriate design, siting, and technology from the outset.

For the Carbon Neutral scenario, we considered and quantified the impact of several residential building strategies in two broad categories:

- **Lowering building energy use though deep efficiency design and retrofits**
    - We assume a ramp up in the fraction of buildings subject to aggressive (about 50% reduction in energy use) and, ultimately deep (about 75% reduction in energy use) green building design levels; by 2030, all new buildings are built to deep efficiency design levels. *[Strategy RB1]*

[35] http://ilbi.org/lbc

[36] Pacific Gas and Electric and San Diego Gas and Electric have both achieved 2.0% penetration as of December 31, 2030. http://www.cpuc.ca.gov/NR/rdonlyres/D2C385B4-2EC3-4F9D-A2B9-48D06C41C1E3/0/DataAnnexQ42010.pdf

[37] Draft estimate provided by Ryan Liddell (Pennsylvania State University, Black & Veatch). Methodology included: analyzing LiDAR data obtained from the Puget Sound LiDAR Consortium (PSLC) to extract building rooftops and generate a 3D urban model; analyzing solar radiation using the Area Solar Radiation tools in ArcGIS; calibrating raster data against modeled PV outputs in PVWatts (NREL); and accounting for unusable rooftop space. This estimate does not address infrastructure issues (e.g. number and location of substations, smart grid implementation, etc.).

  - Similarly, retrofits to the existing residential building stock yield energy intensity reductions of 40% to 75%. As with new building design, we estimated these reduction levels based on respected studies and real-world examples. By 2050, we assume that programs can reach 90% of all currently existing buildings with aggressive or deep retrofits, leaving only about 10% of buildings untouched. *[Strategy RB2]*
- **Switching from fossil fuel use (largely natural gas for heat and hot water) to electric heat pumps and district energy for heat and hot water needs**
  - For existing single-family and multi-family homes, we assume that those undergoing deep retrofits (per above) also switch to electric heat pumps.[38] Single family homes not undergoing deep retrofits retain their existing natural gas or electric heating and hot water systems. For new multi-family homes, we assume that about half could be located in areas that could be serviced by a district energy system, while the remainder would rely on heat pumps; new single-family design would rely on heat pumps. These assumptions, while reflecting what appears to be achievable, are nonetheless only illustrative; many other low-carbon heat and hot water options and outcomes are possible, including greater reliance on solar hot water. *[Strategy RB3]*

5.2 Reducing GHG emissions in Seattle's commercial buildings

Commercial buildings represent a source of energy consumption and greenhouse gas emissions in Seattle, consuming 30% of energy use and contributing to 15% of total greenhouse gas emissions in 2008. Construction of new commercial buildings is anticipated to accommodate the regular turnover of building stock as well as meet the increasing demand in commercial floor space driven by anticipated growth in employment.

The suite of strategies for commercial buildings in the Carbon Neutral scenario directly parallels the mix of residential building strategies, i.e.:

- **Lowering building energy use though deep efficiency design and retrofits**
  - Similar to residential buildings, studies and experience suggest low-energy design can readily achieve reductions of over 50% in energy use per square foot relative to current levels. As with residential buildings, we assume a ramp up in the fraction of buildings subject to aggressive and deep design levels. *[Strategy CB1]*
  - Retrofits to the existing commercial building stock yield energy intensity reductions of up to 40% to 70%, depending on end use (heating, cooling, lighting, water heating and other). We assume a similar pace of implementation in aggressive or deep retrofits as the residential sector, leaving 10% of buildings untouched in 2050. *[Strategy CB2]*

[38] Note that if deep retrofits reduce heat requirements to a small fraction of current levels, electric resistance heat may be more cost-effective given the small heating loads. If resistance heating were used in lieu of heat pumps, the increase in electricity use would likely be negligible given the small loads involved.

