Getting to Zero: A Pathway to a Carbon Neutral Seattle

Final Report

Prepared for:

Tracy Morgenstern and Jill Simmons, City of Seattle Office of Sustainability and Environment (OSE)

Project Team:

Michael Lazarus, Pete Erickson, and Chelsea Chandler, Stockholm Environment Institute – U.S.

Marc Daudon and Shannon Donegan, Cascadia Consulting Group

Frank Gallivan and Jeffrey Ang-Olson, ICF International

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Dan Bertolet, GGLO
Julie Colehour, Colehour + Cohen
KC Golden, Climate Solutions
Stephanie Harrington, University of Washington
Matt Kuharic, King County
Michael Mann, Cyan Strategies
Eric de Place, Sightline Institute
Gary Prince, King County
Viccy Salazar, USEPA Region 10
Leslie Stanton, Puget Sound Clean Air Agency
Justus Stewart, ICLEI - Local Governments for Sustainability

Ashley Zanolli, USEPA Region 10

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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.

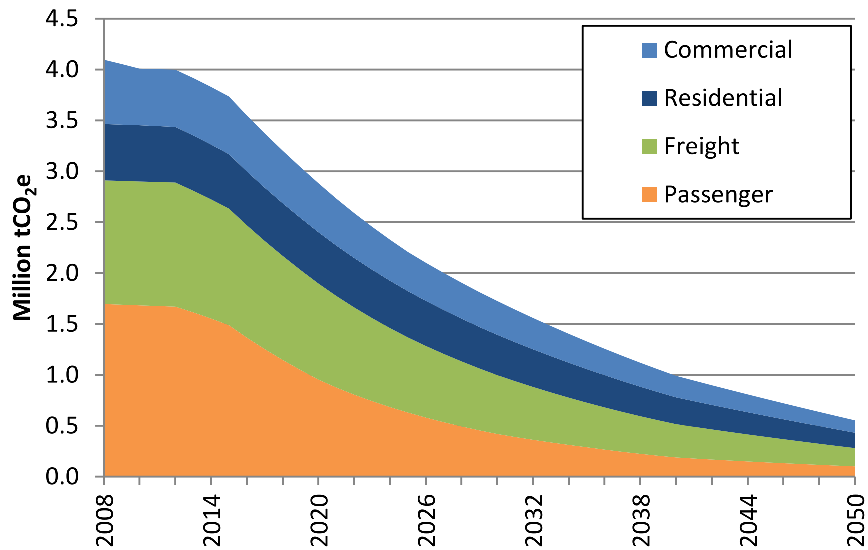
Together, the SEI team and OSE, with guidance from our Technical Review Committee, constructed a Carbon Neutral scenario from the "bottom up" by developing a suite of ambitious strategies based on aggressive deployment at plausible penetration rates of technologies and practices. The Carbon Neutral scenario 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.

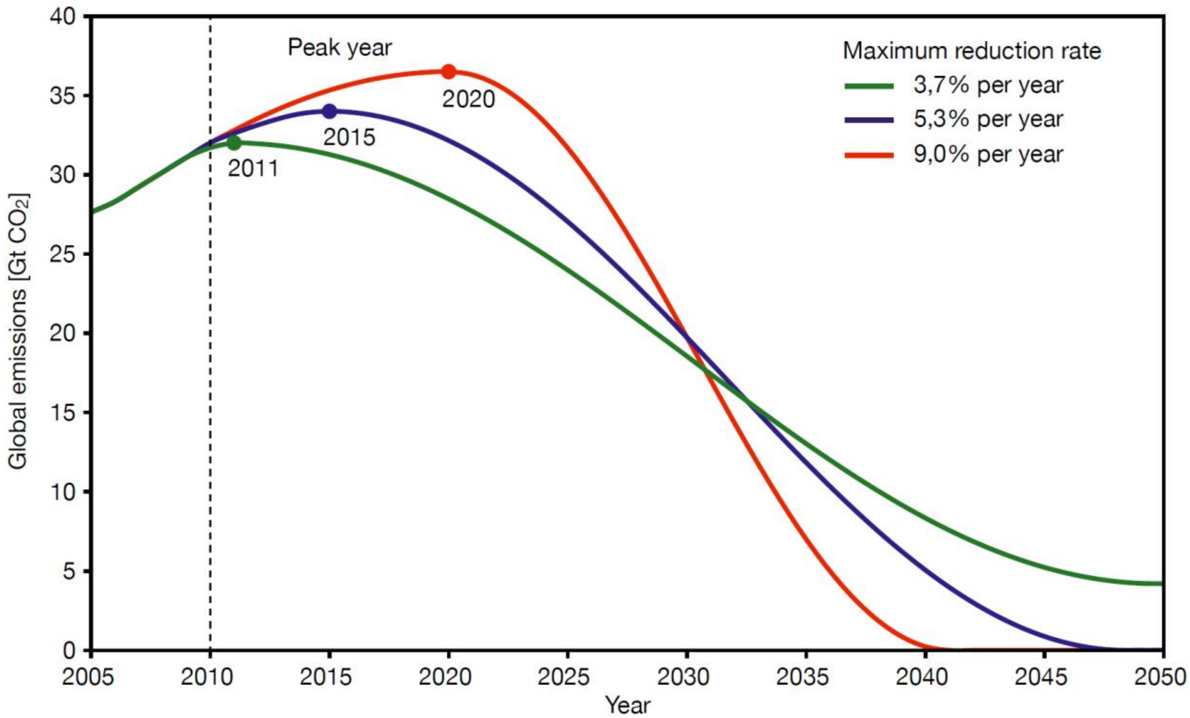
Figure 1 charts three possible global CO_2 emissions pathways that could limit warming to 2 degrees C. The green pathway, for example, suggests that if global emissions were to begin a steady decline at a rather ambitious pace of 3.7% per year, global emissions would need to peak next year in order to

[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_2 Emissions 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

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[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.[8] Depicted in Figure 2, and developed recently under a separate project for King County,[9] 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

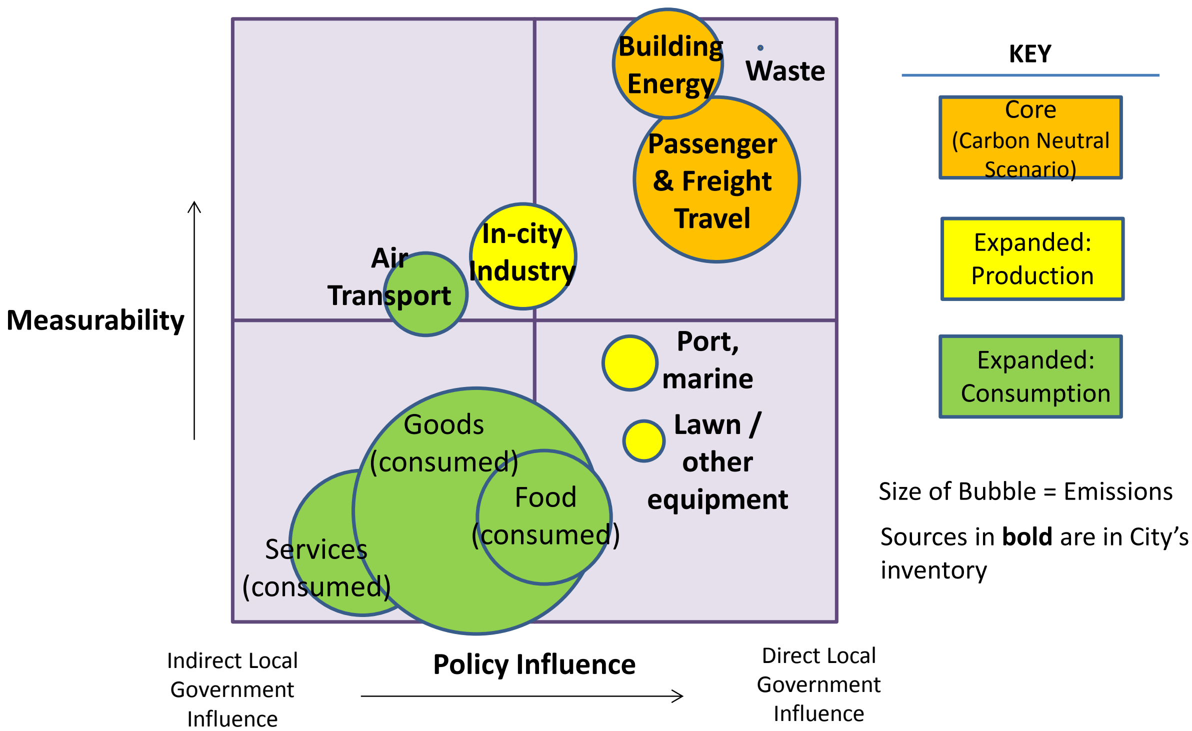
[7] [Explain how the variance in Seattle's inventory 1990-2008 has been driven in good part by the tons of cement produced, and how the closure of Lafarge's kiln provides a big drop in Seattle's emissions that does not correspond to a global emissions reduction]

[8] The framework was developed as part of the King County Communities Emission Inventory and Climate Action Assessment project.

[9] Mention project.

to the majority of emissions reported in the city's official inventory.[10] 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

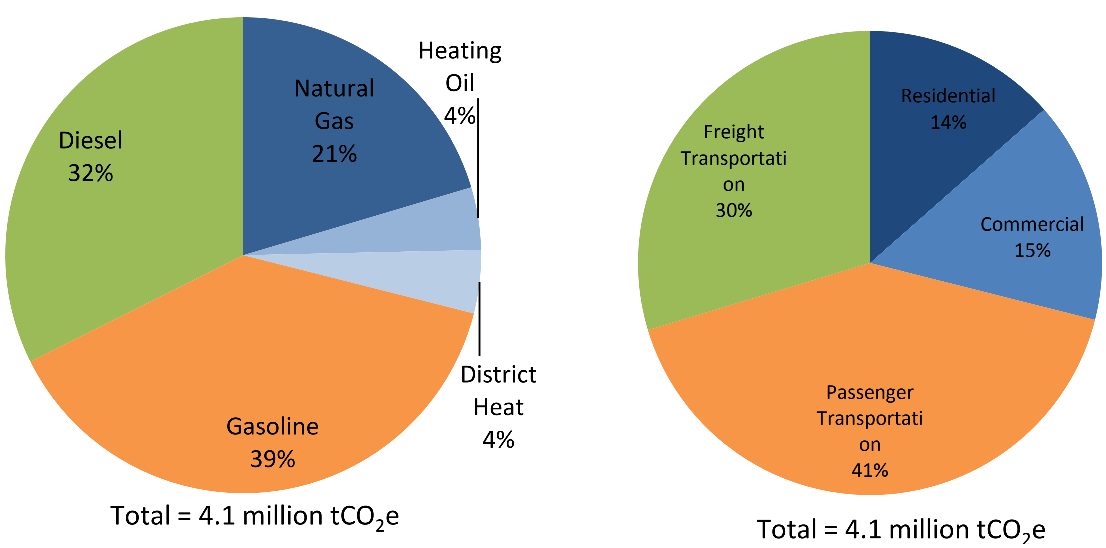
[10] We also depart from the traditional inventory methods in a couple of other ways. First, we adopt the origin-destination method for estimating vehicle miles travelled. This method counts emissions from all trips that occur entirely within Seattle, half of trips that either begin or end in the city, 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).[11] 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)



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[11] 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.[12] 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.

[12] 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

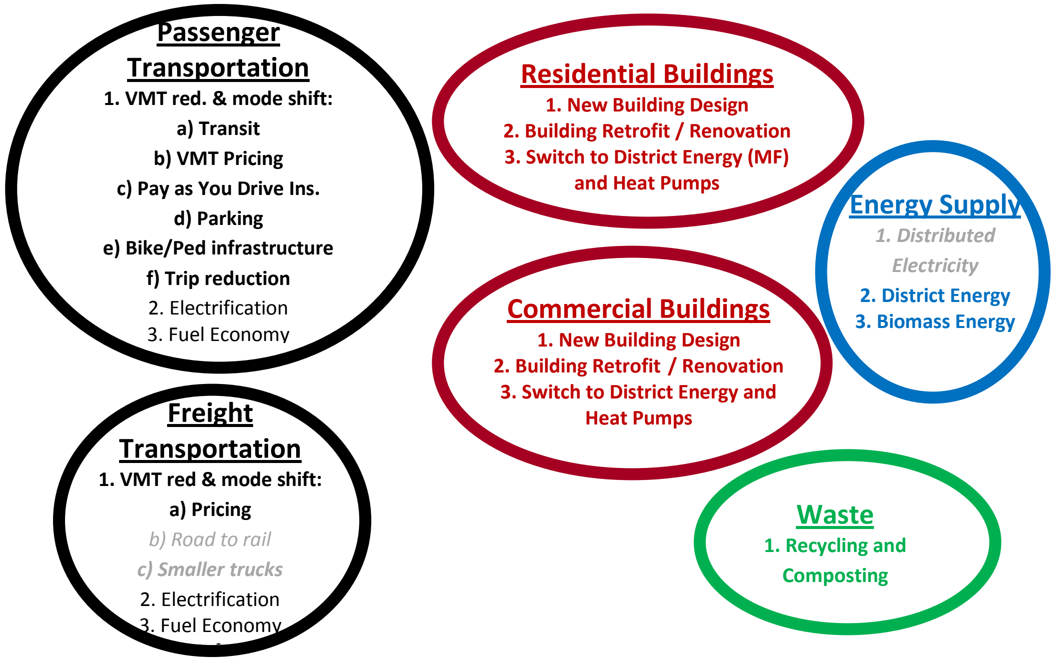
There are many conceivable pathways to a carbon neutral Seattle. One such path might be dominated by renewably-powered smart grids and electric vehicles; another path might rely more heavily on hydrogen fuel cells or next-generation biofuels that pose less competition for agricultural lands. New district 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.)



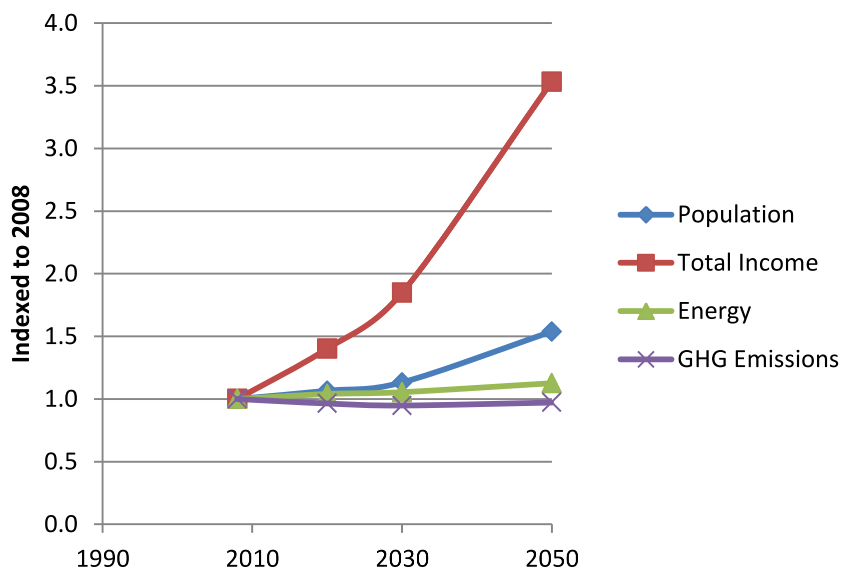
The SEI team identified the suite of strategies shown in Figure 4 by reviewing sectoral trends, other regions climate plans, and collecting input from City staff and the Technical Review Committee. Ultimately, four criteria guided the selection and ambition –achievable penetration rates, technology characteristics, 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. [13] 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 become 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)



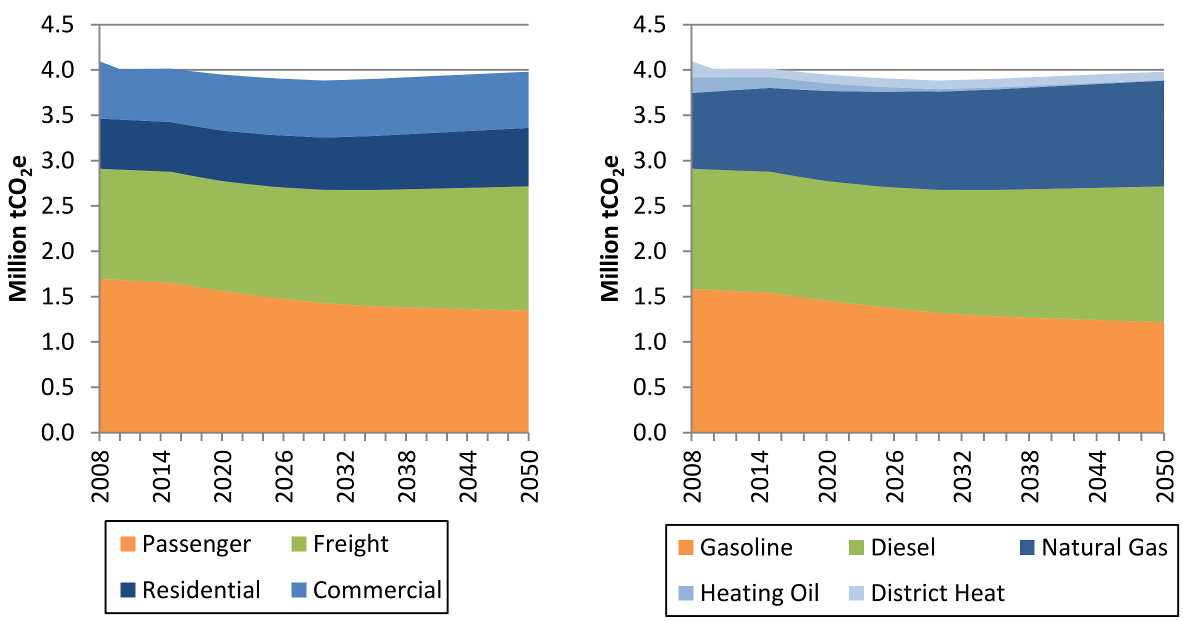
[13] The use of LEAP (the Long-range Energy Alternatives Planning system) facilitates an internally consistent assessment of overlapping strategies (e.g. reducing vehicle travel, increasing vehicle efficiency, and switching vehicle fuels). For further information on LEAP, see http://www.energycommunity.org/.

