Reducing Greenhouse Gas Emissions Through Alterations to the Public Right-of-Way

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A thesis submitted in partial fulfillment of the requirement for the degree of

Master of Urban Planning

University of Washington

2016

Committee:

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Program Authorized to Offer Degree

Urban Design and Planning

University of Washington

Abstract

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The climate system is warming, and the primary cause of this warming since the mid-20th century is likely to be the increase in emissions of anthropogenic greenhouse gases. This thesis examines strategies that reduce greenhouse gas emissions by making modifications to streets and how the implementation of those strategies in Seattle would change the configuration and allocation of the City's right-of-way. The right-of-way is the space where people and goods move through the city, and includes sidewalks, parking, travel lanes, bus lanes, bike lanes, alleys and more. This thesis uses Geographic Information System analysis to create a breakdown of the existing right-of-way and how the right-of-way could change if GHG reduction strategies are implemented. "Moving Cooler: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions" (Cambridge Systematics, Inc. 2009) provides the background information for the strategies and the possible levels of GHG emissions reductions. Greenhouse gas reduction strategies that alter the right-of-way in Seattle could include completing the pedestrian and bicycling networks by adding sidewalks and bicycle

lanes, and increasing the amount of nonmotorized areas. If the GHG strategies were applied in Seattle it would alter 4.2% of the city's right-of-way and has the potential to reduce greenhouse gas emissions by over 6% annually.

Acknowledgements

Thank you to my thesis chair and advisor Christine Bae for all of the guidance, support, and advice that made this thesis possible. And thank you to thesis committee member Jan Whittington her helpful advice and insight during this thesis process. Thank you to the Policy and Planning division of the Seattle Department of Transportation for their support developing this topic, and for all I learned while interning with their division. And finally thank you to my family and friends for their wonderful support along the way.

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CHAPTER 1: INTRODUCTION

The purpose of this thesis is to understand how strategies to reduce greenhouse gases might change the allocation of a city's right-of-way (ROW), using the City of Seattle as a case study. The research question is: how would strategies to reduce Seattle's greenhouse gas emissions alter the City's right-of-way allocation?

The ROW is where people and goods move through the city. People use the ROW for walking, driving, biking, transit, freight, and socializing. The physical expression of ROW uses are sidewalks (paved walkways, landscaping, furniture & frontage zones), parking/loading/driveway spaces, traffic lanes, bus lanes, bike lanes, alleys, and railroad.

This is important to study because the ROW makes up approximately 28% of Seattle's land area. In some cases, ROW uses compete for space. If a parklet is added to a street that will often mean a parking space is lost. A new bike lane may mean that a driving lane is lost. Some of these changes will support one mode of transportation over another, and different modes of transportation emit different levels of Green House Gas (GHG) emissions.

The climate system is warming, and the primary cause of the Earth's warming since the mid-20th century is likely to be the increase in emissions of anthropogenic greenhouse gases since the pre-industrial era (IPCC 2014). Earth's average temperature has increased by 1.5°F over the last century, and it is projected to increase another 0.5 to 8.6°F over the next century (EPA 2016). Changes in the planet's temperature can cause large changes in climate and weather. Changes to the climate system have already been observed, including a warmer atmosphere and ocean, diminished amounts of snow and ice, and rising sea levels. Natural and

human systems across all continents and oceans have experienced and will continue to experience impacts from the change in climate (IPCC 2014).

The U.S. transportation sector is responsible for 27 percent of the GHG emissions from the U.S. economy. Without a change in policy the U.S. transportation sector's GHG emissions are predicted to grow by close to 10 percent by 2035 (Pew Center 2011).

Publicly owned ROW makes up significant portions of land areas in many cities, so how cities manage ROW can have significant impacts. The impacts of climate change have already been observed, such as a reduction in cold temperature extremes, an increase in warm temperature extremes, an increase in extreme high sea level, and more frequent heavy precipitation events in many regions. These conditions result in more heat waves, droughts, floods, cyclones and wildfires. In the future, according to the 2014 IPCC report, existing risks of climate change will intensify and new risks will be created. These new risk will very likely include more and longer heat waves, an increase in intensity and frequency of extreme precipitation events, continued ocean warming and acidifying, and more global mean sea level rise Finding ways to considerably shrink GHG emissions in the next several decades will decrease the risks of climate change (IPCC 2014).