- **Switching from fossil fuel use (largely natural gas for heat and hot water) to electric heat pumps and district energy for heat and hot water needs**
    - We assume that about half of commercial buildings adopt district energy, either when newly built or when retrofit to our "aggressive" or "deep" levels. The other half of new or retrofit commercial buildings adopts heat pump systems. *[Strategy CB3]*

5.3 Overall findings for the buildings sector

Under the Carbon Neutral scenario, overall GHG emissions associated with Seattle's building stock decline to slightly less than 80% below 2008 levels by 2050. As shown in left-hand chart of Figure 12, the phase-out of heating oil use in buildings and the full conversion of district heat to sustainable net low carbon biomass almost entirely eliminate emissions from these fuels. On the other hand, emissions from the direct use of natural gas for space and water heating, and to a much lesser extent for other end-uses such as cooking, are expected to grow over the next decade, as the result of the general preference for natural gas in new residential construction. The lock-in of new natural gas infrastructure as well as the challenges of converting all of the existing natural gas equipment in buildings is one of the major challenges in eliminating direct fossil fuel use in the City. The right hand chart of Figure 12 shows that while electricity grows in its share of total building energy use, with the transition from natural gas to electricity (and district heat), overall electricity use declines as the increased energy efficiency more than offsets the added demands from this shift to electricity.

Figure 12. Residential and Commercial Building GHG Emissions (left) and Energy Use (right) by fuel, Carbon Neutral Scenario, 2008-2050

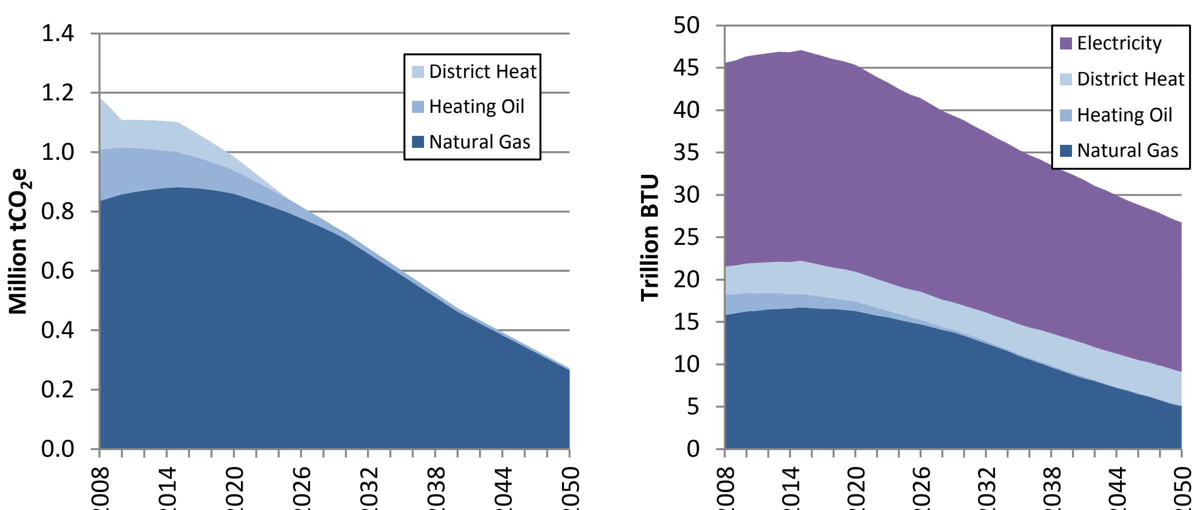


Table 4 indicates that decreasing energy intensity (per capita for residential buildings and per square foot for commercial) and reducing the carbon intensity of that energy both contribute strongly to reducing emissions. The strategies in the Carbon Neutral scenario lead to a slightly greater emphasis on energy savings in homes and on fuel switching in the commercial sector, roughly consistent with what other studies and existing opportunities (e.g., district energy) appear to suggest. That said, the strategies explored in the Carbon Neutral, as noted above, are far from exhaustive, and other pathways and potentially deeper reductions are certainly possible.

