Technical Appendix

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

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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.

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[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]

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[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]

[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.

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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.)

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[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 CO_2 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 CO_2 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 52 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 53 illustrates the life cycle emission implications. These impacts are in addition to those shown in Table 52.

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

2030	2050
-122,000	-160,000

References

Adelaar, Martin, Mark Pasini, Odón de Buen, and Stephen Selkowitz. 2008. *Green Building in North America: Paper 1: Green Building Energy Scenarios for 2030*.

APTA. 2009. *Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit*. American Public Transportation Association (APTA) Climate Change Standards Working Group.

Becker, Thomas A., Ikhlaq Sidhu, and Burghardt Tenderich. 2009. *Electric Vehicles in the United States: A New Model with Forecasts to 2030*. Center for Entrepreneurship & Technology, U.C. Berkeley.

Cambridge Systematics. 2007. *PSRC 2006 Household Activity Survey Analysis Report*. Cambridge Systematics for Puget Sound Regional Council and Washington State Department of Transportation, April.

———. 2009. *Moving Cooler: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions*. Washington, D.C.: Urban Land Institute, July.

CARB. 2009. *Detailed California-Modified GREET Pathway for Conversion of Midwest Soybeans to Biodiesel (Fatty Acid Methyl Esters-FAME)*.

Cascadia Consulting GroupInc. 2007. *2006 Residential Waste Stream Composition Study: Final Report*.

———. 2008. *2008 Commercial & Self-Haul Waste Streams Composition Study: Final Report*.

City of Seattle. 2007. *Seattle Bicycle Master Plan*.

Coffey, Brian, Sam Borgeson, Stephen Selkowi, Joshua Apte, Paul Mathew, and Philip Haves. 2009. "Towards a very low-energy building stock: modelling theUS commercial building sector to support policy and innovation planning." *Building Research & Information* 37 (5-6): 610-624.

Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles, NRC, , and , TRB. 2010. *Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles*.

D&R InternationalLtd. 2009. *2009 Buildings Energy Data Book. Prepared for: Buildings Technologies Program, Energy Efficiency and Renewable Energy, U.S. DOE*.

Electrification Coalition. 2009. *Electrification Roadmap: Revolutionizing Transportation and Achieving Energy Security*.

Environmental Defense Fund. 2010. *Greenhouse Gas Management for Medium-Duty Truck Fleets: A Framework for Improving Efficiency and Reducing Emissions*.

Ewing, R et al. 2008. *Growing Cooler: The Evidence on Urban Development and Climate Change*. Urban Land Institute.

Ewing, R, and Robert Cervero. 2010. "Travel and the Built Environment: A Meta-Analysis." *Journal of the American Planning Association* 76 (3): 265-294.

Fargione, Joseph, Richard J. Plevin, and Jason D. Hill. 2010. "The Ecological Impact of Biofuels." *Annual Review of Ecology, Evolution, and Systematics* 41 (1): 351-377. doi:10.1146/annurev-ecolsys-102209-144720.

Friedman, David. 2010. "The Evolution of a Revolution." *Union of Concerned Scientists, Catalyst*.

Greene, David L., and Steven E. Plotkin. 2011. *Reducing Greenhouse Gas Emissions from U.S. Transportation*. Pew Center on Global Climate Change, January.

Hale, Elaine, Matthew Leach, Adam Hirsch, and Paul Torcellini. 2009. *General Merchandise 50% Energy Savings: Technical Support Document*. NREL, September.

IEA. 2008. *Energy Technology Perspectives 2008: Scenarios & Strategies to 2050*. Paris: International Energy Agency.

———. 2009. *Transport, Energy and CO2: Moving Toward Sustainability*. Paris.

———. 2010. *Energy Technology Perspectives 2010: Scenarios & Strategies to 2050*. Paris: International Energy Agency.

Jiang, W., K. Gowri, M.D. Lane, B.A. Thornton, M.I. Rosenberg, and B. Liu. 2009. *Technical Support Document: 50% Energy Savings Design Technology Packages for Highway Lodging Buildings. Prepared for the U.S. Department of Energy under Contract DE-AC05-76RL01830*. Pacific Northwest National Laboratory, September.

Leach, Matthew, Elaine Hale, Adam Hirsch, and Paul Torcellini. 2009. *Grocery Store 50% Energy Savings Technical Support Document. Prepared under Task No. BEC71204*. NREL, September.

Leach, Matthew, Chad Lobato, Adam Hirsch, Shanti Pless, and Paul Torcellini. 2010. *Technical Support Document: Strategies for 50% Energy Savings in Large Office Buildings. Prepared under Task No. BEC7.1309*. NREL, September.

Lee, Carrie, Peter Erickson, Michael Lazarus, and Gordon Smith. 2010. *Greenhouse gas and air pollutant emissions of alternatives for woody biomass residues: Final Draft Version 2.0*. Stockholm Environment Institute - U.S. Center for the Olympic Region Clean Air Agency, November.

Litman, Todd. 2011. *Transportation Elasticities: How Prices and Other Factors Affect Travel Behavior*. Victoria Transport Policy Institute.