This inquiry started as a Seattle Department of Transportation (SDOT) internship project. The original purpose of the project was to calculate how the ROW was distributed between different uses to help explain the context of changes to the ROW. For example, if a new bike lane was being added where there had previously been parking, this data could explain that overall bike lanes made up a very small portion of the ROW and parking lanes still made up a much larger portion of the ROW.

ROW reallocation can be a cause of concern and lead to tensions among local residents and business owners. One recent example is the construction of the Westlake Avenue N Cycle track in Seattle. This project created a much needed cycle track in the Westlake corridor, which is a connection between the Fremont Bridge and Downtown Seattle/South Lake Union. A group of business owners and residents became upset over the loss of 1,300 publicly owned parking stalls and filed a lawsuit. The issue was eventual solved through a community design process, but the situation illustrates the potential road bumps associated with ROW reallocation (Cohen 2016).

This study focuses on the right-of-way used for transportation in the City of Seattle. Property owned by the City of Seattle that is not used for or reserved for transportation is a part of the ROW GIS layer, but will not be examined in depth. This study examines strategies that reduce greenhouse gas emissions by making alterations to streets and how the implementation of those strategies in Seattle would change the ROW.

Chapter 2 of this thesis reviews literature on the causes and impacts of climate change, strategies to reduce greenhouse gases, policies and investments that can influence modal shift, and Seattle's contribution and response to climate change. Chapter 3 explains the data and methods used for analysis. The first part of the analysis looks at the ROW as it is today, and the second part looks at how greenhouse gas reduction strategies would alter the ROW. Chapter 4 discusses the results of the ROW analysis. It begins with an overview of the ROW as it exists today, including the different categories of ROW parcels and the different uses that take place in the ROW. Next Chapter 4 looks at how greenhouse gas reduction strategies would change

the ROW, and what the reductions in emissions would be. Chapter 5 makes recommendations based on the findings of this thesis.

CHAPTER 2: LITERATURE REVIEW

The following is a review of literature about the causes and impacts of climate change, strategies to reduce greenhouse gases, policies and investments that can influence modal shift, and Seattle's contribution and response to climate change.

CLIMATE CHANGE

Since the 1950s scientists have observed warming in the atmosphere and ocean, a decreased amount of snow and ice, and an increase in the sea level. This warming is extremely likely to have been caused by an increase in anthropogenic greenhouse gas emissions - largely carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O). The concentrations of these three gases in the atmosphere are higher than they have been in the last 800,000 years. Human produced GHG emissions are a product of population size, economic activity, lifestyle, energy use, land use patterns, technology and climate policy (IPCC 2014).