Table 4. Changes Relative to 2008 in Building Energy Use and GHG Intensity in the Carbon Neutral Scenario

	2008	2020	2030	2050
Residential Buildings				
Energy/capita	--	-14%	-31%	-65%
GHG per unit of energy	--	-1%	-8%	-50%
GHG emissions	--	-9%	-28%	-73%
Commercial Buildings				
Energy per square foot	--	-16%	-33%	-58%
GHGs per unit of energy	--	-27%	-41%	-69%
GHG emissions	--	-24%	-47%	-81%

6 Sector Deep Dive: Waste

A "waste commitment" measurement methodology counts emissions associated with all waste generated from within the geographic boundaries of Seattle in one year, regardless of when or where those emissions actually occur. Counting emissions from a "waste commitment" perspective aligns better with the policy influence of Seattle over emissions associated with waste, such as via recycling programs and infrastructure contracted by Seattle Public Utilities, than would the alternative method of counting emissions from the (few, retired) waste landfills within the city limits. Seattle's GHG inventory estimates that, from a waste commitment perspective, net emissions associated with waste management are near zero.

As Figure 13 shows, new waste commitment emissions are close to zero because of the magnitude of the different components of managing waste: in short, emissions avoided (though long-term carbon storage) by landfilling are on the same magnitude as emissions released through transporting and landfilling the materials. More specifically, for the year 2030 we estimate that:

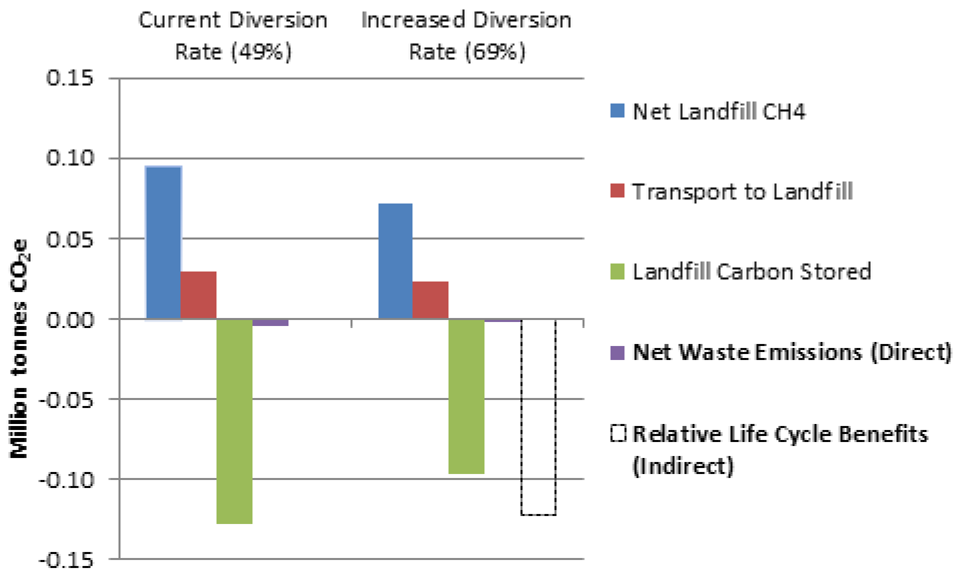
- Net landfill methane totals 0.095 MtCO2e. This assumes continuation of current waste management practices, whereby 49% of waste is diverted from landfilling to recycling or composting. Of the waste that is landfilled, we assume (as in the current Seattle inventory) that 75% of the methane generated by the waste degrading in the landfill is recovered and not emitted.
- Transporting waste to the landfill emits 0.029 MtCO2e, based on the assumption that waste continues to be sent to the Arlington landfill, approximately 250 miles away.
- Long-term landfilling of certain materials stores 0.128 $MtCO_2e$. Some organic materials, such as wood and paper products, decompose relatively little under anaerobic landfill conditions (even after more than 100 years) and therefore lead to carbon storage that would not normally occur under natural conditions.[39]

The amount of carbon storage (0.128 $MtCO_2e$) is roughly equal to the emissions from landfill gas and transportation, and thus, as shown, net direct waste emissions are very close to zero.