NESCCAF, ICCT and SWRI, , and , LLC. 2009. *Reducing Heavy-Duty Long Haul Combination Truck Fuel Consumption and CO2 Emissions*.

OSE & SCL. 2009. *Council SLI # 16-1-A-2: Response to the Seattle City Council Energy & Technology Committee*.

PSRC. 2010a. *Transportation 2040: Appendix A: Alternatives Technical Report*. Puget Sound Regional Council.

———. 2010b. *Transportation 2040: Toward a Sustainable Transportation System*. Puget Sound Regional Council.

R.W. Beck. 2004. *Anaerobic Digestion Feasibility Study for the Bluestern Solid Waste Agency and Iowa Department of Natural Resources: Final Report*.

RPS & COWI. 2008. *Dublin District Heating Project: 2007 Feasibility Study*.

Seattle City Light. 2010a. *2010 Integrated Resource Plan: Appendix D: The Impact of Electric Vehicles on System Load*.

———. 2010b. *2010 Integrated Resource Plan*.

Seattle Planning Commission. 2010. *Seattle Transit Communities: Integrating Neighborhoods with Transit*.

Seiden, Ken, and Collin Elliot. 2006. *Conservation Potential Assessment: Final Report. Prepared for: Seattle City Light*. Quantec, LLC.

Selkowitz, Stephen, Jessica Granderson, Phil Haves, Paul Mathew, and Jeff Harris. 2008. *Scale Matters: An Action Plan for Realizing Sector-Wide "Zero Energy" Performance Goals in Commercial Buildings*. 2008 ACEEE Summer Study on Energy Efficiency in Buildings. Lawrence Berkeley National Laboratory & Alliance to Save Energy, June.

Sims, Ralph, Michael Taylor, Jack Saddler, and Warren Mabee. 2008. *From 1st- to 2nd-Generation Biofuel Technologies: An overview of current industry and RD&D activities*. Bioenergy., International Energy Agency. file://C:\Users\Victoria Clark\Documents\Zotero\References for Upload\EndNote_Library_Pete\My EndNote Library.Data\PDF\2nd_Biofuel_Gen-3782648581/2nd_Biofuel_Gen.pdf.

Tachibana, Debra. 2010. *Residential Customer Characteristics Survey 2009*. Planning, Research & Evaluation, Conservation Resources Division, Seattle City Light.

The Cadmus GroupInc. 2009. *Comprehensive Assessment of Demand-Side Resource Potentials (2010-2029). Prepared for: Puget Sound Energy*.

TIAX LLC. 2010. A LCFS for Washington: Informing the Decision September 27.

Transportation Research Board. 2006. *Commuting in America III: The Third National Report on Commuting Patterns and Trends*.

U.S. DOT. 2010. *Report to Congress: Transportation's Contribution to Reducing United States Greenhouse Gas Emissions*.

U.S. EIA. 2010. *Annual Energy Outlook 2010 with Projections to 2035*.

U.S. EPA. 2010a. *Regulatory Impact Analysis: Renewable Fuel Standard Program*.

———. 2010b. *Documentation for Greenhouse Gas Emission and Energy Factors Used in the Waste Reduction Model (WARM): Introduction & Background*.

U.S. EPAand CARB. 2010. *Interim Joint Technical Assessment Report: Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards for Model Years 2017-2025*.

URS Corporation, Inc., , and , Norton-Arnold Company. 2007. *Seattle Solid Waste Recycling, Waste Reduction, and Facilities Opportunities*.

YangC. et. al. 2009. Identifying Options for Deep Reductions in Greenhouse Gas Emissions from California Transportation: Meeting an 80% Reduction Goal in 2050 presented at the Annual Meeting of the Transportation Research Board, January.

Yoder, Jonathan, Richard Shumway, Philip Wandschneider, and Douglas Young. 2008. *Biofuel Economics and Policy for Washington State*.

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)

<table>
<tr><td rowspan="2">HVAC</td><td>Boiler Efficiency</td><td>A/C SEER</td><td colspan="2">Ventilation</td></tr>
<tr><td>Electricity:
• Heat Pump
• Heating COP: 3
• Cooling SEER: 14
Natural Gas:
• 95% condensing boiler</td><td>N/A</td><td colspan="2">• Heat recovery (40–80% efficiency)
• Demand-controlled ventilation (DCV)
• Variable speed fans
• Displacement ventilation</td></tr>
<tr><td>DHW</td><td colspan="4">• 0–70% hot water reduction
Primary:
• Solar hot water (solar fraction: 60%)
Secondary:
• Natural Gas: 85–95% condensing boilers</td></tr>
<tr><td>Windows</td><td colspan="4">• U_{sl} 0.94–1.68
• 30–50% 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">3.5–5.0</td><td colspan="2">3.5–5.5</td></tr>
<tr><td>Lighting</td><td colspan="4">• Daylighting and occupancy controls
• LPD: 4.0–7.0 W/m^2</td></tr>
</table>

Figure 5. SE2 Archetype - Commercial

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

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

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.