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)



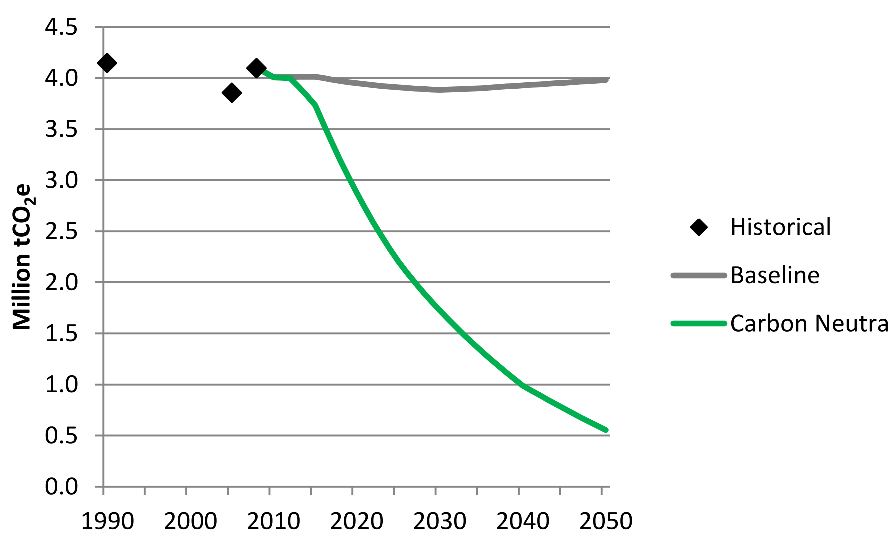
Box 2. What about the efforts the City and other local actors are already undertaking?

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[14]



[14] 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 **t**he 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[15] 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.[16] Deep improvements in the efficiency of the

[15] 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.

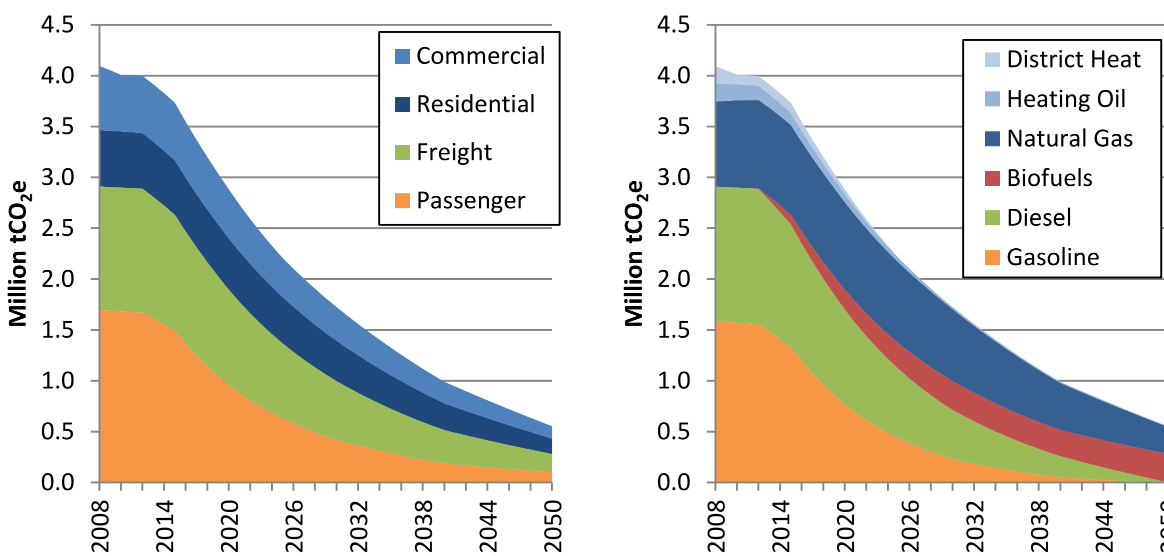
[16] Under the Baseline scenario, electricity use in the City of Seattle (including industrial) increases from 920 aMW in 2008, to 1090 aMW in 2030 and 1250 aMW in 2050. (This pace of growth is similar to that projected in SCL's 2010 load forecast (http://www.seattle.gov/light/news/issues/irp/docs/dbg_538_app_e_4.pdf). 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.[17] 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.

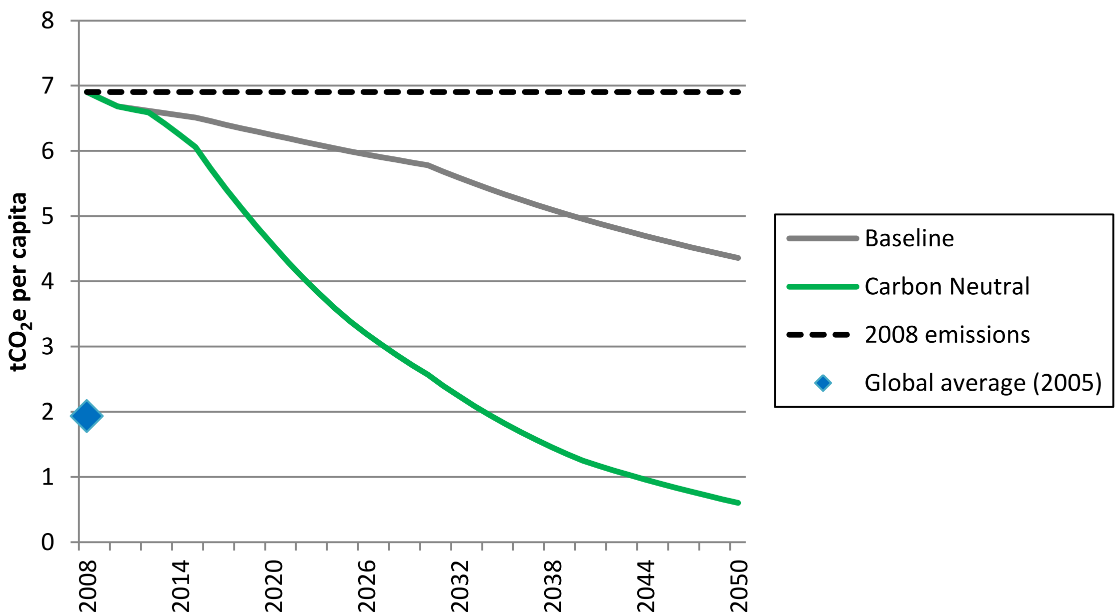
Figure 8. GHG Emissions in the Carbon Neutral Scenario, by Sector (left) and by Fuel (right)



17 See footnote 15 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. [18] In the Carbon Neutral scenario, emissions drop by 91% to 0.6 tCO_2e per person by 2050. (See Table 1 below).

[18] 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 tCO2e 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/tCO2e 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.[19] 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[20], 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:[21]

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[19] 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%).

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

[21] 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).[22] 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.[23] 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.

[22] 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/.

[23] 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.[24])

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.

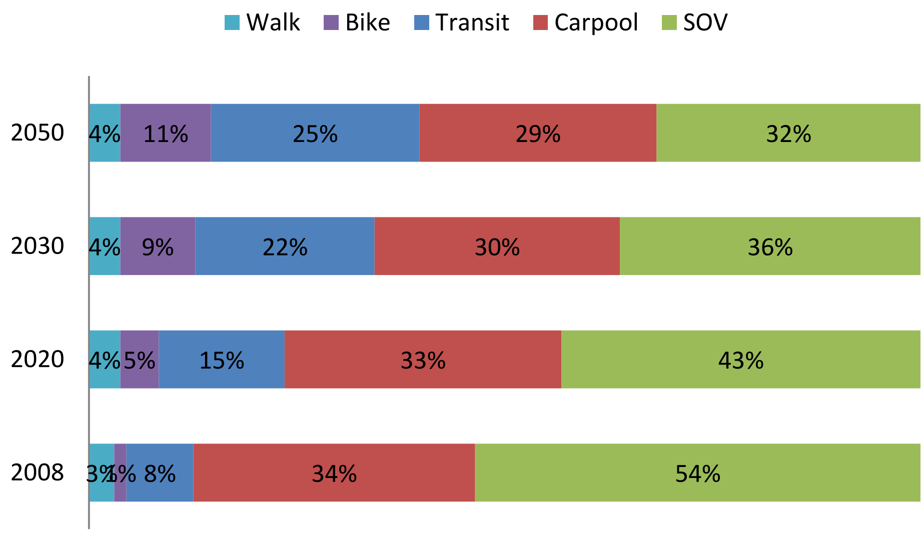
Figure 10 illustrates the major shift in how people move under the Carbon Neutral scenario. Biking, walking, and transit shares nearly double by 2020 and triple by 2050. It is important to note that the shares shown here in this figure are in in terms of passenger-miles traveled (PMT), where a passenger-mile is one mile travelled by one passenger in a given mode.[25] 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

[24] 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.

[25] 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.[26] A number of recent efforts have described some of the possible benefits of transit- and pedestrian-oriented developments for Seattle and the region,[27] 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

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

[27] 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.[28]

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

[28] 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.[29] 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.[30] *[Strategies PT4, FT4]*

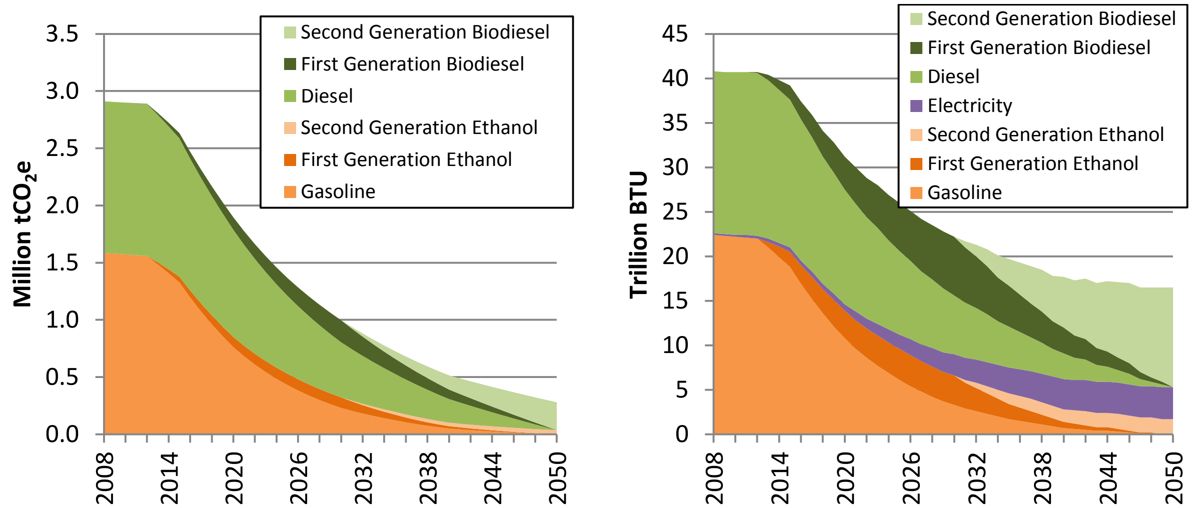
4.4 Overall findings for the transportation sector

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.

[29] 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.

[30] 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).[31] 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[32,33] 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.[34,35]

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.

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[31] http://www.eia.doe.gov/oiaf/aeo/assumption/pdf/commercial_tbls.pdf
[32] Funded by the American Recovery and Reinvestment Act of 2009 and awarded by U.S. DOE.
[33] http://www1.eere.energy.gov/wip/eecbg.html
[34] Wigington, Linda. Affordable Comfort Inc. (ACI). "Deep Energy Reductions in Existing Homes: Strategies for Implementation." ACEEE Summer Study 2008. Asilomar, Pacific Grove, CA.
[35] 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.[36] 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.[37] 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[38], 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]*

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

[37] 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

[38] 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.[39] 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]*

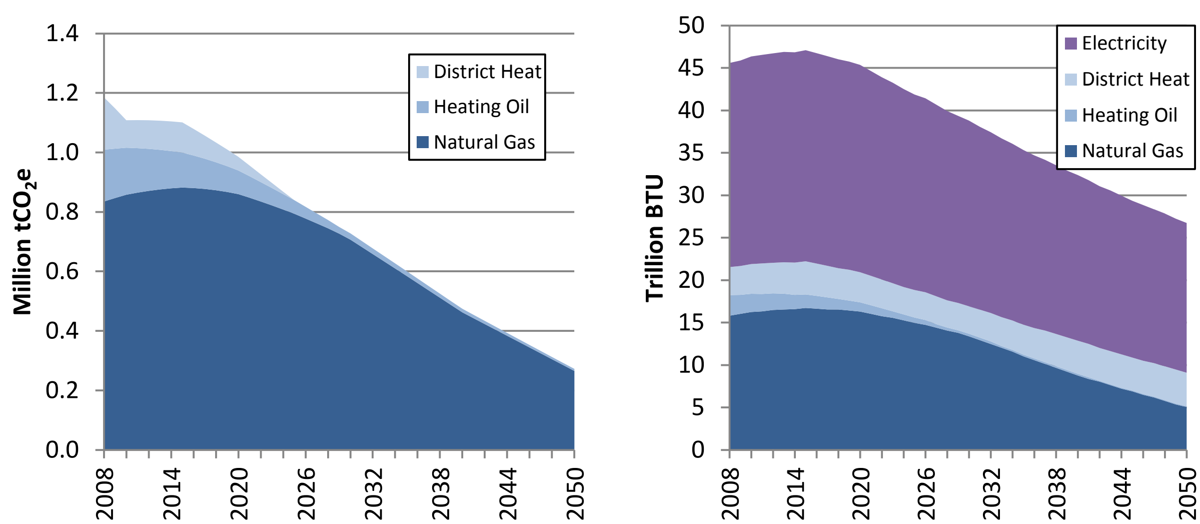
[39] Note that if deep retrofits reduce heat requirements to a small fraction of current levels, electric resistance heat may be more cost-effective given the small heating loads. If resistance heating were used in lieu of heat pumps, the increase in electricity use would likely be negligible given the 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.[40] 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



[40] DOUBLE CHECK/VERIFY

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:

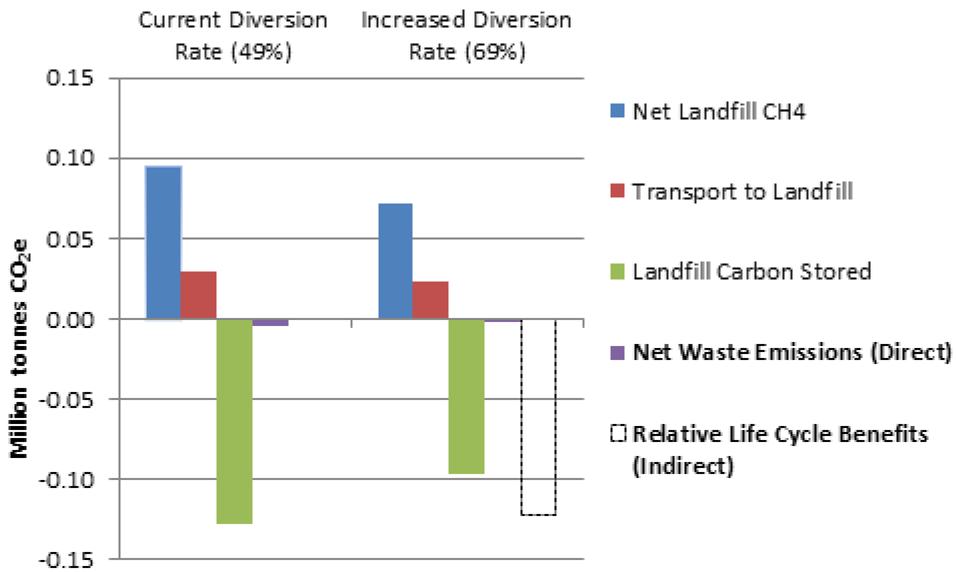
- Net landfill methane totals 0.095 MtCO2e. This assumes continuation of current waste management practices, whereby 49% of waste is diverted from landfilling to recycling or composting. Of the waste that is landfilled, we assume (as in the current Seattle inventory) that 75% of the methane generated 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.[41]

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.

[41] 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.[42]

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.

[42] 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

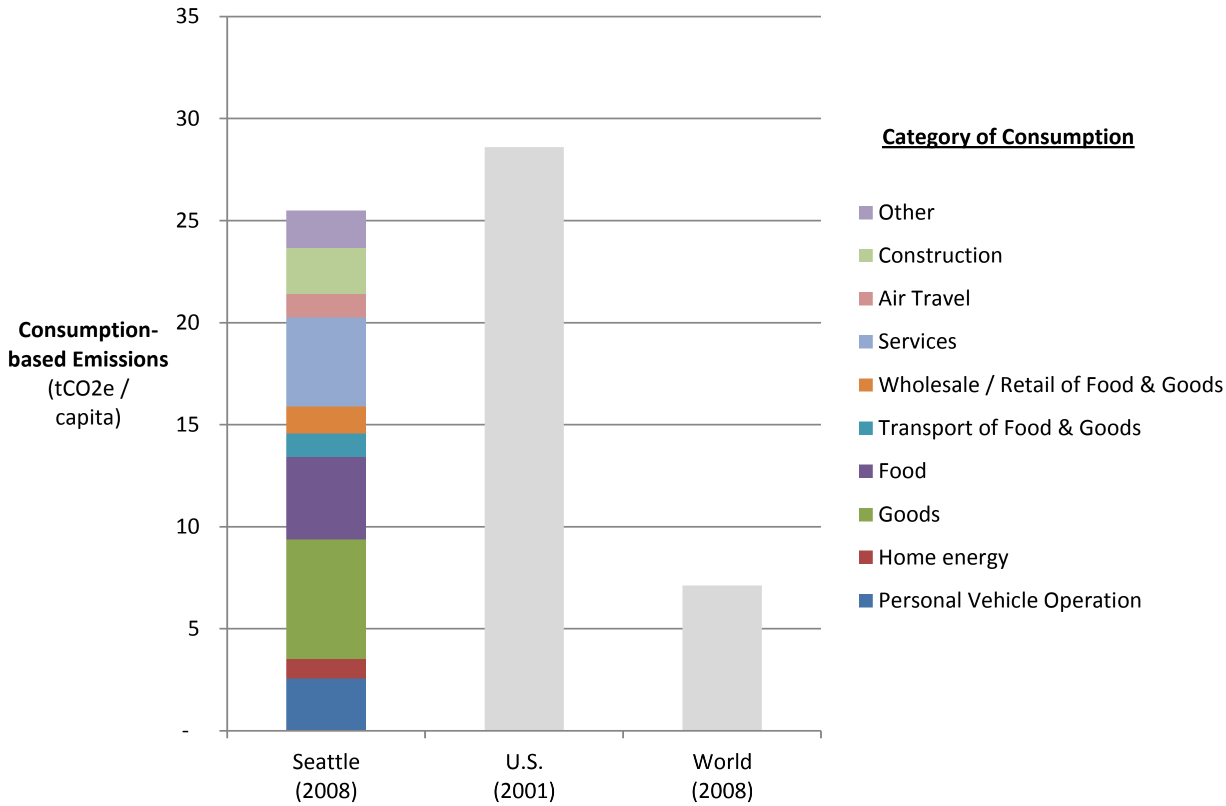
The predominant method of attributing greenhouse gas emissions to a community is to compile estimates of GHGs released within the community, plus those emissions associated with electricity used within the community. The core GHG-reduction scenario described in this report uses such a method, with a 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.[43] 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

[43] 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.[44]

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.