For the Carbon Neutral scenario, we assumed that Seattle achieves 69% diversion, consistent with the City's current Zero Waste strategy. Figure 13 illustrates that while increased diversion reduces transportation and landfill GHG emissions, these savings are offset by lost carbon storage of a similar magnitude.

[39] All calculations regarding waste emissions are based on methods developed by the US EPA (2010).

Figure 13. Effect of increasing waste diversion on GHG emissions in 2030 (waste commitment perspective)



Although the net effect of increased diversion on direct GHG emissions is negligible, the indirect emissions benefits from this diversion are significant. Looking only at the emissions or storage associated with material disposal ignores the alternate potential uses of those materials. Landfilled materials may instead be reused, recycled or composted, activities which may bring significant emissions benefits. Recycling and composting offer indirect (or "life cycle") emissions benefits by reducing virgin material extraction and processing requirements, leaving trees in forests to continue sequestering carbon, and increasing soil carbon through application (composting). The dotted bar in Figure 13 approximates the magnitude of these indirect benefits relative to the net waste emissions.

As described above, our calculations assume that Arlington landfill captures 75% of the methane generated. Seattle City Light purchases electricity generated from all captured methane at the landfill to help meet its goal of carbon neutrality. If more of the remaining methane emissions could be captured, methane emissions would decrease and more electricity would be generated. King County reports that its landfill, Cedar Hills, recovers 90% of its landfill gas.[40]

The most significant overall GHG emission benefit in waste management comes from increasing waste diversion (to recycling), and where possible, reducing waste generation in the first place. These emissions savings largely result from reducing the life-cycle emissions required to produce goods, emissions that occur across the globe through processes that Seattle can only indirectly influence. Therefore, we do not account for these emissions savings in the core emissions scope. Nonetheless, much like the emissions from consumption patterns in general, local government, residents, and businesses can have an important, if indirect, impact. The next section turns to the emissions implications of our broader consumption practices.

[40] We are uncertain on the exact methane recovery rate at Arlington, and whether there is scope for increasing it.

7 Alternative Perspectives on Seattle's GHG Emissions

Our Carbon Neutral Scenario focuses on a core set of policy-relevant and readily trackable emissions sources. As displayed in Figure 14, other sources of emissions could also be associated with Seattle beyond this "core" scope. In this section, we consider two complementary perspectives: one is an expanded focus on consumption, and the other is an expanded focus on in-city emissions (like industry) that fall outside the "core" scope.