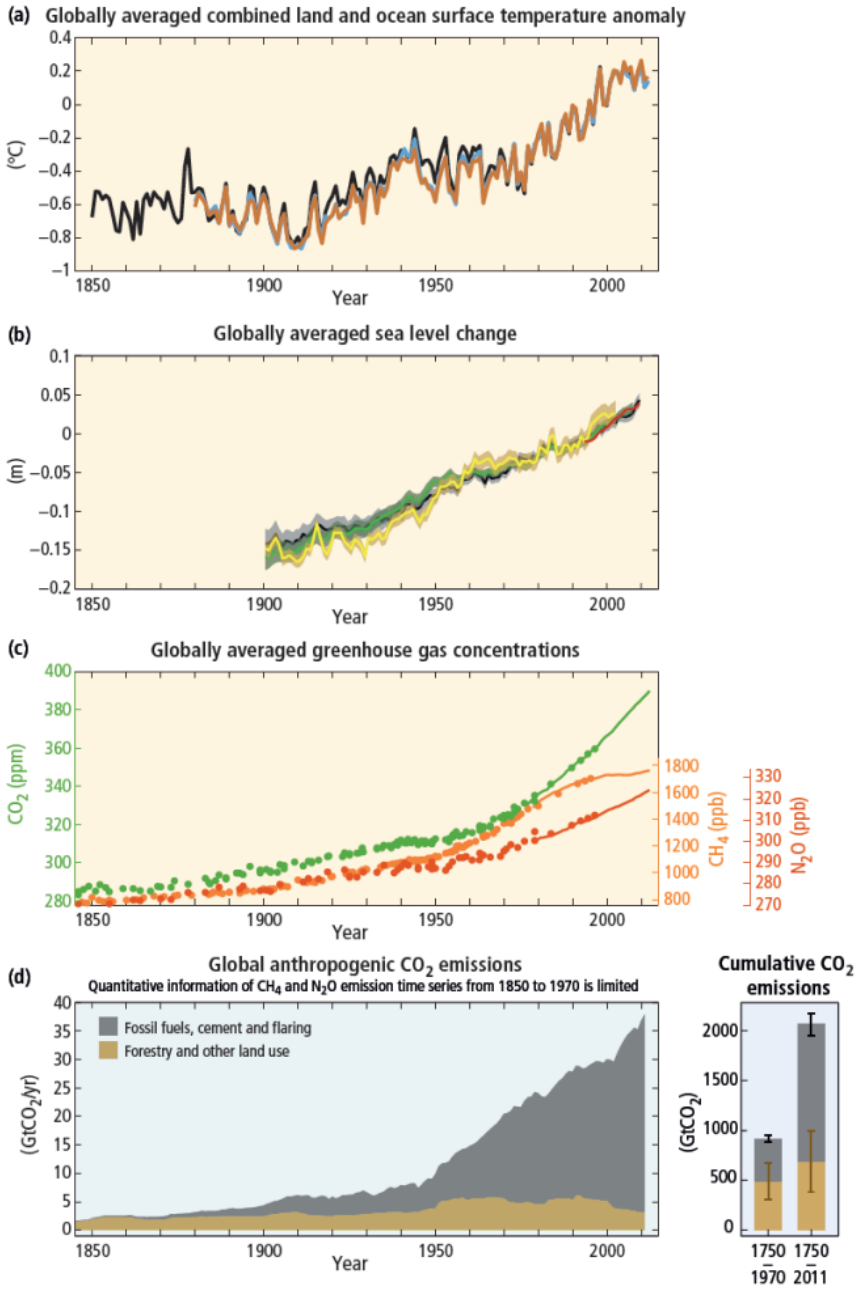


Figure SPM.1 | The complex relationship between the observations (panels a, b, c, yellow background) and the emissions (panel d, light blue background) is addressed in Section 1.2 and Topic 1. Observations and other indicators of a changing global climate system. Observations: **(a)** Annually and globally averaged combined land and ocean surface temperature anomalies relative to the average over the period 1986 to 2005. Colours indicate different data sets. **(b)** Annually and globally averaged sea level change relative to the average over the period 1986 to 2005 in the longest-running dataset. Colours indicate different data sets. All datasets are aligned to have the same value in 1993, the first year of satellite altimetry data (red). Where assessed, uncertainties are indicated by coloured shading. **(c)** Atmospheric concentrations of the greenhouse gases carbon dioxide (CO_2, green), methane (CH_4, orange) and nitrous oxide (N_2O, red) determined from ice core data (dots) and from direct atmospheric measurements (lines). Indicators: **(d)** Global anthropogenic CO_2 emissions from forestry and other land use as well as from burning of fossil fuel, cement production and flaring. Cumulative emissions of CO_2 from these sources and their uncertainties are shown as bars and whiskers, respectively, on the right hand side. The global effects of the accumulation of CH_4 and N_2O emissions are shown in panel c. Greenhouse gas emission data from 1970 to 2010 are shown in Figure SPM.2. *{Figures 1.1, 1.3, 1.5}*

Figure 1 Globally averaged temperature anomaly, sea level change, GHG concentrations, and anthropogenic CO2 emissions

Source: IPCC (2014), Figure SPM1, p.3

Impacts from climate change have occurred in natural and human systems across the world. Since the middle of the 20th century there have been changes in extreme weather and climate events. These changes include a reduction in cold temperature extremes, an increase in warm temperature extremes, an increase in extreme high sea level, and more frequent heavy precipitation events in many regions. This leads to more heat waves, droughts, floods, cyclones and wildfires (IPCC 2014).