[44] 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[45]	"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[46]	"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[47]	"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[48]	"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[49]	"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[50]	"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[51]	"carbon-neutral"	Full community	-Carbon neutral; zero-waste	Yes, aim to limit to 1%
Dongtan, China[52]	"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[53]	"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[54]	"PlaNYC"	Full community	- Reduce global warming emissions by over 30% by 2030	N/A
London, UK[55] (not official plan)	"capital consumption"	Full community (consumption-based)	- Reduce consumption-based emissions 70% by 2030 and 90% by 2050.	N/A

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

46 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

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

48 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

49 http://postcarboncities.net/europes-greenest-city-even-its-power-plant-smells-more-sauna http://www.unep.org/ClimateNeutral/Default.aspx?tabid=208

50 http://www.scientificamerican.com/article.cfm?id=sunrise-on-chinas-first-carbo-neutral-city;http://www.unep.org/ClimateNeutral/Default.aspx?tabid=205; http://www.renewablepowernews.com/archives/546

51 http://www.masdarcity.ae/; http://www.npr.org/templates/story/story.php?storyId=90042092

52 http://www.c40cities.org/docs/casestudies/buildings/dongtan_carbon.pdf; http://www.arup.com/_assets/_download/8CFDEE1A-CC3E-EA1A-25FD80B2315B50FD.pdf; http://www.sustainablecityblog.com/2010/01/dongtan-delayed-but-not-dead/

53 http://www.chicagoclimateaction.org/filebin/pdf/finalreport/CCAPREPORTFINALv2.pdf

54 http://www.nyc.gov/html/planyc2030/downloads/pdf/report_climate_change.pdf; http://www.nyc.gov/html/planyc2030/downloads/pdf/progress_2008_climate_change.pdf

55 http://www.bioregional.com/files/publications/capital-consumption.pdf

Technical Appendix

Review of Approach and Assumptions for Seattle Carbon Neutral Sector and Strategy Analysis

Prepared for:

Tracy Morgenstern and Jill Simmons, City of Seattle Office of Sustainability and Environment (OSE)

Project Team:

Michael Lazarus, Pete Erickson, and Chelsea Chandler, Stockholm Environment Institute – U.S.

Marc Daudon and Shannon Donegan, Cascadia Consulting Group

Frank Gallivan and Jeffrey Ang-Olson, ICF International

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Table of Contents

Introduction

The purpose of this technical appendix is to document our approach and assumptions for the Seattle Carbon Neutral scenario analysis. We circulated prior versions of this document to the Technical Review Committee (TRC) and City staff in December 2010, and held two meetings to discuss this material on transportation and buildings/energy. Through these meetings and further communications, staff and TRC members provided very useful feedback on the strategy choices and ambition, as well as specific suggestions for additional data sources.[1]

We have organized this appendix around the sectors comprising the "core emissions" that will be the focus of, and metrics for, the City's carbon neutral goal:

- Transportation (Passenger and Freight);
- Buildings (Residential and Commercial);
- Energy Supply (Electricity and Biofuels); and
- Waste

For each sector, this appendix lists the key assumptions – projected activity levels such as population, and expected trends in energy use and mobility – that we use to develop a **baseline scenario**. The baseline scenario represents a business-as-usual projection out to the year 2050 taking into account local analyses (e.g. by PSRC or City Light) together with the projected impact of policies currently in place at the federal and state levels, such as appliance and vehicle standards, that can be expected to significantly affect energy use and emissions over the time frame of the study. In contrast, the baseline scenario does not aim to capture recently enacted policies and investments at the local level, such as the bicycle, pedestrian, and transit plans, green building block grants, or utility conservation programs. We reflect the potential impacts of these and other policies in a separate analysis of City and local policies, which we will circulate for review at later time.

The **Carbon Neutral Seattle scenario** builds on the foundation of these existing policies, and posits the aggressive implementation of ambitious transportation, built environment, energy supply and other strategies out to the year 2050. Much of this appendix to outlines these strategies from a relatively technical perspective. The strategies presented here are broad technical options (e.g. "building retrofits", "improved vehicle fuel economy", or "vehicle electrification") rather than specific policy options (e.g. "carbon pricing" or "building code revisions"). We develop these options at a relatively high level of aggregation, given the need to project out to 20-40 years amid inherent uncertainties about fuel prices, economic trends, and lifestyle changes. This scenario aims to provide a vision and existence proof of a low-carbon future that is possible, but certainly not the only such future, nor necessarily the most ambitious one. The planning process that will follow provides the opportunity to translate this vision into discrete policies and actions for implementation.

With that context in mind, the reader will notice that our approach to assessing reduction on passenger vehicle travel (VMT analysis) differs from other sectors and strategies. For VMT related options, we tend to examine policies rather than technical options. There are two principal reasons for this approach. 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 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, OSE recognizes that VMT and mobility policies are ones where a municipality has significant influence and leverage; therefore, at their suggestion, we provide deeper analysis of this suite of strategies.

Table 1 lists the strategies considered in the Carbon Neutral scenario.

[1] Attendees at the 12/14 transportation meeting: Barbara Gray, SDOT; Dorinda Costa, SDOT; Jemae Hoffman, SDOT; Tony Mazzelli, SDOT. Attendees at the 12/16 buildings meeting: Mike Little, SCL; Joshua Curtis, OSE; Peter Dobrovolny, DPD; Sandra Mallory, DPD. Additional comments received from attendees as well as from Gary Prince, King County.

Table 1. Strategies Considered in the Seattle Carbon Neutral Scenario

Passenger Transportation 1. VMT Reduction and Mode Shift: a) Transit, b) VMT Pricing, c) Pay as You Drive (PAYD) Insurance, d) Parking, e) Bicycle/Pedestrian Infrastructure, f) Trip Reduction Programs 2. Electrification 3. Fuel Economy 4. Biofuels	**Freight Transportation** 1. VMT Reduction and Mode Shift: a) Pricing, b) Road to Rail, c) Smaller trucks 2. Electrification 3. Fuel Economy 4. Biofuels
Residential Buildings 1. New Building Design 2. Building Retrofit and Renovation 3. Switch to District Energy (MF) and Heat Pumps	**Commercial Buildings** 1. New Building Design 2. Building Retrofit and Renovation 3. Switch to District Energy and Heat Pumps
Energy Supply 1. Distributed Electricity Production 2. District Energy 3. Biomass Energy	**Waste** 1. Recycling and Composting

In developing this list of strategies, we applied the following criteria:

- significance (i.e. generally excluding options with less than 1% contribution to goal achievement)
- technological maturity (i.e. avoiding reliance on unproven technologies such as algae biofuels)
- cost-effectiveness (limiting penetration of very high cost technologies, especially in the near-term, e.g. rooftop PV), and,
- consistency with a carbon neutral trajectory.

For example, we do not include strategies involving conversion of vehicle fleets to natural gas or investment in high-efficiency gas furnaces, since either the emissions savings would be relatively small[2] (significance) or the investments could lock in dependence on fossil fuels for an extended period (consistency).

For each strategy, we present the following information:

- Introduction/Context: a brief description of the technologies and practices, noting major related activities underway in Seattle or nearby.
- Strategy Ambition: assumptions regarding the intensity of strategy implementation, such as the penetration rate of low-carbon building designs and retrofits, the rate of expansion of transit infrastructure, or road and parking pricing levels. Based on other studies and input from sector experts, these assumptions seek to reflect a balance of vision and ambition with constraints of technology, investment, and inertia.
- Technical Assumptions and Results: technical assumptions regarding strategy elements and characteristics such as energy efficiencies, emission rates, and elasticities. We draw these assumptions from published literature to the extent available. We show intermediate results where relevant (e.g. impact on mode shares of pedestrian infrastructure).

We provide references at the end of this appendix.

[2] For example, according to U.S. DOT (2010), conversion of fleets to natural gas would yield <1% reduction in transportation GHG emissions by 2030.

Macroeconomic Assumptions

We base our baseline and scenario energy calculations on underlying assumptions of macroeconomic variables. Energy use in buildings, for example, directly correlates with the number of residents and employees in Seattle, as this drives the number of residential and commercial buildings consuming energy for temperature regulation, lighting, appliances, electronics, and other demands.

PSRC[3] provided forecasts of population, number of households (by type), employment, and vehicle miles traveled (by vehicle type) according to the Baseline Alternative from Transportation 2040 (PSRC 2010a). Population, number of households, and employees are shown in Table 2, Table 3, and Table 4, respectively.[4] (VMT is described in greater detail in the Passenger and Freight Transportation sections of this report.)

Table 2. Seattle population (thousand people)

2008	2020	2030	2050
593	633	672	913

Table 3. Seattle households (thousand households)

Household Type	2008	2020	2030	2050
Existing SF	136	134	132	127
Existing MF	139	136	134	130
New SF	0	13	19	24
New MF	0	21	49	194

Table 4. Seattle employees (thousand people)

2008	2020	2030	2050
577	714	767	854

[3] Data provided by Mark Simonson, PSRC, 12/18/10.
[4] As these figures did not include 2008 values, we approximated our base year with 2006 values. Also, since these forecasts end in 2040, we extrapolated to 2050 based on the growth rate of the prior ten years.

Passenger Transportation

Baseline Scenario

Base year data (2008)

- Passenger transportation includes
  - Light Duty Vehicles (LDVs), which include Single Occupancy Vehicles (SOV), High-Occupancy Vehicles with 2 and 3 passengers (HOV2 and HOV3), Vanpools, and Light Trucks
  - Transit (Bus and Light Rail)
  - Pedestrians and Bicycles
- **Activity:** For the base year (2008), we use estimates for vehicle miles traveled (VMT) for SOV, HOV2, HOV3, Vanpool, and Light Trucks, as provided by PSRC[5,6] using an origin-destination pair approach. This method counts 100% of trips that both begin and end within Seattle, 50% of trips that either begin or end in Seattle, and no pass-through trips (i.e. those that neither begin nor end in Seattle). For other modes in the year 2008, we estimate:
  - Bus VMT (including Metro Transit and Sound Transit) from the 2008 Seattle Community Greenhouse Gas Inventory
  - Bicycle VMT based on the Census bureau survey of commute trips by bicycle[7], and convert trip share to VMT share using the ratio of average bicycle trip length to overall average trip length (Cambridge Systematics 2007)
  - We assume pedestrian VMT is double bicycle VMT based on this ratio from the PSRC household survey (Cambridge Systematics 2007).
- Load Factors, or the number of people per vehicle, for each vehicle type are used to translate between VMT and PMT (passenger-miles traveled). PMT is calculated by multiplying VMT by the load factor for each vehicle type. Load factors for each vehicle type are presented in Table 5. Load factors for SOV, HOV2, HOV3 are implicit by mode definition. Similarly, for walk and bike, we assume “vehicle” and “passenger” miles are equivalent. We assume the light truck load factor to be the average of SOV and HOV2. The bus load factor was provided by King County DOT and estimates the average number of passengers per bus within Seattle[8]. For light rail, the load factor is based on the number of passenger miles and the number of vehicle miles traveled in its first year of operation.[9]
- **Efficiency:** We draw vehicle fuel economy (mpg) from the U.S. Energy Information Administration (EIA)’s 2010 Annual Energy Outlook (AEO) (U.S. EIA 2010). See Table 7.
- **Fuel choice/technology:** Baseline fuel mix is considered to be all gasoline for cars, 89% diesel / 11% electric (trolleybuses) for buses[10], and 60% gasoline / 40% diesel for light trucks (based on AEO (U.S. EIA 2010))[11]. While ethanol is currently blended into gasoline, the life cycle GHG emissions of first generation corn-based ethanol is so similar to that of petroleum-based gasoline,

[5] Data provided by Kris Overby, PSRC, 9/10/10. Daily weekday VMT was adjusted to an average daily figure, and scaled to annual VMT.
[6] This VMT data was provided for 2006, and scaled to 2008 by the relative average VMT in King County for the two years as reported by the Highway Performance Monitoring System.
[7] http://www.factfinder.census.gov/servlet/ADPTable?_bm=y&-geo_id=16000US5363000&-qr_name=ACS_2008_3YR_G00_DP3YR3&-ds_name=&-_lang=en&-redoLog=false
[8] Provided by Matt Wold, King County DOT, 12/10/10. Estimate includes deadheading, i.e. returns without passengers.
[9] http://www.soundtransit.org/News-and-Events/News-Releases/Link-Anniversary.xml. This assumption should be revisited when better estimates are available.
[10] Based on the ratio of trolleybus to diesel bus VMT, from the 2008 Seattle Community Greenhouse Gas Inventory.
[11] http://www.eia.doe.gov/oiaf/aeo/supplement/suplp.html, Table 46.

that we do not account for it separately. See the biofuel strategy below for further discussion of life cycle emission estimates.

Baseline Scenario Projections:

- **Activity**: We project VMT to grow at the rates forecast by PSRC, by mode, for the Transportation 2040 study for SOV, HOV2, HOV3, Vanpool, and Light Trucks. See Table 6.
    - Bus VMT grows at the same rate as population (i.e. bus transit miles per capita remain constant).
    - No changes in bicycle or pedestrian calculation methods.
    - No changes in vehicle load factors.
- **Efficiency:**
    - We estimate changes in vehicle fuel economy (mpg) based on AEO 2010 projections through 2035 (U.S. EIA 2010). We assume that by 2050 average fuel economy for the entire stock reaches the level of on-road new light-duty vehicles sold in 2035. The improvements shown reflect the implementation of current fuel economy standards (36 mpg by 2016). See Table 7.

Existing Local Actions (beyond the baseline scenario):

- We include elements of the Sound Transit 2 plan, including Light Link Rail expansion and BRT systems.
- We do not quantify the impact of other actions that are expected to reduce passenger vehicle emissions, such as the City's vehicle electrification efforts, transit community work, or bicycle and pedestrian master plans. While alone their direct emissions benefits are relatively small, especially for elements that are fully funded, these actions set the stage for transformative changes that are modeled in the related strategies of the Climate Neutral scenario.

Table 5. Load factors (people per vehicle)

Vehicle Type	2050
SOV	1
CP2	2
CP3	3
Vanpool	8
Light Truck	1.5
Buses	14.2
Walk	1
Bike	1
Light Link Rail	35.8

Table 6. Baseline VMT (million VMT)

Vehicle Type	2008	2020	2030	2050
SOV	2839	3047	3183	3379
CP2	510	533	551	583
CP3	248	252	262	294
Vanpool	4	7	9	10
Light Truck	164	177	186	203
LDV Subtotal	*3766*	*4017*	*4191*	*4468*
Buses	27	29	30	41
Walk	119	127	133	142
Bike	60	64	66	71
Light Link Rail	1	6	9	9

Table 7. Baseline fuel economy (mpg)

Vehicle Type	2008	2020	2030	2050
Car	20.9	24.3	28.0	32.5
Light Truck	14.3	16.2	18.0	19.1
Bus	3.7	4.1	4.3	4.3

Land Use & Compact Development

Introduction/Context

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. In a meta-analysis of literature on the relationship between development patterns and driving, Ewing and Cervero suggest quantitative relationships between VMT and five factors in land use and transportation systems: density, land use mixing, street design, proximity of regional destinations, and distance to transit (R Ewing and Cervero 2010).

As a dense, core city in a large metropolitan region, Seattle has excellent opportunities to accommodate growth in jobs and population within compact developments, and thereby reduce average per capita VMT in the region. In the context of a Carbon Neutral Seattle, the city has two main types of growth opportunities to reduce VMT:

1. *Increase the share of regional jobs and population accommodated in Seattle.* Seattle's per capita VMT is less than that of other communities in the region, thanks to the prevalence of high density mixed use neighborhoods with high-quality transit and street designs amenable to walking and biking. If higher rates of growth in Seattle allow more jobs and residents to locate there rather than in suburban communities, total VMT in Seattle will increase, but regional per capita VMT will decrease. PSRC's Vision 2040 calls for Seattle to accommodate more growth than is provided for in the city's current Comprehensive Plan. Shifting regional growth to Seattle and the region's other metropolitan cities is a core component of Vision 2040's Regional Growth Strategy.

2. *Organize planned growth in Seattle around neighborhood centers that emphasize a dense core, land use mixing, access to high quality transit, and street designs supportive of walking and biking*. Within the City of Seattle, there are wide variations in urban environment. Per capita VMT is higher in lower density car-dependent neighborhoods than in Seattle's "urban villages." Accommodating future growth in denser "urban villages" will reduce both per capita VMT and total VMT in Seattle. The Seattle Planning Commission's *Seattle Transit Communities: Integrating Neighborhoods with Transit* establishes a vision for such growth patterns (Seattle Planning Commission 2010).

Strategy Ambition

Potential emissions savings from land use and compact development strategies are not quantified in this analysis.

Technical Assumptions and Results

Forecasting changes in travel patterns in response to changes in land use patterns is a complex task. The task becomes increasingly more complex at finer geographical scales, and as changes in land use patterns become more specific and more subtle. Three recent studies have estimated the potential to reduce VMT by shifting growth to compact development patterns at the national scale: *Growing Cooler* (R et al Ewing 2008), *Driving and the Built Environment* (TRB 2009), and *Moving Cooler* (Cambridge Systematics 2009). Each study characterized the average difference in per capita VMT between sprawling and compact development patterns and the potential to shift growth from sprawl to compact patterns. *Moving Cooler* applied forecasts of VMT per capita by density of census tract to calculate VMT reductions (see below) (Cambridge Systematics 2009). In the case of Seattle, these forecasts or similar forecasts developed for the PSRC region could be used to estimate the potential impact of compact development on VMT.