7.1 GHG Emissions associated with Consumption in Seattle

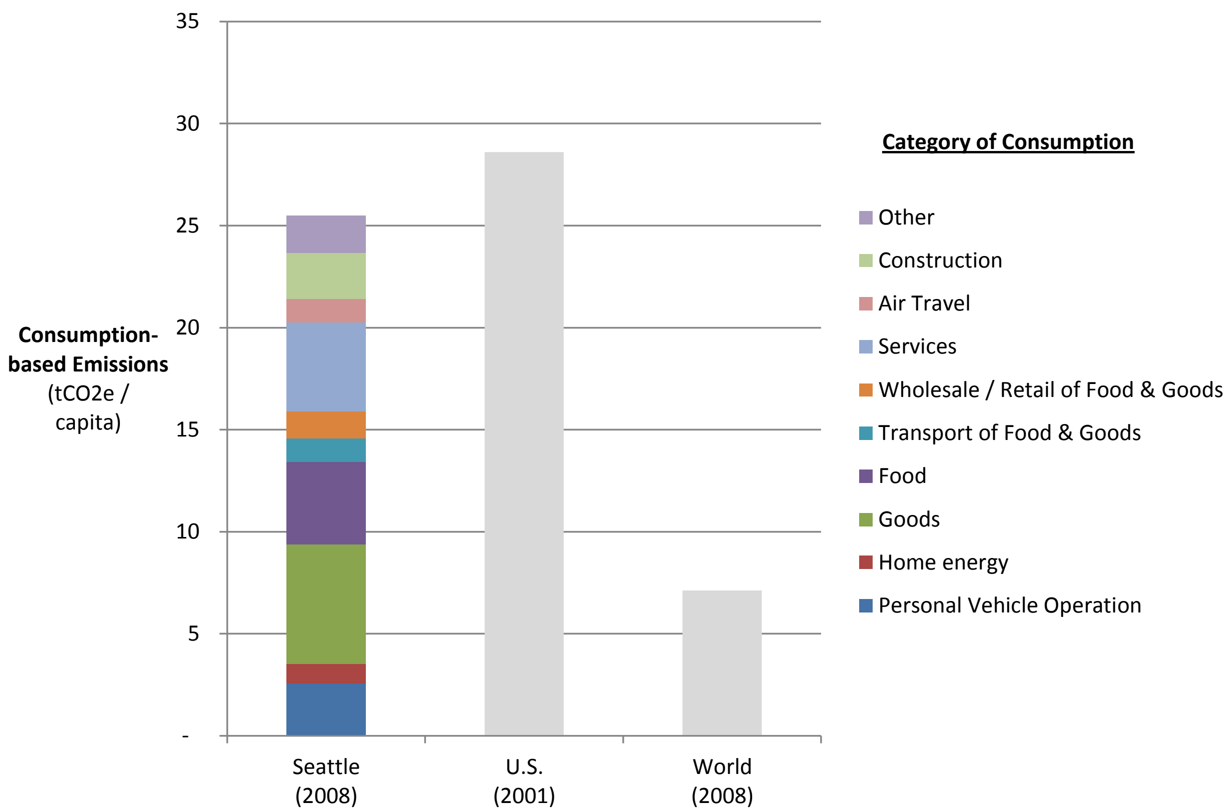
The predominant method of attributing greenhouse gas emissions to a community is to compile estimates of GHGs released within the community, plus those emissions associated with electricity used within the community. The core GHG-reduction scenario described in this report uses such a method, with a particular focus on transportation, buildings, and waste – three sectors where the City of Seattle and its partners have a unique influence through policies such as transportation and land use planning, energy codes, and waste management infrastructure, and where emissions are highly measurable. Other means of attributing emissions to a community also exist, however. In particular, an alternate view estimates emissions associated with all goods and services consumed in the community, even if those emissions were released far away in the course of making the products, such as computers or clothing. Such a "consumption-based" GHG inventory provides an additional, view on a community's contribution to global climate change.

Methods for conducting consumption-based GHG inventories are evolving rapidly, and there is no single standard method. Nevertheless, nearly all consumption-based inventories for communities start with economic data on purchasing behaviors and use "input-output" analysis to approximate what industries ultimately produce the materials, goods, and services consumed. King County has recently been undertaking a path-breaking effort to conduct a consumption-based GHG inventory for all goods and services consumed in the county, including Seattle, in 2008. Although that project and its final results were not available at the time we conducted this analysis for Seattle, we used preliminary results to approximate a consumption-based GHG inventory for Seattle, presented below. To compile this estimate, we scaled King County's consumption-based inventory to Seattle according to the ratio of the two regions' populations, but we substituted Seattle's figures for emissions from use of energy in the home and in personal vehicles.[41] King County's consumption-based inventory, and therefore also our estimate here, defines *consumption* as the sum of consumer expenditures, government purchasing, and business capital investment (or net accumulations to business inventory). Under this definition, which is also termed "final demand" and is based on common practice for national economic accounts, emissions associated with business operation (e.g., energy, intermediate goods, food) are only

[41] To match King County's method, we also should have included emissions associated with operation of government buildings and vehicles in Seattle. Since these figures were not readily available, we did not include them here, but they are not expected to contribute substantially to our estimate of Seattle's consumption-based emissions.

attributed to Seattle to the extent those businesses' services are consumed by Seattle residents or government.[42]

Figure 14. Per capita emissions from a consumption-based perspective



As displayed in Figure 14, we estimate that about 25 tonnes CO_2e are associated with Seattle's consumption on a per capita basis, several times more than the 2008 per capita emissions in the "core" scope that is the focus of the Carbon Neutral Scenario (4.1 million tonnes CO_2e, or about 7 tonnes CO_2e per capita.