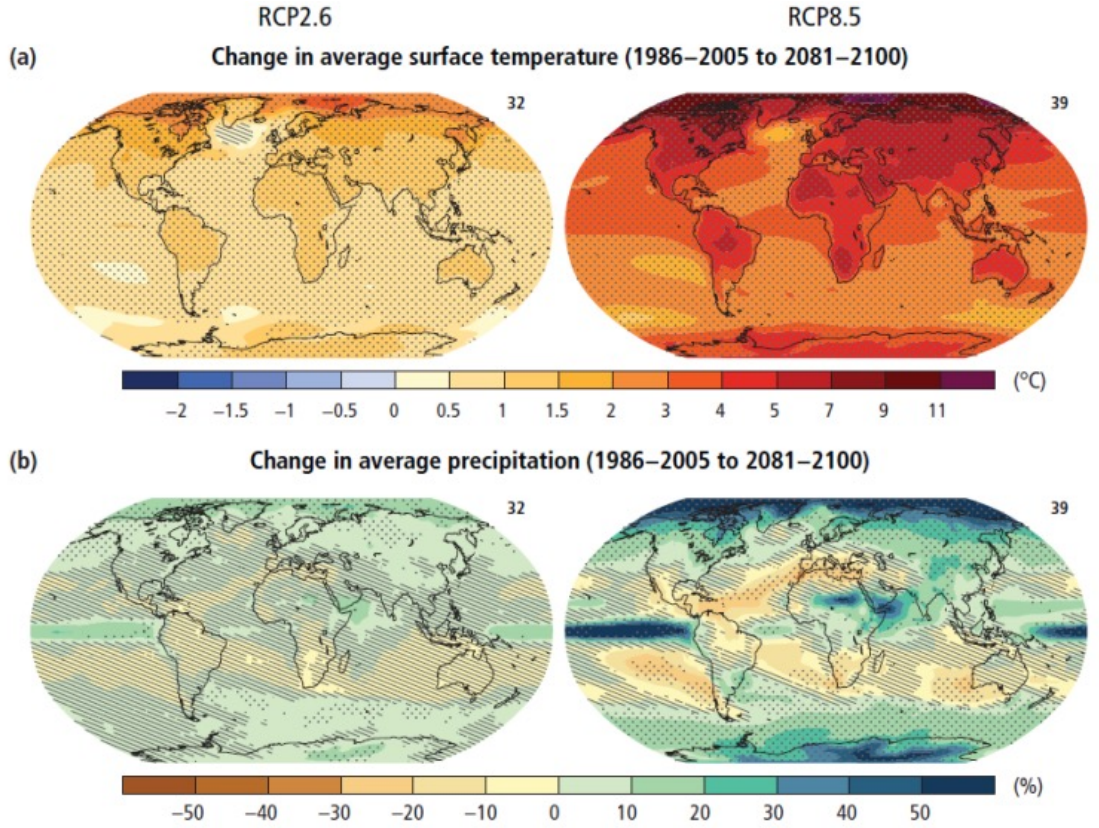


Figure SPM.7 | Change in average surface temperature **(a)** and change in average precipitation **(b)** based on multi-model mean projections for 2081–2100 relative to 1986–2005 under the RCP2.6 (left) and RCP8.5 (right) scenarios. The number of models used to calculate the multi-model mean is indicated in the upper right corner of each panel. Stippling (i.e., dots) shows regions where the projected change is large compared to natural internal variability and where at least 90% of models agree on the sign of change. Hatching (i.e., diagonal lines) shows regions where the projected change is less than one standard deviation of the natural internal variability. *(2.2, Figure 2.2)*

Figure 2 Change in average surface temperature and average precipitation

Source: IPCC (2014), Figure SPM.7, p.12

Surface temperature is projected to continue to increase during the 21st century, which will intensify the risks that exist today and create new risks in the future. There will very likely be more and longer heat waves, an increase in intensity and frequency of extreme precipitation events, continued ocean warming and acidifying, and more global mean sea level rise (IPCC 2014).