Table 8. CUTR VMT Forecasts by Census Tract Density (Annual VMT per Capita)[12]

Tract Density Range (Persons Per Square Mile) (ppsm)	2005	Difference relative to low density (0-499 ppsm)	2035	Difference relative to low density (0-499 ppsm)	2055	Difference relative to low density (0-499 ppsm)
0-499	11,422	--	13,798	--	16,191	--
500-1,999	10,083	-11.7%	12,196	-11.6%	14,359	-11.3%
2,000-3,999	9,345	-18.2%	11,345	-17.8%	13,406	-17.2%
4,000-9,999	7,986	-30.1%	9,782	-29.1%	11,651	-28.0%
10,000+	4,437	-61.2%	5,651	-59.0%	5,940	-63.3%

For a regional scale growth strategy (Option #1 above), VMT reductions could be estimated by comparing tract densities in Seattle to tract densities in other parts of the region. A forecast or vision for regional growth patterns, such as Vision 2040, would dictate the amount of additional growth accommodated in Seattle. To analyze a local growth strategy (Option #2 above), more specific estimates of the amount of growth that could be shifted between density ranges within Seattle would be required. These estimates would ideally correspond to Seattle land use plans or an assessment of the development potential of various neighborhoods.

(Note that increasing population per Option #2 would require analysis not just of VMT implications, and the need for more residential units to be built, but also in terms of services provided and goods transported.)

[12] Source: Polzin et al, 2007, as referenced in *Moving Cooler* Appendix B-17 (Cambridge Systematics 2009)

Combined VMT Strategy Results

The total reductions in light-duty vehicle VMT from the suite of "Mobility, reducing VMT, and shifting travel modes" (PT1) strategies are summarized in Table 9, below. The total shown accounts for overlap among strategies. Note that strategies and VMT reductions do not begin until 2012. Each strategy is described in detail in the following pages.

Table 9. Combined VMT Strategy Reduction

Strategy	Description	% reduction from BAU in light duty vehicle VMT		
		2020	2030	2050
PT1a	Transit	2.8%	6.1%	8.7%
PT1b	Pricing	9.7%	14.5%	19.4%
PT1c	Pay as You Drive (PAYD) Insurance	5.6%	5.6%	5.6%
PT1d	Parking	1.4%	3.5%	8.4%
PT1e	Bicycle & Pedestrian Infrastructure	1.9%	4.1%	6.0%
PT1f	Trip Reduction Programs	0.9%	0.9%	0.9%
	Overlaps among strategies	*-1.1%*	*-1.5%*	*-2.0%*
Total		**19.6%**	**29.5%**	**39.4%**

It is important to emphasize that while we calculate VMT reduction associated with individual strategies in order to estimate total VMT reduction, VMT reduction estimates for individual strategies (and the strategies themselves) should not be viewed in isolation. These strategies work in tandem and have synergistic effects. For example, the ability of pricing strategies to yield high reductions depends on having transit, walk, and bike alternatives for trips to shift to. In that sense, **the combined VMT reduction estimate is more relevant than the individual strategy values.**

Strategy PT1a: Transit

Introduction/Context

Seattle can aspire to much higher transit service and use. In 2009, 20% of Seattle residents took transit to work. In comparison, transit mode share for commuting was 32% in San Francisco and 55% in New York City. Many of the other strategies in this scenario, such as VMT pricing and land use measures to encourage developing compact, "transit communities", will contribute to greater transit use.

To be competitive with personal transportation, transit must be fast, reliable, comfortable, and affordable. Most travelers who have a car at their disposal will take transit only when it offers better travel times than the private vehicle. By increasing the geographic coverage and the frequency of transit service and reducing travel times, this strategy will dramatically increase the attractiveness of transit as a travel mode. Strategies such as reducing transit fares, reducing vehicle headways, improving transit speed and reliability, and improving on-time arrivals produce measurable increases in transit ridership (Litman 2011).

Strategy Ambition

- Increase transit ridership by 5% per year from 2010-2020 (roughly equivalent to the most aggressive scenario in the *Moving Cooler* study heavily referenced for our Carbon Neutral analysis (Cambridge Systematics 2009), then at a constant annual amount (equal to the 2020 increase) per year thereafter.[13] This growth is in addition to anticipated added ridership from the Sound Transit Light Link rail system.
- This increase will be driven by a number of developments, including most importantly:
    - Expansion of the geographic extent of the system
    - Land use changes that focus neighborhoods around high quality transit (Seattle Planning Commission 2010)
    - Increase in the price of driving (see Pay-as-You-Drive, Pricing, and Parking strategies)

Technical Assumptions and Results

- Average transit vehicle passenger loads (number of passengers per vehicle) increase by 12% by 2030. (*Moving Cooler*'s most aggressive scenario assumes that average passenger loads increase by 12% by 2050 (Cambridge Systematics 2009).)
- New transit trips replace light-duty vehicle trips at a rate of 47%, i.e. for every 100 new transit trips 47 LDV trips are removed from the road (APTA 2009). Driving trips shifted to transit are of average length.
- Table 10 and Table 11 summarize the resulting impacts (starting in 2012) on transit and LDV VMT.

Table 10. Transit Results

Percentage Increase from BAU Forecast	2020	2030	2050
Transit Passenger Trips	47.9%	105.5%	148.9%
Transit Vehicle Miles Traveled	45.2%	94.3%	133.1%

[13] For reference, Sound Transit's ST2 Plan envisioned a 2-3% annual increase in ridership to 2030.

Table 11. Light-Duty VMT Results

Percentage Reduction from BAU Forecast	2020	2030	2050
Light-Duty VMT	2.8%	6.1%	8.7%

Strategy PT1b: VMT Pricing

Introduction/Context

Increasing the price of roadway travel provides a direct incentive for travelers to reduce vehicle miles travelled. Roadway pricing also has other benefits, including generating new revenue for transportation projects and programs, and reserving limited roadway capacity for more economically productive uses. Roadway pricing 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.

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 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.

The Seattle region has been the subject of several road pricing studies in recent years. These include a study of tolling options on the SR 520 and I-90 bridges[14], a study of variable tolling (congestion charging) for the City of Seattle[15], and a pilot study of congestion charging in the PSRC region[16]. PSRC also examined road pricing policies in the analysis for its most recent Regional Transportation Plan—*Transportation 2040* (PSRC 2010b).

For the sake of simplicity, this strategy is defined as a flat per mile fee on all of Seattle's roadways, supplemented by an additional charge on congested facilities. The analysis demonstrates the level of GHG reductions that road pricing can produce, while recognizing that there are a wide variety of pricing approaches that could be adopted. Different approaches may have widely different impacts in terms of GHG reductions, congestion reduction, mode shift, revenue generation, and equity impacts.

Strategy Ambition

- We assume a VMT fee is levied on all light-duty travel starting in 2012, increasing to 12 cents per mile (2008 $) by 2020. While we do not suggest that this is necessarily an optimal fee level, it would bring the combination of VMT fee and gas taxes roughly in line with current Western European gas taxes. Implementation might need to occur at a regional or state level. This VMT fee level was assumed in the *Moving Cooler* study as well (Cambridge Systematics 2009).
- We assume the fee rises to 25 cents per mile (2008 $) by 2050.
- We also consider an additional VMT fee will be applied to peak travel on all congested facilities, and posit a 65 cents per mile (2008 $) by 2020, similar to the assumption used in *Moving Cooler* (Cambridge Systematics 2009). Implementation might need to occur at a regional level.
- Note that the 2020 VMT fee alone is equivalent to raising the price of a gallon of gas (for present day vehicles) by $2.50. If the baseline price of driving falls, taxes will have to be higher to achieve the results projected.[17]

[14] http://www.psrc.org/data/research/520-tolling/
[15] http://www.seattle.gov/transportation/docs/FINAL%20Tolling%20Study%20report%20revised%206.25.10.pdf
[16] http://psrc.org/transportation/traffic
[17] Note that effects are modeled assuming that the baseline price of driving remains relatively constant to 2050. Electric vehicles will be cheaper to operate on a per mile basis. If and as the average price of driving falls with greater electrification, the VMT fee would need to be increased by a corresponding amount to achieve the results projected here.

Technical Assumptions and Results

- Current average cost of driving per mile: 60 cents (Cambridge Systematics 2009)
- Price elasticity of VMT: -0.45 (Cambridge Systematics 2009)
- Cross-elasticity of transit trips with respect to price of driving: 0.15 (Litman 2011)
- Proportion of urban VMT congested: 29% (Cambridge Systematics 2009)
- Reduction in total VMT from congestion pricing: 0.7% (derived from *Moving Cooler* (Cambridge Systematics 2009))
- VMT results are presented in Table 12.

Table 12. VMT results

Percentage Reduction from BAU Forecast	2020	2030	2050
VMT Fee: Light Duty VMT Reduction	9.0%	13.9%	18.8%
Congestion Pricing: Light Duty VMT Reduction	0.7%	0.7%	0.7%
Total Light Duty VMT Reduction	9.7%	14.5%	19.4%

In addition to reducing VMT, congestion pricing will also reduce GHG emissions by improving the flow of traffic and reducing the amount of time that vehicles spend idling. The congestion benefits of the strategy could reduce GHG emissions an additional estimated 1.5% (not included here).[18]

[18] Per *Moving Cooler*, 29% of VMT on urban facilities is congested. Congestion pricing reduces fuel consumption by about 5% for priced VMT. 29% x 5% = 1.5%. (See Moving Cooler Appendix B-14) (Cambridge Systematics 2009)

Strategy PT1c: Pay as You Drive (PAYD) Insurance

Introduction/Context

Pay as You Drive (PAYD) insurance is a relatively new concept in transportation pricing. 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 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. Drivers are expected to respond as they would to other per mile fees. Pilot studies of PAYD have been conducted in Oregon, Washington State, and a handful of other locations.

Pay at the Pump (PATP) insurance is an alternative concept, whereby drivers would pay their insurance per unit of fuel consumed rather than per mile. PATP would incentivize the purchase of more fuel efficient vehicles, in addition to encouraging less driving. Some studies have suggested that the two effects combined would produce a greater GHG reduction than PAYD at a comparable pricing level (Green and Plotkin 2010); however, it is unlikely that PATP would reduce VMT as much as PAYD in the long run, given that drivers have an alternative cost saving option. Since the fuel economy of a vehicle is not a factor in insurance risk, there is also less justification for pricing insurance relative to fuel consumption.

Strategy Ambition

- We assume 100% of driver insurance policies are PAYD by 2020. This would likely require implementation at the state level, where vehicle insurance is regulated.

Technical Assumptions and Results

- Current average cost of driving per mile (less insurance): 53 cents (Cambridge Systematics 2009)
- Price elasticity of VMT: -0.45 (Cambridge Systematics 2009)
- Average cost of vehicle insurance per mile: 6.6 cents (Cambridge Systematics 2009)
- Cross-elasticity of transit trips with respect to price of driving: 0.15 (Litman 2011)
- VMT results are presented in Table 13.

Table 13. VMT results

Percentage Reduction from BAU Forecast	2020	2030	2050
Light Duty VMT Reduction	5.6%	5.6%	5.6%

Strategy PT1d: Parking

Introduction/Context

The City manages on-street parking to balance competing needs (transit, customers, residents, shared vehicles), move people and goods efficiently, support business district vitality, and create livable neighborhoods. The Seattle City Council recently approved a new parking policy that raises the maximum rates for on-street parking. The new 2011 rates increased in four neighborhoods, decreased in 11 neighborhoods, and stayed the same in seven neighborhoods, compared to 2010 rates.. The City is now conducting a variable pricing feasibility analysis to look at the possibility of establishing 2012 variable rates for different times of day based on demand,

Higher parking prices in some neighborhoods may or may not decrease the total number of vehicle trips made in Seattle. It is more likely that the policy will reduce the time that motorists spend looking for parking, which will reduce GHG emissions by eliminating some mileage devoted to cruising for parking and by thereby alleviating some roadway congestion.

Other types of parking policies could be considered to focus more specifically on the goal of reducing VMT by charging higher parking fees. Examples of policies that could be considered include maintaining target occupancy rates for on-street parking by further increasing prices and reducing (or not expanding) the number of parking spaces available. Off-street parking prices could be increased by taxing private parking lots. The City could place a moratorium on new private parking lots in the CBD. Seattle could also increase prices for residential parking permits for on-street parking to encourage Seattle residents to reduce levels of car ownership and use alternative modes of transportation.

Strategy Ambition

- Reduce VMT by building upon the City's recently enacted market-based parking management program, and by sending a price signal that discourages (single occupancy) light duty vehicle trips. We model such a policy by assuming that the price of all on-street parking (in the CBD) will increase by at least 25% by 2020, 50% by 2030, and 100% by 2050 either as a result of the city's existing policy or through additional fees that will also generate revenues dedicated to other transport modes to the CBD and urban villages.
- Tax free private parking lots in the CBD with >50 spaces to raise the average trip cost (round trip to/from the CBD) by $2.40 by 2020 (*Moving Cooler*) (Cambridge Systematics 2009), increasing to $4.80 by 2050.
- Institute a policy, such as a City Sticker program, to discourage vehicle ownership in the City (not quantified).
- A policy to ensure no net growth in parking spaces in Seattle's CBD and urban villages, phased in by 2025.

Technical Assumptions and Results

- One-third of parking in Seattle's CBD and urban villages is on-street.
- Trips to and from the CBD and urban villages account for 30% of urban VMT. This is double the estimate in *Moving Cooler*, which only includes the CBD trips (Cambridge Systematics 2009).
- VMT results are presented in Table 14.

Table 14. VMT results

Percentage Reduction from BAU Forecast	2020	2030	2050
Total Light Duty VMT Reduction	1.4%	3.5%	8.4%

Strategies PT1e: Bicycle Infrastructure and Pedestrian Infrastructure

Introduction/Context

The term "Complete Streets" refers to streets that are equally accessible to motorized vehicles, bicyclists, and pedestrians of all ages. Rather than emphasizing throughput of cars alone, Complete Streets provide safe and comfortable facilities for walking, biking and taking transit, including dedicated bike lanes, wider sidewalks, narrower pedestrian crossings, trees and street furniture, convenient transit stops, and traffic signals that allow for safe and efficient movement by all modes of travel.

Providing infrastructure intended for bicyclists and pedestrians is a key component of Complete Streets. Well-maintained sidewalks and bike lanes encourage more people to walk or bike for their shopping and work trips, but they are also indispensable components of a broader multi-modal transportation strategy. Complete Streets enable pricing, transit, land use, and demand management programs to realize their full potential by providing the means for travel by alternative modes. In addition to supporting trips mode solely by bicycle or foot, bicycle and pedestrian infrastructure also supports transit trips that begin with a walk or bike trip.

Much of the measurable benefit of these strategies is subsumed in the benefits of other quantified strategies. The reductions calculated specifically for this measure should be understood as additional reductions.

Strategy Ambition

- Bike stations at all major activity centers and transit hubs by 2020 (adapted from *Moving Cooler* Scenario C (Cambridge Systematics 2009)).
- Bike network at 1/4 mile spacing citywide by 2050, i.e. 8 miles of bike lanes, bike trails, or bicycle boulevards per square mile (from *Moving Cooler* Scenario C (Cambridge Systematics 2009)).
- Full implementation of Seattle Bicycle Master Plan.
- Resulting length and density of bike lanes, boulevards, and trails are shown in Table 15, below.

Table 15. Bike lane characteristics[19]

Characteristic	2007	2017	2050
Miles of bike lanes, boulevards, and trails	65	219.6	664
Density of bike lanes, boulevards and trails per square mile	0.78	2.65	8

- Bicycle trip share goals are derived as follows:
  - 2017 – from Seattle Bicycle Master Plan (2007)—triple number of 2007 bicycle trips.
  - 2030 – roughly equivalent to the highest mode share achievable in dense urban areas under *Moving Cooler*'s most aggressive assumptions (high gas price and full build out of 2050 bicycle network) (Cambridge Systematics 2009); however *Moving Cooler*'s results only account for the mode shift impact of dedicated bike lanes. We believe that a 20% goal by 2030 is achievable with the additional impact of sharrows, bike signage, bike stations, and other supporting infrastructure and programs. For reference, the San

[19] Sources: 2007, 2010, and 2017 from Seattle Bicycle Master Plan (City of Seattle 2007). 2050 from Strategy Ambition above. Seattle encompasses 83 square miles, per U.S. Census.

Francisco Board of Supervisors is proposing a 20% bicycle mode share goal for 2020, up from 6% today.[20]

- 2050 – 30% bike trip share represents a significant stretch goal for Seattle, but one that is achievable in the long term. Present day such mode shares are seen only in a few European cities. This transformational case might include significant technological changes, such as widespread availability of electric bicycles, not captured in the policy assumptions above.

- The pedestrian strategy includes the following elements:
  - "Complete Streets" in all new developments (Cambridge Systematics 2009) – i.e. all new developments have buffered sidewalks on both sides of the street, marked/signalized pedestrian crossings at intersections on collector and arterial streets, and lighting. New or fully reconstructed streets incorporate traffic calming measures such as bulb-outs and median refuges to shorten street-crossing distances.
  - Audit and retrofit existing streets within 1/2 mile of transit stations, schools, and business districts for pedestrian accessibility by 2020 (Cambridge Systematics 2009) – i.e. curb ramps, sidewalks, cross-walks and extensive traffic calming measures.
  - These policies are consistent with the Seattle Pedestrian Master Plan, though that document does not provide specific quantified goals for the type and scope of pedestrian improvements.

Technical Assumptions and Results

- Current Seattle Bicycle Commute Trip Share: 3%[21]
- Baseline bicycle commute trip share remains at 3% to 2050
- Commute bike trip shares are assumed to represent all trip shares
- Each 1% shift of driving trips to bicycles reduces VMT by 0.5% (bicycle trips are about half the length of an average trip, per PSRC 2006 household travel survey) (Cambridge Systematics 2007) . We project that with increasing bicycle ridership, average trip lengths will decrease to 1/3 of driving trips by 2050, as bikes are used more extensively for short and non-commute trips.
- Bicycle goals and trip shares, and corresponding LDV VMT reductions are presented in Table 16.