The reason for this departure is that the consumption-based inventory includes all the emissions associated with producing the goods, food, and services consumed in Seattle.   As is the case in most urban areas in the U.S., most of these foods and goods are produced outside the city border. As a result, our estimate of a consumption-based emissions inventory is also higher than Seattle's official greenhouse gas inventory (which includes in-city manufacturing) of 6.8 million tonnes CO_2e, or about 11 tonnes CO_2e per capita.

[42] For example, emissions associated with the headquarters of Starbucks or Amazon.com would largely (though not entirely) be attributed to consumption outside Seattle and not included in Seattle's consumption-based inventory.

At 25 tonnes CO_2e per capita, our estimate of Seattle's consumption-based emissions are somewhat less than the national average, but significantly greater than the world average.

Although most of the emissions associated with consumption are well beyond the scope of direct local government influence, community actions may be able to affect the emissions associated with consumption. For example, as indicated in Figure 14 above, emissions associated with producing goods and food together total about 10 tonnes CO_2e per capita, or about 40% of total consumption-based emissions. Opportunities may exist to shift consumption from highly GHG-intensive food and goods to less-intensive alternatives, including (in some cases) to services. Although evaluating specific alternatives is beyond the scope of this analysis, we note that emissions associated with producing goods and food are significantly greater than the emissions associated with transporting them, even (in most cases) over long distances. Accordingly, efforts to analyze low-GHG consumption behaviors would benefit by looking primarily at the relative emissions associated with *producing* different alternatives.

For further details on emissions-intensive categories of food, goods, and services, as well as for the methodology of this consumption-based inventory, including details by life-cycle phase (e.g., production, transport, use, and disposal) and a recommended framework for tracking changes over time, please see King County's upcoming report. The report, tentatively titled *Greenhouse Gas Emissions in King County*, is expected to be released in the summer of 2011 and was completed by the Seattle office of the Stockholm Environment Institute.

7.2 Expanded Production Perspective

Besides vehicle transportation, buildings, and waste generation, other sources of emissions in Seattle's GHG inventory include in-city industrial facilities and the Port of Seattle. These activities are largely driven by demand outside the city. In a sense, emissions associated with producing cement, steel, or glass in Seattle or in operating ships or freight equipment at the Port are associated largely with consumption elsewhere and could therefore be considered part of some else's "consumption-based" emissions inventory, as described in the prior section.

Emissions associated with in-city industry and Port activity can, and do, fluctuate with broader economic demand outside the region. For this reason, and to avoid leakage in the industrial sector (e.g., driving industry outside of Seattle to avoid being counted as contributing to the City's greenhouse gases, but without actually reducing emissions), these emissions are best tracked separately, and are not included in the core Carbon Neutral Scenario. Metrics such as GHG or energy use per ton of output (e.g., tCO_2e/t cement) could be developed, to track industrial emissions. Where data do not support tracking emissions per ton of physical output, other metrics, such as number of employees or dollars of economic output, could be used. Emissions from port and marine activity could be tracked by normalizing emissions per ton, or per number of containers, of Port throughput.

Compared to opportunities in the transport, buildings, and waste sectors, in most cases local government (and the broader Seattle community) have less unique and direct influence over emissions associated with in-city industry activity. However, opportunities do exist. For example, through zoning, financial incentives, or other forms of support, local governments can in some cases assist industrial developments in sharing energy and material (including waste) resources for mutual benefit and reduced GHG emissions.