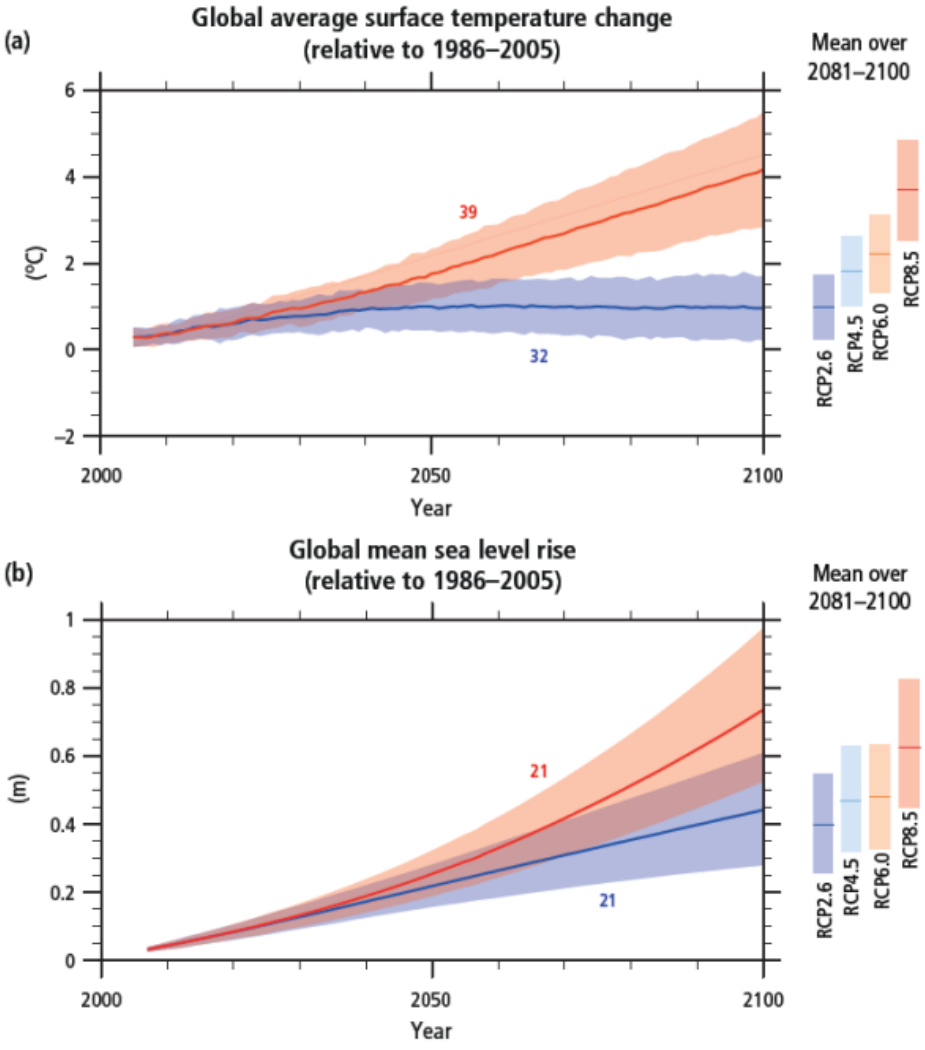


Figure SPM.6 | Global average surface temperature change **(a)** and global mean sea level rise[10] **(b)** from 2006 to 2100 as determined by multi-model simulations. All changes are relative to 1986–2005. Time series of projections and a measure of uncertainty (shading) are shown for scenarios RCP2.6 (blue) and RCP8.5 (red). The mean and associated uncertainties averaged over 2081–2100 are given for all RCP scenarios as coloured vertical bars at the right hand side of each panel. The number of Coupled Model Intercomparison Project Phase 5 (CMIP5) models used to calculate the multi-model mean is indicated. *[2.2, Figure 2.1]*

Figure 3 Global average surface temperature change and mean sea level rise

Source: IPCC (2014), Figure SPM.6, p.11

The impacts of climate change will not be experienced equally by all people. The risks will be greater for disadvantaged people. Sea level rise will put coastal and low-lying areas at risk. It will be a threat to food security. Renewable surface water and groundwater resources in dry subtropical regions are predicted to be diminished. Human health issues that exist today will worsen, particularly in developing countries (IPCC 2014).