Table 16. Bicycle Strategy Results

Results	2017	2030	2050
Bicycle Trip Share Goal	9.0%	20.0%	30.0%
Bicycle Trip Share Baseline	3.0%	3.0%	3.0%
Bicycle Trip Share Increase from Baseline	6.0%	17.0%	27.0%
VMT Decrease from Baseline (Cars and Light Trucks)	1.3%	3.5%	5.4%

- Pedestrian improvements will produce a 0.6% reduction in VMT in urban areas (Cambridge Systematics 2009)
- Each 1% shift in driving trips to walk trips reduces VMT by 0.2% (walk trips are about one fifth the length of an average trip, per PSRC 2006 household travel survey)

[20] http://sf.streetsblog.org/wp-content/uploads/2010/10/Bicycling-20-Percent-by-2020.pdf
[21] U.S. Census Bureau. 2009 American Community Survey. http://www.census.gov/acs/www/

- 78% of passenger car VMT are SOVs (estimated from PSRC 2006 household survey (Cambridge Systematics 2007))
- We calculate just the shift from driving trips to walking trips, assuming that all of the affected driving trips are SOV
- VMT and mode shift results are shown in Table 17 and Table 18, respectively.

Table 17. Bike and Pedestrian VMT Results

Percentage Decrease from BAU Forecast	2020	2030	2050
Light Duty VMT Reduction	1.9%	4.1%	6.0%

Table 18. Pedestrian Mode Shift Results

Percentage from BAU Forecast	2020-2050
SOV Trips Shifted to Walking	4.2%

Strategy PT1f: Trip Reduction Programs

Introduction/Context

Trip reduction programs include a wide variety of initiatives to encourage, incentivize, and support Seattle workers and residents in using alternative modes of transportation. Many traditional trip reduction programs have focused on commute trips, with programs typically administered by or through employers. Program elements include rideshare assistance, Guaranteed Ride Home, amenities for bicyclists and pedestrians, onsite transit pass sales and transit subsidies, employee shuttles, alternative work schedules and telecommuting programs, and marketing and personalized assistance for use of alternative modes.

A few cities now have trip reduction programs focused on households, which may affect commute and non-commute trips such as King County's In Motion and Portland's Smart Trips programs. In both cases, the local government conducts outreach to a distinct set of households each year to inform them about their alternative travel options. Outreach includes informational mailings, tailored information on alternative mode options, and promotional events. Seattle already has robust trip reduction initiatives in the state-mandated Commute Trip Reduction (CTR) program, which requires large employers to provide commuter benefits programs, and King County's In Motion. Another commuter program focused on smaller employers, the Growth and Transportation Efficiency Center (GTEC) program, operated in 2008 but has been suspended due to lack of funds. Seattle could achieve modest additional VMT reductions through expansion and re-funding these existing programs. For analytical purposes, we assume that this strategy emphasizes commute trip reduction for small employers.

Strategy Ambition

- All employers with fewer than 100 employees implement robust commuter benefits programs by 2020. (Employers with more than 100 employees are excluded. These are already covered by Seattle's successful CTR program, which requires these employers to provide commuter benefits).
- Affected employers subsidize 65% of employees' transit fares.
- Affected employers provide all of the following benefits: transit subsidies, vanpool subsidies, carpool subsides, bike subsidies, walk subsidies, carpool matching services, Guaranteed Ride Home, a vehicle provided by the organization for employee trips, flexible work hours, compressed work week, and formal telework program.
- Many small employers would struggle to provide these levels of benefits on their own. Therefore, the strategy assumes that a public agency provides resources and support targeted to small employers. Seattle's GTEC program was established to do just that, but has been suspended due to lack of funding. If smaller employers are unable to achieve the reductions assumed in this strategy, additional reductions may come from larger employers.

Technical Assumptions and Results

- 58% of employees work for an establishment with less than 100 employees[22]
- 25% of all person trips are commute trips (Cambridge Systematics 2009)[23]
- Program implementation reduces drive-alone mode share by 3.5% and increases transit mode share by 4.9% at affected employers.[24]

VMT results are presented in Table 19.

[22] 2006 County Business Patterns, national average. Available online at: http://www.census.gov/econ/cbp/index.html.
[23] Based on: *Commuting in America III: The Third National Report on Commuting Patterns and Trends* (Transportation Research Board 2006).
[24] Based on an analysis that ICF conducted of three employment zones in San Francisco, using the TRIMMS© model.

Table 19. VMT Results

Percentage Reduction from BAU Forecast	2020	2030	2050
Total Light Duty VMT Reduction	0.9%	0.9%	0.9%

Strategy PT2: Electrification

Introduction/Context

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. The City is already preparing electric vehicle infrastructure through Seattle City Light research, the Plug-In Ready Project, and revision to electrical codes to require residential buildings to develop capacity for EV charging stations (OSE & SCL 2009), and planned investment of up to $20 million for charging station infrastructure.[25,26]

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. For example a recent U.S. DOT report to Congress, projected that the level of GHG benefits in 2050 would be comparable under electric vehicle (78-87% GHG reduction per vehicle) or hydrogen fuel cell (79-84% GHG reduction) pathways (U.S. DOT 2010). We selected the electric vehicle pathway for this scenario because of the current interest and infrastructure investment in Seattle and the region.

Strategy Ambition

- Table 20 provides our assumptions for the penetration rate of light-duty electric-drive vehicles under the carbon neutral scenario, assuming electrification begins in 2012. We drew these rates from a review of the current literature on vehicle electrification and potential rates of change, as illustrated in Table 21. In general, the more aggressive scenarios are in congruence. The stock change assumptions are consistent with those of the Electrification Coalition (Electrification Coalition 2009) and (Yang, C. et. al. 2009), who project that as much as 84% of LDV stock could be electric by 2050. This estimate is similar to the Union of Concerned Scientists' analysis wherein 80% of all vehicles sold in 2040 would be electric (Friedman 2010). While our assumptions are more aggressive than some studies shown in Table 21, those studies focus on the U.S. as a whole. We assume that in an urban region, particularly one dedicated to achieving carbon neutrality and already developing EV infrastructure, electric vehicles can be introduced at the more ambitious rates.

Table 20. Electrification assumptions

	2020	2030	2040	2050
Share of new vehicle sold in that year that are electric only (market sales)				
Share of all vehicles on the road in that year that are electric only (stock)	5%	40%	70%	80%

[25] Funding for this infrastructure development has been awarded through two sources. In August 2009, the U.S. Department of Energy (DOE) awarded a grant to Electric Transportation Engineering Corporation (eTec). Furthermore, through the American Recovery and Reinvestment Act, U.S. DOE has awarded the Puget Sound Clean Cities Coalition a grant for alternative fuel and vehicle projects in the region, $1.4 million of which will be used for EVs and charging infrastructure in Seattle.

[26] http://www.pscleanair.org/news/newsroom/releases/2009/08_26_09_Clean_Cities_Receives_$15_million.aspx

Table 21. Studies addressing electric vehicle penetration rates

Study	Vehicle Type	Projected Market Sales	Projected Stock	Notes
(Friedman 2010)	Car and light truck	3-5% by 2020, 15% by 2025, 80% by 2040		
(Electrification Coalition 2009)	LDV	25% by 2020, 90% by 2030, then flatten and asymptote to max. sales penetration rate estimated at 95%	5% by 2020, 42% by 2030, 70% by 2040	"grid enabled vehicles" (PHEV or EV)
(Becker, Sidhu, and Tenderich 2009)	Light-vehicle	baseline: 3% by 2015, 18% by 2020, 45% by 2025, and 64% by 2030; high oil price scenario: 90% by 2030		
(U.S. DOT 2010)	LDV		56% by 2050	Assume BEV market no larger than PHEV market in long run
(Yang, C. et. al. 2009)	LDV		84% by 2050	
(IEA 2010)	Passenger LDVs	FCV reach nearly 20% by 2050; EVs/PHEVs reach nearly 50% by 2050		global
	Trucks	FCVs reach nearly 20% sales of large trucks by 2050, PHEVS: 5-10%, CNG: about 15%		
(Seattle City Light 2010a)	Passenger LDVs	baseline: 49% by 2029 aggressive: 79% by 2029		

Technical Assumptions and Results

- Rather than modeling hybrid electric vehicles as a separate category, the model will focus only on electric vehicles.
- Electric energy consumption for light-duty vehicles is initially assumed to be equal to EPA rating of the 2011 Nissan Leaf. Efficiency improvements are assumed over time, reaching the U.S. DOT rate by 2050. These electricity consumption rates are presented in Table 22.

Table 22. Electricity consumption of LDV EVs

Model/Study	Electricity Consumption (kWh/mi)	Notes
2011 Nissan Leaf	0.34	Depending on source. EPA rating is 34 kWh per 100 mi
2011 Chevy Volt	0.36	EPA rating is 36 kWh per 100 mi
(U.S. DOT 2010)	0.26	100 to 200 mi operating range; assume same efficiency as PHEVs in the long run

Strategy PT3: Fuel Economy

Introduction/Context

In addition to decreasing the amount of driving that occurs in the Seattle area, another important strategy for decreasing GHG emissions associated with vehicle use is consuming less fuel per mile. Vehicle fuel economy has consistently improved over time, and as the result of federal Corporate Average Fuel Economy (CAFÉ) regulations. State-level initiatives have, in turn, been the major drivers of CAFÉ standards. The recent CAFÉ amendments to move to 36 mpg for new vehicles by 2016 are a direct consequence of state clean car standards, passed in Washington State in 2005, and originally spawned by California through its AB 1493 "Pavley" bill signed in 2002. Similarly, Seattle can spur the state of Washington to join California, where the Air Resources Board (ARB) is considering new standards that would increase new vehicle fuel economy by between 3 and 6 percent a year from 2017 to 2025, to as high as 62 miles per gallon in 2025. ARB will announce its new vehicle standards this fall, along with the Obama administration (U.S. EPA and the National Highway Traffic Safety Administration) who is considering a similar range[27].

Strategy Ambition

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. We model this level of improvement based on proposed state and federal standards, as well as a recent Pew study scenario as described below.

Technical Assumptions and Results

- Assume federal action on fuel economy is consistent with the initial assessment of potential LDV model year (MY) 2017-2025 scenarios[28].
- In conjunction with a Notice of Intent (NOI) by the EPA and NHTSA to develop new standards for LDV, the agencies (supported by research from the California Air Resources Board (CARB)) have released a Joint Technical Assessment Report (TAR) (U.S. EPA, and CARB 2010). The TAR analyzed four potential GHG targets representing reductions from the MY 2016 fleet-wide average of 3, 4, 5, and 6% per year. These reductions are equivalent to a range of 47 to 62 mpg in MY 2025 vehicles.
- The 5% reduction per year pathway focuses on advanced gasoline vehicles and mass reduction, and is roughly equivalent to a 56 mpg fleet average. While the 6% pathway does consider electric vehicles, to avoid double counting, we do not include this additional efficiency as benefits from EVs are represented elsewhere in our analysis. As this fuel economy is associated with new MY 2025 vehicles, it will take many ten years for the average vehicle stock to turn over, and degradation of performance will occur as vehicles age.
- Therefore, in the carbon neutral scenario, we adopt a fuel economy trajectory for the light duty fleet that is perhaps slightly less aggressive, based on the medium mitigation scenarios from a recent Pew study (Greene and Plotkin 2011), reaching 38 mpg by 2035 and 53 mpg by 2050. The advantage of this scenario estimate is that it relies only on hybrid electric (not plug-in) and advanced standard ignition vehicles, and thus does not overlap with the electrification strategy. We assume improvements do not begin until 2015.

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[27] Jason Plautz, *Calif. Will align GHG standards timeline with EPA,* E & E News PM, January 24, 2011 (subscription required)
[28] http://epa.gov/otaq/climate/regulations/ldv-ghg-noi.pdf

Strategy PT4: Biofuels

Introduction/Context

Current (i.e., "first generation") biofuels are largely produced from food crops (e.g., corn, soy, oil seeds) and are limited in their ability to reduce greenhouse gases. Producing biofuels from food crops may result in increasing demands for land, and thus increasing emissions from clearing land, either directly to produce the biofuel crop or indirectly to produce crops that were diverted from other areas to meet the biofuel demand (Fargione, Plevin, and Hill 2010). Second-generation biofuels, derived from non-food sources (e.g., lingo-cellulosic materials like cereal straw or forest residues), avoid some of these challenges and are generally considered to be less GHG-intensive than first-generation biofuels, though few are available at commercial scale. 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).

Interest in biofuels in the Seattle area is high. The region has been cited has having the highest per-capita use of biodiesel in the country[29], a demand that has helped encourage several biodiesel producers to locate in the region, including a facility in Seattle (Seattle Biodiesel), a large facility in Grays Harbor, Washington (Imperium Renewables), and a number of smaller facilities throughout the state. Several ethanol facilities are in planning or construction, though the world economic recession has stalled many plans.[30] Washington State University is conducting research on biofuels, including methods and varieties for growing oil seeds (e.g., canola, mustard) for biodiesel feedstocks. Several biofuel start-ups also exist in the Seattle area, including several focused on algae biofuels.

Our carbon neutral Seattle scenario includes phasing out of most first-generation biofuels, while increasing use of second-generation, low-greenhouse gas biofuels in both light-duty and heavy-duty vehicles. We do not include any third-generation (algae) fuels due to the fact that these fuels are still in the early stages of development. To the extent these fuels can be developed with GHG-reduction potential near the maximum envisioned, greenhouse gas emissions could be reduced even further.

Strategy Ambition

We make the following assumptions (summarized in Table 23) regarding penetration of biofuels under an aggressive carbon neutral strategy. We assume that the introduction of best first generation biofuels begins in 2012.

Table 23. Emissions savings and penetration of biofuels

Biofuel	Emissions savings relative to petroleum fuels	Share of fuel content (on energy basis)		
		2010	2030	2050
Gasoline Substitutes				
Corn ethanol	0%	5%	0%	0%
Best first generation (Sugarcane ethanol or equivalent)	60%	0%	50%	0%
Second generation (Cellulosic ethanol or equivalent[31])	70%	0%	0%	100%[32]

[29] http://www.harvestcleanenergy.org/biofuel/index.html
[30] Per (Yoder et al. 2008) and recent news reports.
[31] By "equivalent", we assume that various ligno-cellulosic feedstocks (e.g., switchgrass, forest residues) would be able to produce biofuels with similar greenhouse gas intensities.

Biofuel	Emissions savings relative to petroleum fuels	Share of fuel content (on energy basis)		
		2010	2030	2050
Diesel Substitutes				
Best first generation (oil-seeds)	60%	0%	50%	0%
Best second/third generation (algae or cellulosic)	70%	0%	0%	100%

Technical Assumptions and Results

Both the California Air Resources Board (CARB) and the US Environmental Protection Agency (EPA) have conducted extensive analyses of biofuels, including assessments of the potential for indirect land use change inherent in biofuel production. In our scenario, we estimate the emissions of biofuels by using the EPA's (EPA 2010) assessment of relative emissions reductions of biofuels.[33] We use the EPA analysis primarily because it includes a broader suite of biofuels than did the CARB analysis. Furthermore, a recent review of these two analyses conducted for the Washington State Department of Ecology concluded that the CARB analysis had significant limitations and that the EPA analysis, though also limited, was more "comprehensive" (TIAX LLC 2010).

Table 24 below presents emissions from biofuels relative to the comparable petroleum fuel. All emissions from the EPA (2010) analysis are conducted for a new plant in the year 2022.

Table 24. Life-cycle GHG Emissions for Select Biofuels Compared to Petroleum Fuels (U.S. EPA 2010a)
(Figures assume a new plant operating in the year 2022)

Biofuel	Generation	% Reduction in GHG emissions (tCO2e/MMBtu) Compared to Petroleum Fuels	Description of Fuel and/or Key Assumptions	Market Status
Gasoline Substitutes				
Corn ethanol	First	-21%	Assumes a natural gas fired ethanol plant[34]	In production currently
Sugarcane ethanol	First	-61%	Assumes made in Brazil and that crop residues are	In production currently

[32] We assume, based on review of the technology roadmaps for biofuels produced by the IEA (IEA 2008), that deployment of second-generation biofuels can proceed rapidly such that sales are limited only by land availability after the middle part of the 2030s. While land availability may be a very real concern and indeed a limiting factor, in our scenario here we assume that biofuels are a back-up fuel where full vehicle electrification is not possible, and so resource constraints (e.g., land availability) are not a limiting factor.

[33] Our baseline and carbon neutral scenario includes only the "tailpipe" emissions associated with gasoline and diesel, to be consistent with existing GHG inventory practice. The EPA's relative emission factors for biofuels are relative, however, to the full life-cycle (including production and transportation) of the petroleum-based fuels. As a result, our assessment slightly underestimates full life-cycle emissions from both petroleum-based and biofuels.

[34] EPA results indicate a coal-fired ethanol plant would result in an estimated 1% reduction in GHG-intensity.

Biofuel	Generation	% Reduction in GHG emissions (tCO2e/MMBtu) Compared to Petroleum Fuels	Description of Fuel and/or Key Assumptions	Market Status
			not collected and burned as process energy[35]	
Switchgrass ethanol (thermo-mechanical)	Second	-72%[36]		Not yet at commercial scale
Diesel Substitutes				
Soy biodiesel (other oil seeds)?	First	-57%		In production currently
Biodiesel from other oil seeds (e.g. canola or camelina)	First	-51% [37]		In production (canola) or demonstration (camelina)
Waste grease biodiesel	First	-86%		In production currently but limited scale
Switchgrass	Second	-71%	Fischer-Tropsch Process	May be at commercial scale within 5 to 10 years and could be the dominant fuel by 2050[38]
Algae	Third	-72%[39]	Assumes produced in a photobioreactor (PBR) using near-optimal algae	Early stages, with dozens of start-up companies globally[40]

Because the emission reductions in the table above are calculated assuming highly efficient, new, future facilities, they are not necessarily representative of emissions of currently available biofuels. Therefore, we use a different assessment of the current biofuels (e.g., corn ethanol and soy biodiesel) currently in use in small quantities and which we phase out in our scenario. In particular, we assume that corn-based ethanol has the *same* emissions intensity as gasoline[41] and that soy-based biodiesel is 12% less emissions-intensive than diesel.[42] We assume that waste grease biodiesel, a very small portion of the current biodiesel supply, has the same emissions reduction as estimated by EPA (2010).[43]

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[35] EPA results indicate that if crop residues are collected and burned as process energy, the reduction can be 91%.
[36] According to the EPA report, a biochemical process to produce switchgrass ethanol could result in a 110% reduction in GHG emissions due to the generation of surplus electricity that displaces GHG-intensive grid electricity. Given that our carbon neutral Seattle scenario analysis includes aggressive state and federal action for reducing greenhouse gas emissions, the electricity displaced by such a process would be lower than assumed in the EPA analysis and so the 110% reduction is not consistent with our scenario and so not used here.
[37] Based on a supplemental determination by EPA for canola biodiesel, available at http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2010-0133-0087.. EPA will also be conducting a life-cycle assessment of camelina in the near future.
[38] Per (IEA 2009) and (Sims et al. 2008)
[39] GHG emissions could be reduced further if the maximum level of photosynthetic productivity was achieved.
[40] Per EPA (2010) and (IEA 2009)
[41] Based on review of the CARB (2009) life-cycle results for the current average Midwest ethanol plant having slightly *higher* emissions than gasoline. The EPA (2010) analysis also shows that a coal-fired ethanol plant, even in 2022, would also produce a fuel with higher life-cycle emissions than gasoline.
[42] Based on review of an update to CARB (2009) for soy biodiesel (CARB 2009) of 83.25 gCO2e/MJ, compared to ultra low sulfur diesel of 94.71 gCO2e/MJ as in CARB (2009).
[43] Values for biodiesel from used cooking oil were similar in CARB (2009).