A final, small category of emissions that we include in this expanded production perspective are emissions associated with fossil fuel use in mobile equipment used for lawn care, landscaping, and other applications in homes and businesses. The primary method known to us to estimate these emissions is a model created by the EPA (called NONROAD) that scales national estimates to the local circumstance. Accordingly, any policy action taken to address these sources of emissions would be unlikely to be measurable in existing tracking systems. While local governments may have some control over these emissions – for example, through regulations on gas-powered landscaping equipment and incentives for electric alternatives – these sources are less central to Seattle's emissions and degree of influence, and less trackable, than emissions in the core Carbon Neutral Scenario.

8 Conclusion

The scenario presented here represents one of many possible pathways to carbon neutrality and serves to illuminate the depth of potential emissions reductions that could move Seattle toward becoming a carbon neutral city. Results of the Carbon Neutral scenario suggest that aggressive implementation of a full suite of emissions-reducing strategies could reduce Seattle's per capita GHG emissions by 30% by 2020, 60% by 2030, and 90% by 2050, relative to 2008 levels.

Three broad outcomes are central to the rapid pace of emission reductions in the Carbon Neutral scenario:

- Shifts to less GHG-intensive travel modes such as ride sharing, transit, walking and biking lead to 30% less per capita travel by light duty vehicles in 2030 and 50% less by 2050, relative to 2008 levels.
- Second, dramatic increases in energy efficiency in building design and operations, and vehicle efficiency result in over 30% energy savings by 2030 (per capita in residential and per square foot in commercial) and over 50% by 2050, relative to 2008 levels.
- Finally, homes, businesses, and vehicles transition to lower carbon energy sources: electricity (or possibly hydrogen) in the long run, biofuels as a bridging strategy for transportation until electric vehicles predominate, and to a much lesser extent, sustainable biomass sources (for district energy systems).

The City can do much within its sphere of influence to reduce VMT, develop alternative transportation modes, lower building energy use and emissions, develop district energy and electric vehicle infrastructure, and increase recycling, composting, and waste reduction. That said, federal and international action will be essential for the City's goals to be achievable. Over half of the reductions in this scenario result from improving the efficiency of vehicles and appliances and developing and delivering alternative fuels and the equipment to use them. While cities can pilot and create markets for these technologies, they will require the global market demand and research, development, and deployment support that only national and international actions can provide.

Even with concerted action at federal and international as well as the City level, eliminating every ton of GHG emissions may prove too difficult or costly to achieve, especially in the next few decades. Consequently, reaching the City's goal of zero net emissions by 2050 may require additional steps to offset remaining emissions such as increased sequestration activities, credit for selling excess renewable energy, or other measures. The City can also use these options to achieve more ambitious goals than these scenario results might suggest. As noted in Section 1, restricting global warming to less than 2 degrees relative to pre-industrial levels may ultimately require going beyond zero net emissions to carbon "negative".

Seattle already possesses a carbon-neutral electricity supply, and plans to maintain it, along with a strong foundation of existing emission reducing activities in the transportation, buildings, and waste sectors. For these reasons, the city is uniquely positioned to demonstrate how communities can address the climate challenge. The City Council has articulated its goal of carbon neutrality, and this report describes how a suite of emission reducing strategies can move the City towards this goal. The City's planning process will provide the opportunity to translate the vision embodied in the Carbon Neutral scenario into discrete policies and actions for implementation, in light of funding and political challenges, as well as community support for individual strategies.

Indeed, many of the strategies considered in the Carbon Neutral scenario can provide benefits well beyond emissions reductions. Building design and retrofits, expanded transit investments, and new infrastructures for district energy and electric vehicles can help to create healthier, more vibrant communities, and provide foundations for new, green jobs and businesses.