In urban areas there will be an increase in the risk to people, assets, economies and ecosystems. Urban areas will also experience increased heat stress, storms and extreme precipitation, inland and coastal flooding, landslides, air pollution, drought, water scarcity, and sea level rise and storm surges. Rural areas will have issues with water availability and supply, food security, infrastructure and agricultural incomes, and changes to where crops are grown. People will be displaced because of climate change (IPCC 2014).

Even if the emissions of greenhouse gases ceased, climate change and its impacts would continue for centuries. The more warming we experience, the greater the chance of sudden or irreversible changes. If we can considerably shrink the GHG emissions in the coming decades we can decrease the risks of climate change, which would make adaptation more successful and make mitigation less costly (IPCC 2014).

If we fail to add more mitigation measures beyond what we have in place today, by the end of the century we risk severe, wide reaching and irreversible impacts throughout the world. Without increased mitigation global warming is more likely than not to exceed 4°C above pre-industrial levels by 2100 under most scenarios (IPCC 2014, p.19). Risks of that level include sizeable species extinction, and global and regional food insecurity. (IPCC 2014)

Moreover, when looking at reducing GHG emissions we need to consider equity. Countries have emitted different levels of GHG emissions in the past, and will emit different levels in the future. Different countries have different challenges when it comes to mitigation and adaptation. We have to consider equity, justice, and fairness with mitigation and adaptation. In the majority of cases the people that are most vulnerable to the impacts of climate change have not added many GHG emissions to the atmosphere. Putting off mitigation in the present shifts the burden to future generations. (IPCC 2014)

The UN Framework Convention on Climate Change (UNFCCC) is an international treaty providing an outline for intergovernmental efforts for fighting climate change. The treaty was negotiated in 1992 at the Earth Summit in Rio de Janeiro and entered into force 1994. Its goals are to limit the average global temperature increases and deal with the inevitable impacts of the resulting climate change (UNFCCC 2014 a). The Convention asked governments to gather and share information on climate change, create national strategies for reducing GHG emissions and adapting to impacts, and to provide financial and technological assistance to developing countries (UNFCCC 2014 b).

The Kyoto Protocol extended the original UNFCCC by establishing internationally binding emission reduction targets. It assigns a heavier burden on developed countries because the protocol recognizes that these countries are responsible for the majority of GHG emissions. It was adopted in Kyoto, Japan in 1997 and entered into force in 2005 (UNFCCC 2014 c). The first commitment period ran from 2008 to 2012, and the second commitment period runs from 2013 to 2020 (UNFCCC 2014 a). The UNFCCC currently has 197 parties and the Kyoto Protocol has 192 parties.

The 2015 Paris Agreement is the latest international agreement built on the work of the Convention. The negotiations for this agreement took place at the annual Conference of Parties 21 in Paris, and it opened for signature and approval by Parties from April 2016 to April 2017. The aim of the Paris Agreement is to "strengthen the global response to the threat of climate change" (COP 2015). This includes keeping the global average temperature to well under 2°C above pre-industrial levels, and to work to limit the temperature rise to 1.5°C above pre-industrial levels. Limiting warming to 1.5°C above pre-industrial levels would greatly decrease the risks and impacts of climate change. Other aims include increasing the capacity to adapt to negative climate change impacts, encouraging low GHG emission and resilient development, and creating complementary finance flows. The Agreement recognizes that there are different national circumstances and will be implemented based on the principle of common but differentiated responsibilities and capabilities (COP 2015).