Freight Transportation

Baseline Activity

Base year data (2008)

- Freight transportation includes Medium and Heavy Duty Trucks (MDV and HDV).
- **Activity:** For the base year (2008), we use estimates for VMT for MDV and HDV, provided by PSRC[5],[6] with the same origin-destination pair approach used for passenger transportation.
- Load factors for MDV and HDV are presented in Table 25, and assume one commercial truck driver per vehicle is typical.
- **Efficiency:** We draw vehicle fuel economy (mpg) from the EIA's 2010 Annual Energy Outlook (U.S. EIA 2010). See Table 27.
- **Fuel choice/technology:** We assume baseline fuel mix is 100% diesel in freight trucks (adapted from AEO (U.S. EIA 2010))[11].

Baseline Scenario Projections:

- **Activity**: We project VMT to grow at the rates forecast by PSRC, by mode, for the Transportation 2040 study for MDV and HDV[5,6]. See Table 26.
  - No changes in vehicle load factors
- **Efficiency:**
  - We estimate changes in vehicle fuel economy (mpg) based on AEO 2010 projections through 2035 (U.S. EIA 2010). We assume MDV and HDV (combined into Commercial Trucks) improve according to freight truck efficiencies to 2035, and continue to improve at the same rate to 2050. Commercial truck fuel economy is shown in Table 27.
- **Fuel choice/technology:** No change from base year.

Existing Local Actions (beyond the baseline scenario):

- None identified with significant impact.

Table 25. Load factors (people per vehicle)

Vehicle Type	2050
Med Truck	1
Heavy Truck	1

Table 26. Baseline VMT (million VMT)

Vehicle Type	2008	2020	2030	2050
Med Truck	310	350	382	446
Heavy Truck	414	445	476	548

Table 27. Baseline fuel economy (mpg)

Vehicle Type	2008	2020	2030	2050
Commercial Truck	6.0	6.6	6.9	7.3

Strategy FT1a: Pricing

Introduction/Context

Increasing the price of road transportation would reduce freight VMT in the same way that pricing road travel reduces passenger VMT. Freight VMT is generally understood to be less elastic than passenger VMT for several reasons. A smaller proportion of freight trips can be classified as discretionary. For some commodities, consumers will more readily absorb higher transportation costs rather than reduce consumption; however, higher transportation costs could encourage shippers to consolidate trips in larger vehicles or make more efficient use of the freight capacity of existing vehicle trips. Responses depend on the individual commodities being transported.

This strategy would impose the same VMT fees on heavy duty vehicles as Strategy PT1b imposes on light-duty vehicles. Since only the portion of trips within Seattle would be charged, long haul trips with origins or destinations outside of the Seattle region are unlikely to be affected.

Strategy Ambition

- This strategy models VMT pricing as a VMT fee of 12 cents per mile (2008 $) on all heavy-duty travel by 2020. This is the same fee level modeled in *Moving Cooler* (Cambridge Systematics 2009). The fee will increase to 25 cents per mile (2008 $) by 2050.
- We also analyze an additional VMT fee to peak travel on all congested facilities—65 cents per mile (2008 $) – by 2020.. This level is also drawn from *Moving Cooler* (Cambridge Systematics 2009).

Technical Assumptions and Results

- Current average cost of heavy-duty truck operation per mile: $1.73 (ATRI, Operational Costs of Trucking, 2009)
- Price elasticity of freight VMT: -0.25 (Small and Winston (1999) quoted in (Litman 2011)
- Proportion of urban VMT congested: 29% (Cambridge Systematics 2009)
- Reduction in total VMT from congestion pricing: 0.7% (derived from *Moving Cooler* (Cambridge Systematics 2009))
- VMT results are presented in Table 28.

Table 28. VMT results

Percentage Reduction from BAU Forecast	2020	2030	2050
VMT Fee: Freight VMT Reduction	1.5%	2.3%	3.1%
Congestion Pricing: Freight VMT Reduction	0.7%	0.7%	0.7%
Total Freight VMT Reduction	2.1%	2.9%	3.7%

In addition to reducing VMT, congestion pricing will also reduce GHG emissions by improving the flow of traffic and reducing the amount of time that vehicles spend idling. The congestion benefits of the strategy could reduce GHG emissions an additional estimated 1.5% (not included here).[44]

[44] Per *Moving Cooler*, 29% of VMT on urban facilities is congested. Congestion pricing reduces fuel consumption by about 5% for priced VMT. 29% x 5% = 1.5%. (See Moving Cooler Appendix B-14) (Cambridge Systematics 2009)

Strategy FT1b: Road to Rail

Transportation of freight by rail is typically far more fuel efficient than transportation by truck. One study of 23 freight shipping corridors found that rail transportation was between 1.9 and 5.5 times more fuel efficient per ton-mile than truck transportation.[45] With significant fuel savings come significant reductions in GHG emissions.

The majority of GHG emissions from long-haul freight transportation are not included in Seattle's GHG inventory and under the accounting framework used for this study. Therefore we do not quantify this strategy. However, the City can contribute to a less GHG intensive national freight transportation network by encouraging use of rail for freight transportation.

The Port of Seattle has access to rail facilities that provide a viable alternative for freight bound on long distance trips to and from the Port. Key initiatives for facilitating rail transportation include infrastructure improvements that better connect the Port to the rail mainlines. Current projects include grade-separating rail tracks to reduce congestion near the Port.[46]

Strategy FT1c: Smaller Trucks

A potentially important opportunity for reducing fuel consumption and associated GHG emissions from freight trucks is "right-sizing" a fleet, thereby avoiding the use of trucks that are larger or more powerful than necessary (Environmental Defense Fund 2010). However, we have yet to find studies that have evaluated the potential benefits of such a strategy, therefore, we have not attempted to quantify potential emission savings.

[45] ICF International for Federal Railroad Administration, Comparative Evaluation of Rail and Truck Fuel Efficiency on Competitive Corridors, 2009.
[46] http://www.portseattle.org/community/development/regionaltransport.shtml

Strategy FT2: Electrification

Introduction/Context

As discussed previously under Strategy PT2, electrified transport can be a powerful strategy for creating a cleaner fleet. Seattle is already involved in, and continues to expand, investment in and development of charging infrastructure to accommodate anticipated and encouraged growth in electric vehicles.

Strategy Ambition

- Electrifying larger trucks poses greater technical challenges than passenger vehicles. For example, range requirements for long-haul trucks, as well as limited recharging times, challenge the feasibility of BEV for heavy-duty applications (U.S. DOT 2010). Therefore, smaller, localized truck fleets (such as those previously described in Strategy FT1c) are most conducive to electrification, and are considered the best candidates for electrification in this study.
- Given these greater challenges, we adopt a more moderate goal than for passenger fleets. Accordingly, we assume a greater fraction of MDV (2/3 of passenger potential) than HDV (1/3 of passenger potential) will be electrified. It is worth noting that, particular for long-range heavy-duty trucks, electrification can be considered a proxy for hydrogen fuel cells, which have a similar emission saving potential but may be more suitable for this application given the previously noted constraints. Hydrogen for fuel cells could be generated from electricity and would therefore have roughly equivalent life cycle emissions as electrification. The penetration of electrified medium- and heavy-duty vehicles is shown in Table 29, and does not begin to take effect until 2012.

Table 29. Electrification assumptions

	2020	2030	2040	2050
Share of LDV stock that is electric only	5%	40%	70%	80%
Share of MDV stock that is electric only	3%	27%	47%	53%
Share of HDV stock that is electric only	2%	13%	23%	27%

Technical Assumptions and Results

- Consistent with our approach for passenger transportation, rather than modeling hybrid electric vehicles as a separate category, our analysis only considers electric vehicles.
- Range efficiencies for medium- and heavy duty-trucks (classes 4-7) are presented in Table 30. We assume the efficiency for a class 4-5 truck is representative of MDVs and that class 6-7 is representative of HDVs. We further assume that HDV efficiency will improve over time at the same rate as MDV. The electric energy consumption for medium- and heavy-duty vehicles used in this analysis is shown in Table 31.

Table 30. Range Efficiency of EVs for class 4-7 trucks

Study	Range Efficiency (mi/kWh)	Notes
(Electrification Coalition 2009)	1.5 mi/kWh in 2010 1.8 mi/kWh in 2020	Class 4-5 truck (medium short haul) Assuming 65 kWh battery size and 125,000 mi battery life.
	1.2 mi/kWh	Class 6-7

Table 31. Electricity consumption of MDV and HDV EVs

Vehicle Type	Electricity Consumption (kWh/mi)	
	2010	2020
MDV	.67	.56
HDV	.83	.69

Strategy FT3: Fuel Economy

Introduction/Context

As is the case with passenger vehicles, there is much potential for efficiency improvements in freight vehicles, corresponding to decreased fuel use and GHG emissions.

Strategy Ambition

We assume that a combination of purchasing strategies by Seattle businesses and government together with aggressive action at the state and federal levels, supported by Seattle, achieve significant fuel economy improvements in the freight fleet. Efficiency can be improved in a variety of areas such as engine efficiency, aerodynamic drag, turbocharging and supercharging, low rolling resistance tires, thermal management, waste heat recovery, freight logistics, driver behavior and idling, and product packaging. We model this level of improvement based on a recent Pew study scenario described below.

Technical Assumptions and Results

- The National Academies undertook a study evaluating approaches for reducing fuel consumption in MDV and HDV (Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles 2010). This analysis indicates potential fuel savings of approximately 50% by 2020 for new vehicles. Assuming a 15-year lifetime (NESCCAF 2009), we estimate the savings for the vehicle stock will reach 50% by 2035 for both MDV and HDV.
- Consistent with LDV fuel economy improvements, in the carbon neutral scenario, we adopt a fuel economy trajectory for the freight truck fleet that based on the medium mitigation scenarios from a recent Pew study (Greene and Plotkin 2011). In this scenario, fuel economy increases 25% (compared to the reference case) by 2035, and 35% by 2050. We assume improvements do not begin until 2015.

Strategy FT4: Biofuels

Introduction/Context

As with passenger transportation, fuel switching from fossil fuels to biofuels will yield reductions in GHG emissions associated with freight transport. Refer back to the discussion in Strategy PT4 on the various types and benefits of biofuels substitution. Given our all-diesel baseline freight fleet, only diesel substitutes are pertinent options for medium- and heavy-duty vehicles.

Strategy Ambition

Based on the EPA's assessment of biofuels (detailed in Strategy PT4), we make the following assumptions for freight transportation (presented in Table 32).

Table 32. Emissions savings and penetration of biofuels

Biofuel	Emissions savings relative to diesel	Share of fuel content (on energy basis)		
		2012	2030	2050
Diesel Substitutes				
Best first generation (oil-seeds)	60%	0%	50%	0%
Best second/third generation (algae or cellulosic)	70%	0%	0%	100%

Technical Assumptions and Results

Lifecycle emissions of various diesel substitutes are detailed above in Strategy PT4 (Table 24).

Residential Buildings

Baseline Activity

Base year data (2008)

- **Activity**: Base year Seattle population and number of households (single and multi-family) were provided by PSRC, and are summarized in the Macroeconomic Assumptions section of this document.
    - Residential area (ft.^{2}/household) for single family and multi-family (including midsize (multiplex) and apartments & condos) was derived from SCL's Residential Customer Characteristics Survey (RCCS) (Tachibana 2010).
- **Efficiency**: Base year (2008) final energy use intensities (EUIs) were estimated for the following end-uses based on SCL's Residential Customer Survey (Tachibana 2010), SCL (Seiden and Elliot 2006) and PSE (The Cadmus Group, Inc. 2009) conservation assessments, sales data from SCL and PSE, and the 2008 Seattle Community Greenhouse Gas Inventory:
    - Heating and cooling
    - Water heating
    - Lighting
    - Other (electric and non-electric)
    - Small equipment
- **Fuel choice/technology**: Base year (2008) fuel shares were also estimated for each end-use based on SCL's Residential Customer Survey (Tachibana 2010), SCL (Seiden and Elliot 2006) and PSE (The Cadmus Group, Inc. 2009) conservation assessments, sales data from SCL and PSE, and the 2008 Seattle Community Greenhouse Gas Inventory.
- Residential energy use in the base year, by fuel type and end-use, is presented in Table 33 and Table 35, for single and multi-family buildings, respectively. Correspondingly, SF and MF EUIs are shown in Table 34 and Table 36.

Baseline Scenario Projections:

- **Activity**: Seattle population and the number of households, provided by PSRC, are discussed under Macroeconomic Assumptions.
    - Households are divided into existing (in place in the base year, 2008) and new (new builds after 2008) stock.
    - The natural decline in existing housing stock reflects by the average historical demolition rate for single and multi-family units. These values were calculated from Seattle Department of Planning and Development permitting data.
- **Efficiency**: Baseline changes in energy use intensity by end-use were drawn from AEO through 2035 (U.S. EIA 2010), and extrapolated to 2050 (based on changes 2025 onward). These estimates incorporate the modeled impacts of response to expected fuel price trajectories, recently enacted federal policies (e.g. appliance standards), and other factors[47].
- **Fuel choice/technology**: We assume a continuation of recent trends in fuel switching, as suggested in the RCCS (Tachibana 2010). For example, for existing single family households,

[47] These baseline improvements were applied an as average to both new and existing buildings, though most benefits occur in new buildings, e.g., the impact of improved building codes. Therefore, while the majority of improvements would be in new buildings rather than existing, we apply an average improvement to all building types. We do so because of data limitations (we were not able to find sufficient data to distinguish energy performance of average new and average existing Seattle buildings, and because we apply an average improvement rates (from AEO) that does not disaggregate by vintage.

we assume a continued switch from heating oil to natural gas in existing buildings at the rate of 1% of building stock per year. We also assume a continued shift from electric to natural gas for water heating at a similar rate of 1% of building stock for the next 20 years. These are the two principal fuel conversion trends over the past few decades; fuel shares for other end-uses remain constant in the baseline scenario. Our projections also reflect current preferences for gas water heating in new single family construction (90% gas/10% electric) and for electric water heating in new multi-family units (30% gas/70% electric).

Existing Local Actions (beyond the baseline scenario):

- We include key existing actions with significant emissions benefits: SCL and PSE conservation plans and the EECGB grant retrofit program.
- We do not quantify the impact of other actions that are expected to reduce residential building emissions, such as Seattle's Sustainable Building Policy or specific codes or incentive programs. While alone their direct emissions benefits are relatively small, especially for elements that are fully funded, these actions set the stage for transformative changes that are modeled in the related strategies of the Climate Neutral scenario.

Table 33. Single family residential energy consumption, by fuel and end-use, 2008 (billion BTU)

	End-Use						
Fuel	HVAC	Water Heating	Lighting	Other Elect	Other NonElect	Equip	Total
Electricity	594	984	860	2029	0	0	**4466**
Gasoline	0	0	0	0	0	117	**117**
Natural Gas	4457	1725	0	0	324	0	**6506**
Oil	1632	0	0	0	0	0	**1632**
Total	**6683**	**2709**	**860**	**2029**	**324**	**117**	***12721***

Table 34. Single family residential EUI by end-use, 2008 (thousand BTU/ft.^{2})

HVAC	Water Heating	Lighting	Other Elect	Other NonElect	Equip	Total
26.7	10.8	3.4	8.1	1.3	0.5	**50.7**

Table 35. Multi-family residential energy consumption, by fuel and end-use, 2008 (billion BTU)

	End-Use						
Fuel	HVAC	Water Heating	Lighting	Other Elect	Other NonElect	Equip	Total
Electricity	1239	731	597	1409	0	0	**3975**
Gasoline	0	0	0	0	0	128	**128**
Natural Gas	850	574	0	0	225	0	**1649**
Oil	53	0	0	0	0	0	**53**
Total	**2142**	**1305**	**597**	**1409**	**225**	**128**	***5806***

Table 36. Multi-family residential EUI by end-use, 2008 (thousand BTU/ft.^{2})

HVAC	Water Heating	Lighting	Other Elect	Other NonElect	Equip	Total
14.0	8.5	3.9	9.2	1.5	0.8	**38.0**

Strategy RB1: New Building Design

Introduction/Context

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. The organization Architecture 2030 has challenged the architecture and building community to reduce the energy use of all new buildings by 60% relative to current norms today, and to become "carbon neutral" by 2030. The Seattle 2030 District has begun to gather data from buildings downtown in order to define baselines and energy efficiency improvements, in accordance with meeting the 2030 Challenge[48].

For this strategy, we consider the energy savings that could be achievable through rapid uptake of very low-energy building design and operation in new single- and multi-family buildings. While these building designs are aggressive, similarly ambitious energy savings have been demonstrated (e.g., Passive House[49]) and supported by other studies. For instance, the Zero Net Energy Buildings Task Force has made recommendations for achieving the zero net energy buildings goal in Massachusetts, where well over half of energy savings are expected from efficiency and design [50]. Furthermore, the UK has established a goal of making all new construction "zero carbon" by 2016[51], and the City of Vancouver has set a target for all new buildings to be carbon neutral by 2030[52].

Strategy Ambition

- There are two levels of design: "aggressive" and "deep." By 2015, half of new builds will be built to "aggressive" design levels, ramping up to 100% by 2020. By 2025, new builds will be half "aggressive" and half "deep" design. Finally, by 2030, all new builds will achieve "deep" design levels. The same design levels are applied to single and multi-family households. These penetration rates are shown in Table 37.