Finally, this report remarks on two additional perspectives on GHG emissions that go beyond the scope of the Carbon Neutral scenario. One perspective is to consider the life-cycle GHG emissions associated with goods, food, and services that Seattle residents consume. About half the emissions associated with Seattle residents' consumption is associated with the production of goods, food, and services, emissions that occur largely outside the city limits. These activities and emissions may be less within the city's sphere of influence than those associated with in-city building energy use, transportation, or waste management. Nonetheless, through complementary efforts, the City may wish to engage the community in efforts to reduce the emissions footprint of their purchasing patterns. The second perspective relates to production activities in Seattle that largely fulfill demands outside the city. Because Seattle's port and industrial activity are driven by external demands for the goods they ship and produce, we exclude them from the scope of our scenario analysis. At the same time, the city can expand its efforts to reduce the emissions intensity of goods produced or transported through the city, for example, through increased port electrification or capture of waste energy. In the report, we suggest some metrics the city can use to track and manage these emissions.

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Annex 1: Summary Table of Community Carbon Neutral Plans

Community	Goal Statement	Goal Scope	Goal Definition	Offsets Allowed?
City plans				
Copenhagen, Denmark[43]	"carbon neutral" by 2025	Full community emissions (geographic)	- Reduce CO2 emissions by 20% between 2005 and 2015	Yes, expected source of ≈half of reductions in 2025
Austin, TX[44]	"carbon-neutral"	Municipal operations; new electricity sources	- City facilities and operations carbon-neutral by 2020. Utility Plan - Expand efficiency and renewable energy programs; cap CO2 emissions from existing power plants; all new electricity generation carbon-neutral.	Yes, loosely
Melbourne, Australia [45]	"zero net emissions" by 2020	Full community emissions (geographic)	- Commercial sector: 25% below 2020 BAU - Residential sector: 20% below 2020 BAU - transport: 10% below 2020 BAU -Energy supply: 18% below 2020 BAU	Yes, expected source for majority of reductions
Vancouver, B.C., Canada[46]	"carbon neutral"	Municipal operations; new buildings	- Municipal operations: carbon neutral by 2012 - Community emissions: 6% below 1990 by 2012, 33% by 2020, 80% by 2050 - All new buildings are carbon neutral by 2030	Yes, in corporate plan
Växjö, Sweden[47]	"fossil fuel-free"	Full community	- Halve per-capita emissions by 2010 (from 1993); reduce by 70% by 2025. - Fossil-fuel-free by 2030.	N/A
Rizhao, China[48]	"carbon neutral"	Full community	– Specific goals for reduction of energy intensity (per unit GDP), but definition of carbon neutrality not clear.	N/A
New cities: designing carbon neutrality from scratch				
Masdar City, U.A.Emirates[49]	"carbon-neutral"	Full community	-Carbon neutral; zero-waste	Yes, aim to limit to 1%
Dongtan, China[50]	"eco-city"	Full community	- 64% reduction in energy demand; no emissions from energy for power/heat; project postponed indefinitely	N/A
Other notable climate plans and initiatives				
Chicago, IL[51]	"climate action plan"	Full community	- 80% below 1990 GHG emissions by 2050, with an initial goal of a 25% reduction below 1990 by 2020	N/A
New York, NY[52]	"PlaNYC"	Full community	- Reduce global warming emissions by over 30% by 2030	N/A
London, UK[53] (not official plan)	"capital consumption"	Full community (consumption-based)	- Reduce consumption-based emissions 70% by 2030 and 90% by 2050.	N/A

43 http://kk.dk/sitecore/content/Subsites/CityOfCopenhagen/SubsiteFrontpage/CitizenInformation/~/media/558FF07CE64041AE85437BB71D9EDF49.ashx

44 http://www.ci.austin.tx.us/acpp/downloads/acpplan_overview.pdf; http://www.ci.austin.tx.us/acpp/downloads/acpp_res021507.pdf; http://www.ci.austin.tx.us/acpp/downloads/report2009.pdf

45 http://www.melbourne.vic.gov.au/Environment/WhatCouncilisDoing/Documents/zero_net_emissions_2020.pdf

46 http://vancouver.ca/sustainability/climate_protection.htm; http://vancouver.ca/sustainability/documents/CommunityClimateChangeActionPlan2005coverandreport.pdf; http://vancouver.ca/sustainability/documents/Progress2007.pdf; http://vancouver.ca/sustainability/documents/corp_climatechangeAP-1.pdf

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