Table 37. Penetration (percent) of design levels

Design Level	2008	2010	2015	2020	2025	2030	2050
BAU design	100	100	50	0	0	0	0
Aggressive design	0	0	50	100	50	0	0
Deep design	0	0	0	0	50	100	100
Total	*100*	*100*	*100*	*100*	*100*	*100*	*100*

Technical Assumptions and Results

- Energy savings are based on two new design levels of varying ambition (described in detail below), both of which are less energy intensive than the current stock. These relative savings are derived from the Green Building in North America (GBNA) study (Adelaar, Pasini, et al. 2008) and are presented in Table 38.

48 http://buildingconnections.seattle.gov/2010/06/30/442/
49 http://www.passivehouse.us/
50 http://www.mass.gov/Eoeea/docs/eea/press/publications/zneb_taskforce_report.pdf
51 http://www.decc.gov.uk/assets/decc/White%20Papers/UK%20Low%20Carbon%20Transition%20Plan%20WP09/1_20090724153238_e_@@_lowcarbontransitionplan.pdf
52 http://vancouver.ca/sustainability/climate_protection.htm

- The design levels used in this analysis are based on the two upgrade archetypes presented in the GBNA analysis. Specifically, Super-efficient Building 1 (SE1) and Super-efficient Building 2 (SE2) are used for our “deep” and “aggressive” design levels, respectively. The SE1 archetype represents the best technically available performance levels, assuming the use of state-of-the-art building envelope construction materials and HVAC equipment. SE2 is less aggressive and assumes use of more conventional and cost-effective materials and practices. As such, SE2 is considered more achievable in the short-term while still improving on baseline building performance (Adelaar, Pasini, et al. 2008). Specific characteristics assumed in residential SE1 and SE2 archetypes are detailed in the Appendix in Figure 1 and Figure 2, respectively. Figure 3 further describes these residential archetype assumptions.
- Half of residential equipment becomes electrified by 2050, with the other half (gasoline equipment) remaining untouched.

Table 38. Percent reduction in household energy intensity from baseline by end-use and design level

Design Level	Archetype	HVAC	Water Heating	Lighting	Other Electric	Other Non-Electric
Aggressive	SE2	50	50	75	50	50
Deep	SE1	75	60	75	50	50

Strategy RB2: Building Retrofit and Renovation

Introduction/Context

Contributing nearly 10% of total greenhouse gas emissions in Seattle in 2008, residential buildings represent a significant target for emissions reduction. Furthermore, due to the long lifetime of buildings, it is crucial to retrofit existing stock as it represents a latent mitigation potential with an enduring impact. This is especially critical given a 40-year timeline for reaching a carbon neutral goal for Seattle is less than half the average lifetime of residential buildings.

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. The City of Seattle has been awarded $20 million through the Energy Efficiency and Conservation Block Grant (EECBG) program[53,54] 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 targeted, with half of the EECGB funds planned for single-family retrofits. Various studies support the feasibility of achieving deep (e.g. Passive House level) energy savings in existing buildings[55].

Strategy Ambition

- There are two levels of retrofits: "aggressive" and "deep." From 2011 to 2020, 1% of housing stock is retrofitted to the "aggressive" level annually. From 2016 to 2020, 1% of households are retrofitted to the "deep" level annually, ramping up to 2.5% annually from 2021 onward. In 2050, this represents a total of 10% "aggressive" retrofits, 80% "deep" retrofits, and a remaining 10% untouched. The same retrofits are applied to single and multi-family households. These penetration rates are presented in Table 39, below.

Table 39. Penetration (percent) of retrofits

Retrofit Level	2008	2010	2015	2020	2025	2030	2035	2040	2045	2050
BAU	100	100	95	85	72.5	60	47.5	35	22.5	10
Aggressive	0	0	5	10	10	10	10	10	10	10
Deep	0	0	0	5	17.5	30	42.5	55	67.5	80
Total	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*

Technical Assumptions and Results

- Energy savings are based on percent improvements from Green Building in North America archetypes, and are shown below in Table 40 (Adelaar, Pasini, et al. 2008).
- The retrofit levels used in this analysis are based on the same GBNA upgrade archetypes (SE1 and SE2) described above (Adelaar, Pasini, et al. 2008) and shown in Figure 1 and Figure 2. In HVAC, these retrofit levels are slightly less ambitious than in new designs.
- Half of residential equipment becomes electrified by 2050, with the other half (gasoline equipment) remaining untouched.

53 Funded by the American Recovery and Reinvestment Act of 2009 and awarded by U.S. DOE.
54 http://www1.eere.energy.gov/wip/eecbg.html
55 Wigington, Linda. Affordable Confmort Inc. (ACI). "Deep Energy Reductions in Existing Homes: Strategies for Implementation." ACEEE Summer Study 2008. Asilomar, Pacific Grove, CA.

Table 40. Percent reduction in household energy intensity from baseline by end-use and retrofit type

Retrofit Level	Archetype	HVAC	Water Heating	Lighting	Other Electric	Other Non-Electric
Aggressive	SE2	37.5	50	75	50	50
Deep	SE1	60	60	75	50	50

Strategy RB3: Switch to District Energy (MF) and Heat Pumps

Introduction/Context

This strategy consists of shifting space heating loads to electric heat pumps and district energy, in selected new and existing buildings undergoing retrofits and renovations as described in the prior two strategies. Electric heat pumps take advantage of existing temperature gradients by extracting heat from outside air, ground, or ground water to efficiently 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. District energy is described in greater detail in Strategy ES2, below.

While we introduce highly energy efficient building design early in the carbon neutral scenario timeline, there is a limit to the ambitious action that can be taken immediately due to technical, political, and economic feasibility considerations. Accordingly, under the construction schedule described in Strategy RB1, new households continue to be built at BAU levels until 2020, locking in building stock with current standard building technologies.

To address this building stock, we switch these buildings to district energy and electric heat pump space heating systems approximately 20 years after construction. Ideally, these buildings will be equipped with the infrastructure such as hydronic or forced air systems that can more readily accommodate district energy and heat pump technologies.

Strategy Ambition

Fuel switching targets for this HVAC and water heating are shown in Table 41 and Table 42, respectively.

Table 41. HVAC Fuel Shift
(increasing linearly from 2012 to 2050 unless otherwise indicated)

	Existing	New
Single-Family		
BAU		Switch to 100% heat pump, starting 20 years after construction
Aggressive		50% heat pump, 50% natural gas
Deep	Switch to 100% heat pump by 2050	100% heat pump
Multi-Family		
BAU		Switch to 50% heat pump, 50% district energy, starting 20 years after construction
Aggressive		50% heat pump, 50% district energy
Deep	Switch to 100% heat pump by 2050	50% heat pump, 50% district energy

Table 42. Water Heating Fuel Shift
(increasing linearly from 2012)

	New
Multi-Family	
Aggressive	50% electricity, 50% district energy by 2025
Deep	50% electricity, 50% district energy by 2025

Technical Assumptions and Results

We assume an average coefficient of performance for new heat pumps of 3.0 to reflect a significant penetration of geothermal (ground-source) systems.

Commercial Buildings

Baseline Activity

Base year data (2008)

- **Activity**: Base year Seattle commercial floor space is estimated based on commercial employment per $ft.^2$ (from Census and CBECS data) and commercial employment in 2008 (from PSRC). (Note that this rough estimate of floorspace is illustrative only and is not directly used in the analysis.) Future commercial energy use is projected based on employment levels and relative changes in energy use intensities.
- **Efficiency**: Base year (2008) final energy use intensities (EUIs) were estimated for the following end-uses based on the SCL (Seiden and Elliot 2006) and PSE (The Cadmus Group, Inc. 2009) conservation assessments, PSE sales data, the 2008 Seattle Community Greenhouse Gas Inventory, and DOE's Buildings Energy Data Book (D&R International, Ltd. 2009):
  - Space heating
  - Space cooling
  - Water heating
  - Lighting
  - Appliances
  - Other (electric and non-electric)
  - Small equipment
- **Fuel choice/technology**: Base year (2008) fuel shares were estimated for each end-use based on the SCL (Seiden and Elliot 2006) and PSE (The Cadmus Group, Inc. 2009) conservation assessments, PSE sales data, the 2008 Seattle Community Greenhouse Gas Inventory, and DOE's Buildings Energy Data Book (D&R International, Ltd. 2009).
- Commercial energy use in the base year, by fuel type and end-use, is presented in Table 43.

Baseline Scenario Projections:

- **Activity**: We assume that commercial building area ($ft.^2$) is a direct function of the number of employees. To be consistent with our population and other projections, we also draw employment growth rates from PSRC.
  - Buildings are divided into existing (in place in the base year, 2008) and new (new builds after 2008) stock.
  - The natural decline in existing commercial buildings is represented by a 1% annual decay, similar to the demolition rate of residential buildings.
  - The new building floor space is the sum of the area demolished and the area needed to accommodate employee growth.
- **Efficiency**: Baseline changes in energy use intensity by end-use were drawn from AEO through 2035 (U.S. EIA 2010), and extrapolated to 2050 (based on changes 2025 onward). These estimates incorporate the modeled impacts of response to expected fuel price trajectories, recently enacted federal policies, and other factors.
- **Fuel choice/technology**: Fuel shares remain constant in the baseline scenario.

Existing Local Actions (beyond the baseline scenario):

- We include key existing actions with significant emissions benefits: SCL and PSE conservation plans, the EECGB grant retrofit program, and the Seattle Steam conversion to biomass (in 2009).

- We do not quantify the impact of other actions that are expected to reduce commercial building emissions, such as Seattle's Sustainable Building Policy or specific codes or incentive programs, either because direct emissions savings are small or insufficient data are available.

Table 43. Commercial energy consumption, by fuel and end-use, 2008 (billion BTU)

	End-Use								
Fuel	Space Heating	Space Cooling	Water Heating	Lighting	Appliances	Other Elect	Other NonElect	Equip	Total
District Steam	2432	0	270	0	0	0	0	0	**2702**
Electricity	1853	5019	632	6237	520	1296	0	0	**15557**
Natural Gas	4411	0	1633	0	1386	0	152	259	**7841**
Oil	583	0	116	0	0	0	62	1849	**2610**
Total	**9279**	**5019**	**2651**	**6237**	**1906**	**1296**	**214**	**2108**	***28710***

Strategy CB1: New Building Design

Introduction/Context

Construction of new commercial buildings is anticipated to accommodate the natural turnover of building stock as well as meet the increasing demand in commercial floor space driven by anticipated growth in the number of employees in Seattle. This new building construction represents an important opportunity to introduce highly energy efficient structures to Seattle's built environment. Lawrence Berkeley National Laboratory has led detailed analyses assessing low- and zero-energy strategies for commercial buildings (Coffey, Borgeson, et al. 2009) (Selkowitz et al. 2008).

Strategy Ambition

- There are two levels of design: "aggressive" and "deep." By 2015, half of commercial area will be built to "aggressive" design levels, ramping up to 100% by 2020. By 2025, new commercial area will be half "aggressive" and half "deep" design. Finally, by 2030, all new building will achieve "deep" design levels. These penetration rates are shown in Table 44, below.

Table 44. Penetration (percent) of design

Design Level	2008	2010	2015	2020	2025	2030	2050
BAU design	100	100	50	0	0	0	0
Aggressive design	0	0	50	100	50	0	0
Deep design	0	0	0	0	50	100	100
Total	*100*	*100*	*100*	*100*	*100*	*100*	*100*

Technical Assumptions and Results

- Energy savings are based on two new commercial design levels (described in detail in the Residential Buildings section), both of which are significantly less energy intensive than the current stock. The relative savings of new green building designs are derived from the Green Building in North America (GBNA) study (Adelaar, Pasini, et al. 2008) and are presented in Table 45. Detailed descriptions of the commercial building archetypes, SE1 and SE2, are presented in the Appendix in Figure 4 and Figure 5, respectively. Figure 6 further details commercial archetype assumptions.
- Other technical studies corroborate the practicality of these assumptions. For example, a series of reports by NREL and PNNL demonstrate the ability to achieve 50% reductions in energy use through the design of various types of commercial buildings: large office buildings, grocery stores, general merchandise stores, and highway lodging ((Leach, Lobato, et al. 2010), (Leach et al. 2009), (Hale, Leach, et al. 2009), (Jiang et al. 2009)). Model results for Seattle (a representative city of a marine climate zone) show 54.1% and 57.1% savings in low-rise and high-rise office large office buildings, respectively. Furthermore, these studies conclude that these savings can be achieved in a cost-effective manner, and do not necessarily require on-site generation technology (e.g., PV) ((Leach, Lobato, et al. 2010)).
- Half of commercial equipment becomes electrified by 2050, with the other half remaining untouched (gasoline and oil equipment each halve).

Table 45. Percent reduction in energy intensity from baseline by end-use and design level

Design Level	Space Heating	Space Cooling	Water Heating	Lighting	Appliances	Other Electric	Other Non-Electric
Aggressive	50	45	40	40	40	10	10
Deep	90	60	50	60	50	20	20

Strategy CB2: Building Retrofit and Renovation

Introduction/Context

Commercial buildings represent a notable source of energy consumption and greenhouse gas emissions in Seattle, contributing to 13% of total greenhouse gas emissions in 2008. As described previously in the Residential Buildings strategies, retrofits are critical in ambitiously reducing emissions from the existing building stock. Deep retrofits are achievable and have been demonstrated today, for instance with the "poster child" energy efficiency retrofit of a 1960s federal office building in Denver, which will cut energy use by 70%[56]. Nearly half of the EECGB funding is intended for use in non-residential building retrofits.

Strategy Ambition

- There are two levels of retrofits: "aggressive" and "deep." From 2011 to 2020, 1% of building stock is retrofitted to the "aggressive" level annually. From 2016 to 2020, 1% of buildings are retrofitted to the "deep" level annually, ramping up to 2.5% annually from 2021 onward. In 2050, this represents a total of 10% "aggressive" retrofits, 80% "deep" retrofits, and a remaining 10% untouched. These penetration rates are presented in Table 46, below.

Table 46. Penetration (percent) of retrofits

Retrofit Level	2008	2010	2015	2020	2025	2030	2035	2040	2045	2050
BAU	100	100	95	85	72.5	60	47.5	35	22.5	10
Aggressive	0	0	5	10	10	10	10	10	10	10
Deep	0	0	0	5	17.5	30	42.5	55	67.5	80
Total	100	100	100	100	100	100	100	100	100	100

Technical Assumptions and Results

- Energy savings are based percent improvements from Green Building in North America (GBNA) archetypes, and are shown in Table 47, below (Adelaar, Pasini, et al. 2008).
- The retrofit levels used in this analysis are based on the same GBNA upgrade archetypes (SE1 and SE2) described previously (Adelaar, Pasini, et al. 2008), and shown in Figure 4 and Figure 5. These retrofit levels are slightly less ambitious than new designs in space heating, space cooling, and "other" end-uses.
- Half of commercial non-building related equipment (for landscaping, warehousing, etc.), is electrified by 2050.

Table 47. Percent reduction in energy intensity from baseline by end-use and retrofit type

Retrofit Level	Archetype	Space Heating	Space Cooling	Water Heating	Lighting	Appliances	Other Electric	Other Non-Electric
Aggressive	SE2	37.5	30	40	40	40	0	0
Deep	SE1	70	50	50	60	50	10	10

[56] 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.

Strategy CB3: Switch to District Energy and Heat Pumps

Introduction/Context

This strategy consists of shifting space and water heating loads to electric heat pumps and district energy, in selected new and existing buildings undergoing retrofits and renovations as described in the prior two strategies.

While we introduce highly energy efficient building design early in the carbon neutral scenario timeline, there is a limit to the ambitious action that can be taken immediately due to technical, political, and economic feasibility considerations. Accordingly, under the construction schedule described in Strategy CB1, new buildings continue to be built at BAU levels until 2020, creating a lock-in of inefficient buildings. In order to address this issue, new buildings initially constructed at BAU levels will later be switched to district energy and electric heat pump space heating systems, beginning 20 years after construction. Ideally, these new BAU buildings will be equipped with heat distribution systems (hydronic or forced air) that can more readily accommodate later switching of heat sources to district heat or heat pumps..

Strategy Ambition

Space and water heating fuel switching targets for this strategy are shown in Table 48 and Table 49, respectively.

Table 48. Space Heat Fuel Shift

	Existing	New
BAU		Switch all new BAU buildings to 50% heat pump, 50% district energy, starting 20 years after construction
Aggressive and Deep	Switch 95% of current gas and oil systems to district energy or building-specific heat pumps by 2050	Switch all new buildings to 50% heat pump, 50% district energy by 2025

Table 49. Water Heating Fuel Shift

	Existing	New
BAU	Switch half of current gas and oil systems to district energy by 2030	
Aggressive and Deep	Switch 95% of current gas and oil systems to district energy or electricity by 2050	Switch all new buildings to 50% electricity, 50% district energy by 2025

Technical Assumptions and Results

We assume an average coefficient of performance for new heat pumps of 3.0 to reflect a significant penetration of geothermal (ground-source) systems.

Energy Supply

Baseline Activity

For electricity supply, we presume that Seattle City Light can maintain its supply of carbon neutral electricity through anticipated additions of new wind, geothermal, and other renewable resources, as outlined in its 2010 Integrated Resource Plan (Seattle City Light 2010b). This situation would be true in both the Baseline and Carbon Neutral scenarios. Under the Carbon Neutral scenario, we find that electricity savings from accelerated electricity efficiency improvements in buildings outpace the added electricity demands from vehicle electrification, and switching to electric heat pumps in buildings. Therefore, the CN scenario does not increase overall electricity loads. However, it does change the characteristics of this load – such as its seasonal and time of use peaks– as well as the system infrastructure requirements to respond to the more intense and distributed demands of a "plug-in" electric vehicle fleet.

Strategy ES1: Distributed Electricity Production

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[57]. 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.[58]

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[59], a figure that represents nearly a quarter of Seattle's electricity demand in 2008.

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

[58] 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

[59] 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.).

Strategy ES2: District Energy

Introduction/Context

District energy systems produce hot water, steam or chilled water at a central location and distribute this energy to multiple buildings through underground pipes. District energy 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. District energy systems are widespread in Northern Europe, delivering over 50% of building heat demand in Scandinavia, with many of these systems relying on biomass or municipal waste as heat sources.[60]

For over a century, Seattle Steam has operated a natural gas-fired district steam system in the City, delivering heat to many downtown buildings. Seattle Steam recently installed a boiler capable of burning biomass, and currently uses wood waste for about half of its energy supply. The City of Seattle recently commissioned a District Energy Pre-Feasibility Study to examine opportunities to expand district energy is Seattle using low-impact renewable energy resources.

Strategy Ambition

For the Carbon Neutral Scenario analysis, we consider the transition over the course of ten years, starting in 2015, to an efficient closed-loop, hot water district heat system:

- using 100% renewable resources, largely in the form of locally-sourced renewable biomass possibly supplemented by waste heat capture (from industrial or wastewater plants) and solar thermal sources
- covering commercial building loads equivalent to those of the Seattle current steam-based system
- expanding to cover additional commercial and new multi-family communities within potential reach of district heat systems

District energy sources may have even greater potential, including meeting cooling loads through chilled water systems, and smaller neighborhood-based systems. The City's district energy pre-feasibility study will inform the possibility of such expansions by providing a better understanding of Seattle loads and resources conducive to district energy.

Another interesting option that we have not explicitly modeled here is combined heat and power, which could offer additional GHG savings due to increased system efficiencies. We have not modeled the conversion of natural gas based CHP, which though under current consideration by Seattle Steam, could lock in dependence on a fossil fuel resource (unless and until sufficient biomass-derived methane were available). The low-carbon district heat source widely used in Europe, waste-to-energy CHP, may offer an attractive option using state-of-the-art technologies, though its GHG emission and other impacts will depend greatly on what waste materials are combusted.

Technical Assumptions and Results

- A more efficient closed-loop hot water system (18% losses) combined with high efficiency boiler (93% efficient) increases overall system efficiency to 76%.[61]
- The number of buildings served by district heat expands as building efficiency measures reduce heat demands per ft^2. (See Strategies RB3 and CB3 for rate of expansion.)

[60] http://www.energia.fi/en/districtheating/districtheating; http://193.88.185.141/Graphics/UK_Facts_Figures/Statistics/yearly_statistics/2007/energy%20statistics%202007%20uk.pdf; http://www.dhcplus.eu/Documents/Vision_DHC.pdf
[61] We draw efficiency estimates from a recent assessment of new district heating system design for Dublin (RPS & COWI 2008).

  - Many commercial buildings (e.g. supermarkets, warehouses, isolated office buildings) are located outside current and promising district energy locations.
  - Since new commercial and multi-family residential development can be directed towards downtown and urban villages, which would be more amenable to district energy systems, we assume that the fraction of buildings using district energy for space heat and hot water loads by 2025 will rise to 50% for new commercial and residential multi-family buildings.
- We assume biomass is ultimately sourced from renewable sources with close to a net zero carbon impact. Currently Seattle Steam sources some of its biomass from construction and demolition wood waste (approximately 25%). Combusting wood waste that would otherwise be destined for a landfill does not necessarily provide a GHG benefit relative to the use of natural gas. Most of the carbon in wood waste is typically sequestered as carbon in a landfill for longer than a century, therefore burning this waste produces net CO2 emissions. However, if district energy providers were to source biomass from residues that would otherwise be burned or decompose the GHG benefits can be considerable, largely avoiding the emission from combusting natural gas (Lee et al. 2010).
  - This treatment of biomass is a simplification of complex issues regarding the appropriate accounting for CO2 emissions from biomass energy, the optimal use of biomass residues, and effects on forest and agricultural carbon stocks and ecosystem function. In order to rely heavily on biomass in a low carbon future, further study of these issues would be needed.

Since the availability of sustainable biomass resources is uncertain, we conduct a sensitivity analysis where we assume that heat recovery heat pumps (e.g. COP 4) are used instead of biomass boilers to drive district heat systems. This substitution would increase electricity demand by approximately 25 aMW in 2030 and 31 aMW in 2050, or 2.7 to 3.7% of projected electricity demand in 2030 and 2050, respectively.

Strategy ES3: Biomass Energy

Two elements of the suite of carbon neutral strategies rely on biomass:

- Biomass for district heat (ES2)
- Biofuels in vehicles (PT4 and FT4)

Many researchers have articulated concerns surrounding biomass energy, for example with respect to sustainability, reliability, impacts on the landscape, and biodiversity. While our scenario relies on biomass in moving towards carbon neutrality, it is worth carefully considering whether the type and amount of biomass required for each of these three strategies can be delivered without negative consequences.

As noted in the prior section (ES2), further study is needed to ensure adequate, sustainable, and truly low-carbon biomass sources can be used for district energy purposes. With respect to liquid biofuels, projected demand in Seattle could be quite high under this scenario, exceeding the per-capita averages reflected in the federal renewable fuel standard[62]. Again, potential supply and sustainability issues warrant further consideration.

[62] In the carbon neutral scenario, approximately 101 million liters of 1st generation ethanol and 121 million liters of 1st generation biodiesel would be consumed in Seattle in 2022, which would comprise less than half a percent of the national supply, assuming federal renewable fuel standards (RFS2) are met.

Waste

Baseline Activity

Base year data (2008)

- **Activity**:
  - Base year Seattle population, number of households (single and multi-family), and number of employees were provided by PSRC, and are summarized in the Macroeconomic Assumptions section of this document.
  - Base year total waste quantities by sector (single family, multi-family, commercial, and self-haul) were provided by SPU.[63] We estimated base year composition for single and multi-family waste based on SPU's 2006 Residential Waste Characterization Study (Cascadia Consulting Group, Inc. 2007), and drew base year composition for self-haul and commercial waste from SPU's 2008 Commercial/Self-Haul Waste Characterization Study (Cascadia Consulting Group, Inc. 2008).
  - Base year total recycling quantities and composition by sector were provided by SPU.

Baseline Scenario Projections:

- **Activity**:
  - Future total waste and recycling quantities were calculated based on projections of waste through 2038 from a 2007 waste reduction opportunity study conducted for the City of Seattle (URS Corporation 2007).
  - Future waste and recycling composition were assumed to be close to the base year composition. Minor adjustments were made to composition to ensure that total tons disposed and diverted matched the 2007 waste reduction opportunity study.
  - As shown below, long-term carbon storage from biogenic materials buried in landfills is roughly equivalent in GHG terms to the fugitive methane commitment and emissions from transportation of waste to the landfill. Since the net emissions are relatively insignificant, below 10,000 tCO2e net sequestration, as shown, we do not include these in our overall emissions estimates[64].
- Baseline waste generation and emissions are shown in Table 50.

[63] Seattle Public Utilities, Garbage Reports, http://www.cityofseattle.net/util/About_SPU/Garbage_System/Reports/Garbage_Reports/index.asp

[64] The figures listed here for 2008 differ somewhat from those in the City of Seattle's 2008 GHG inventory. We use the EPA's WARM model, whereas that inventory used a model developed by Sound Resource Management Group that was not available to us. For example, the net waste emissions in Seattle's 2008 inventory were nearly -22,000 tCO2e, or a somewhat greater quantify of carbon storage than we estimate here.

Table 50. Baseline Waste Generation and Emissions[65]

	2008	2030	2050
Waste Generation (Tons)	767,000	1,087,000	1,367,000
Disposal	395,000	405,000	522,000
Diversion	372,000	681,000	845,000
Waste Emissions (tCO_2e)			
Transportation to Landfill	28,000	29,000	37,000
Fugitive Methane Commitment	98,000	95,000	123,000
Carbon Storage	-133,000	-128,000	-166,000
Total Net Waste Emissions (tCO2e)	**-7,000**	**-4,000**	**-6,000**

[65] Emissions and emissions benefits of waste and recycling were calculated by applying emission factors from version 11 of the US EPA's Waste Reduction Model (WARM) to the projected tons of waste disposed and recycled in Seattle. These factors were adjusted to account for the landfill gas collection efficiency (75%), distance from Seattle to Arlington landfill (254 miles), and a current mix of recycled material inputs to the manufacturing process. For more information on WARM, please visit http://epa.gov/climatechange/wycd/waste/calculators/Warm_home.html.

Strategy W1: Maximize Recycling Rate

Introduction/Context

Recycling programs avoid emissions associated with the disposal of MSW and manufacturing of new materials and products. The City of Seattle has an existing goal for its residents to divert 60% of its waste from landfill. Implementing new strategies to increase recycling and reduce waste have the potential to increase this diversion rate and achieve greater GHG benefits from recycling.

Strategy Ambition

- We assume that Seattle could reach a 70% recycling rate by 2025, as suggested by the 2007 waste reduction opportunity study, by implementing a variety of Zero Waste strategies.[66] Total waste sent to landfills declines by 1% per year during this period.

Technical Assumptions and Results

- We assume a proportional increase in diversion rates across all categories of recyclable materials.
- We assume continued 75% methane recovery and destruction at the Arlington, OR landfill that currently receives Seattle waste.
- The results of increasing Seattle's diversion rate to 70% by 2025 on direct emissions, relative to the baseline scenario are shown in Table 5251 below. While increased diversion reduces transportation and methane commitment by 30,000 to 40,000 tCO2e in 2030 and 2050, respectively, these savings are offset by lost carbon storage of a similar magnitude. The net effect on direct emissions is thus negligible.

Table 51. Waste Generation and Emissions, Strategy W1

	2008	2030	2050
Waste Generation (Tons)	767,000	1,087,000	1,367,000
Disposal	395,000	325,000	416,000
Diversion	372,000	761,000	951,000
Waste Emissions (tCO_2e)			
Transportation to Landfill	28,000	23,000	30,000
Fugitive Methane Commitment	98,000	72,000	92,000
Carbon Storage	-133,000	-97,000	-125,000
Total Net Waste Emissions (tCO2e)	**-7,000**	**-2,000**	**-3,000**

[66] Please refer to *Seattle Solid Waste Recycling, Waste Reduction, and Facilities Opportunities* (URS Corporation 2007) for detailed descriptions of programs, policies, and facilities.

Table 52. Impact of Diversion Strategy on Waste Management and Direct Emissions, relative to Baseline

	2030	2050
Waste Generation (Change in Tons from Baseline)	**0**	**0**
Disposal	-80,000	-106,000
Diversion	80,000	106,000
Waste Emissions (Change in tCO_2e from Baseline)	**2,000**	**4,000**
Transportation to Landfill	-6,000	-7,000
Fugitive Methane Commitment	-24,000	-31,000
Carbon Storage	31,000	41,000

- While the net direct emissions impact (at landfills and from trucks) of the strategy is roughly a "wash", recycling and composting offer indirect (or "life cycle") emissions benefits by reducing virgin material extraction and processing requirements and increasing soil carbon through application (composting). Table 5352 illustrates the life cycle emission implications. These impacts are in addition to those shown in Table 5251.

Table 53. Impact of Increased Recycling and Composting on Indirect (Life Cycle) Emission Reductions (tCO2e)

2030	2050
-122,000	-160,000

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Appendix: Building Archetypes (from (Adelaar, Pasini, et al. 2008))

Figure 1. SE1 Archetype – Residential

(Achieves between 80 and 85 percent savings relative to baseline new home, or an EnerGuide rating of approximately 95)

HVAC	Furnace Efficiency	A/C SEER	Ventilation	
	Electricity: • Heat Pump • Heating COP: 6 • Cooling COP: 10	N/A	• Fans on automatic control using ECM motor • HRV (90% efficiency, 75W motor) • Forced ventilation to achieve 0.3 air changes/hour (ach)	
Air Tightness	1.0 ach			
DHW	Primary: • Solar hot water, 2 panels, CSIA-rating according to Enerworks Solar Calculator Secondary: • Natural Gas: instantaneous heater, 0.83 energy factor • 150 L/day @ 55°C			
Doors	Steel polyurethane, 2 standard-size doors			
Windows	• Triple-glazed, 2 low-e, argon, insulated spacer, vinyl faming, insulated shutters (RSI 1), 50% operable (slider with sash), 50% fixed • BC North WWR reduced from 25% to 10% • AB North WWR reduced from 20% to 10%			
Internal Loads	• 50% of R-2000 defaults (Appliances–5 kWh/day, Lighting–1.5 kWh/day, Other electric–1.5 kWh/day, Exterior–2 kWh/day • 2 adults and 2 children at home 50% of the time			
Thermostat	21°C heating set point (19°C basement), 25°C cooling set point			
Building Envelope RSI Values (m^2°C/W)	**Walls**	**Ceiling**	**Foundation**	**Headers**
	7.5	12	3.52+1.76 (walls), 1.4 (floor)	3.52

Figure 2. SE2 Archetype – Residential

(High Efficiency home (achieves between 50 and 60 percent savings relative to Baseline new home or EnerGuide rating of approximately 88)

HVAC	**Furnace Efficiency**	**A/C SEER**	**Ventilation**	
	Natural Gas: • High efficiency condensing • 95% efficiency Oil: • High efficiency condensing • 95% efficiency Electricity: • Heat Pump • Heating COP: 4 • Cooling COP: 5	N/A	• Fans on automatic control using ECM motor • HRV (85% efficiency, 100W motor) • Forced ventilation to achieve 0.3 ach	
Air Tightness	1.0 ach			
DHW	Primary: • Solar hot water, 2 panels, CSIA rating according to Enerworks Solar Calculator Secondary: • 40 US gal tank • Natural Gas: condensing, 0.86 energy factor • Oil: 0.7 energy factor • Electricity: 0.822 energy factor • 200 L/day @ 55°C			
Doors	Steel polyurethane, 2 standard size doors			
Windows	• Triple-glazed, 2 low-e, argon, insulated spacer, vinyl faming, 50% operable (slider with sash), 50% fixed • Window areas same as baseline except Yukon (see Table 1: Window Specifications) • Yukon North windows reduced from 15% to 10% WWR, North and South windows have insulated shutters (RSI 1) that are closed at night			
Internal Loads	• 80% of R-2000 defaults (Appliances–11.2 kWh/day, Lighting–2.4 kWh/day, Other Electric–2.4 kWh/day, Exterior–3.2 kWh/day • 2 adults and 2 children at home 50% of the time			
Thermostat	21°C heating set point (19°C basement), 25°C cooling set point			
Building Envelope RSI Values (m^2°C/W)	**Walls**	**Ceiling**	**Foundation**	**Headers**
	5.3	10.6	2.11+1.76 (wall), 1.4 (floor)	3.52

Figure 3. Residential Archetype Assumptions

Residential archetype SE1 Assumptions:

- 50% savings in appliance electricity use breakdown: Fridge/freezer–1 kWh/day, stove–1.4 kWh/day, clothes washer–0.5 kWh/day, dishwasher–0.82 kWh/day, dryer (counts towards exterior)–2 kWh/day
- Details on how to achieve insulation values:
  - Foundation: 2" rigid insulation outside, R-20 batt inside, 2" rigid below slab
  - Wall: 2" rigid insulation outside, 5.5" polyurethane spray-foam insulation inside
  - Ceiling: R70 blown cellulose insulation (approximately 20")
- 150 L/day hot water use @ 55°C (assuming low-flow shower heads (1 GPM) and a more efficient washing machine and dishwasher)
- Solar hot water: CSIA remains the same as for 200L/day of hot water consumption, meaning collector efficiency must improve by 15 percent
- Air tightness of 1.0 ach @ 50 Pa should not be difficult to achieve when assuming spray foam insulation is used since it cuts down dramatically on unwanted air infiltration through the building envelope.

Residential archetype SE2 Assumptions:

- Explanation of electrical load reduction: 20 percent savings should be achievable simply through gradual improvements in appliance motor and insulation technology, improvements in lighting technology (i.e., increasing use of LEDs), and through improvements to the power consumption and standby power of electronics.
- Details on how to achieve insulation values:
  - Foundation: 2" rigid insulation outside, R-12 batt inside, 2" rigid below slab
  - Wall: 2" rigid insulation outside, R-20 batt inside
  - Ceiling: R60 blown cellulose insulation (approximately 17")

Figure 4. SE1 Archetype - Commercial

(Achieves approximately 60 percent savings relative to Baseline new building or 10 percent better than C-2000)

HVAC	**Boiler Efficiency**	**A/C SEER**	**Ventilation**
	Electricity: • Heat Pump • Heating COP: 3 • Cooling SEER: 14 Natural Gas: • 95% condensing boiler	N/A	• Heat recovery (40–80% efficiency) • Demand-controlled ventilation (DCV) • Variable speed fans • Displacement ventilation
DHW	• 0–70% hot water reduction Primary: • Solar hot water (solar fraction: 60%) Secondary: • Natural Gas: 85–95% condensing boilers		
Windows	• U_{sl} 0.94–1.68 • 30–50% shading coefficient • 40–60% FWR		
Building Envelope RSI Values (m^2°C/W)	**Walls**	**Ceiling**	
	3.5–5.0	3.5–5.5	
Lighting	• Daylighting and occupancy controls • LPD: 4.0–7.0 W/m^2		

Figure 5. SE2 Archetype - Commercial

(Achieves approximately 35 percent savings relative to Baseline new building or 20 percent better than CBIP)

<table>
<tr><td rowspan="2">HVAC</td><td>Furnace Efficiency</td><td colspan="2">A/C SEER</td><td>Ventilation</td></tr>
<tr><td>Natural Gas, electric:
• 82–100% modulating, condensing, or electric boilers</td><td colspan="2">Heat pump:
SEER 14</td><td>• Heat recovery (40% efficiency)
• Some variable speed fans</td></tr>
<tr><td>DHW</td><td colspan="4">Primary:
• Solar hot water (solar fraction: 50%)
Secondary:
• 80–100% gas or electric boiler</td></tr>
<tr><td>Windows</td><td colspan="4">• U_{si} 1.6–1.9, 40–56% shading coefficient
• 40–60% FWR</td></tr>
<tr><td rowspan="2">Building Envelope RSI Values (m^2°C/W)</td><td colspan="2">Walls</td><td colspan="2">Ceiling</td></tr>
<tr><td colspan="2">2.5–4.5</td><td colspan="2">2.5–4.0</td></tr>
<tr><td>Lighting</td><td colspan="4">• LPD: 9.0–10.0 W/m^2</td></tr>
</table>

Figure 6. Commercial Archetype Assumptions

Commercial Archetype Assumptions:

- Reductions in the energy consumption of ventilation and pumping are due mostly to the increased use of ECM motors.
- Improvements to the heating system include moving from a vented furnace to a high efficiency condensing furnace or condensing boiler, and then moving to ground-source heat pumps.
- Improvement to the cooling system result simply from replacing air conditioners with a unit with a higher SEER, and eventually combining this with the ground source loop used for heating.
- Savings to DHW energy come from reductions in hot water use as well as technologies such as drain water heat recovery. Changes to the DHW system include moving toward condensing boilers and solar hot water collectors.
- Savings in lighting involve migrating towards high efficiency T5 or T8 technology and eventually LED lighting, digital dimming, daylight harvesting, and occupancy sensors.