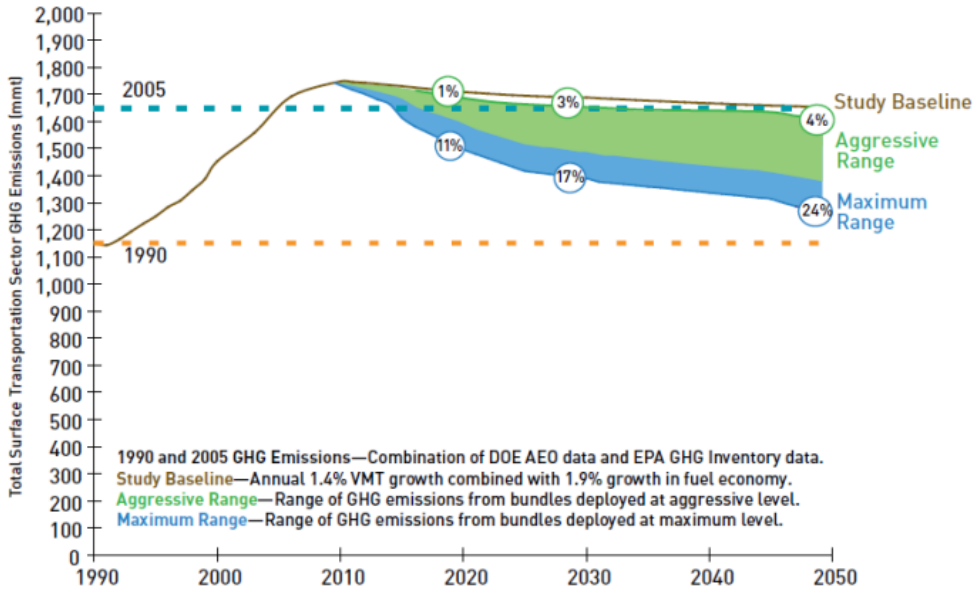
Each Party to the agreement is responsible for preparing nationally determined contributions, which will be achieved through domestic mitigation measures. Parties are required to communicate nationally determined contributions every five years, and successive nationally determined contributions will go further than the last contribution (COP 2015). In the "Intended Nationally Determined Contribution" submitted March 2015 the United States set an economy-wide target to reduce 2025 greenhouse gas emissions by 26-28% below the 2005 level. This target is on track for economy-wide emission reductions of 80% by 2050. (United States of America 2015)

GHG REDUCTION STRATEGIES

This thesis uses the strategies outlined in "Moving Cooler" to analyze how greenhouse gas reduction policies could impact Seattle's ROW. "Moving Cooler: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions" is a 2009 study looking at the effectiveness and costs of almost 50 transportation strategies aimed at reducing greenhouse gas emissions. The strategies examined in this study are broken into 9 categories: pricing and taxes, land use and smart growth, nonmotorized transportation, public transportation improvements, ride-sharing/car-sharing/other commuting strategies, regulatory strategies, operational and intelligent transportation system (ITS) strategies, capacity expansion and bottleneck relief, and multimodal freight sector strategies (Cambridge Systematics, Inc. 2009).

Because most strategies would be enacted with other strategies as part of a package of activities, Moving Cooler grouped the strategies into illustrative 6 bundles: near-term/early results, long-term/maximum results, Land use/transit/nonmotorized transportation, system and driver efficiency, facility pricing, and low cost. To analyze the effectiveness of the strategies and bundles Moving Cooler used a baseline created using an annual rate of vehicle and fuel technological change. Advances in vehicle and fuel technology will have a big effect on GHG emissions, but will be offset by increases in U.S. population and travel. The anticipated GHG emission reductions from the strategies and bundles are shown as a percentage reduction from this baseline (Cambridge Systematics, Inc. 2009).

Figure ES.3 **Range of Annual GHG Emission Reductions of Six Strategy Bundles at Aggressive and Maximum Deployment Levels**
2010 to 2050



Note: This figure displays the GHG emission range across the six bundles for the aggressive and maximum deployment scenarios. The percent reductions are on an annual basis from the study baseline. The 1990 and 2005 baselines are included for reference.

Figure 4 Range of Annual GHG Emission Reductions of Six Strategy Bundles at Aggressive and Maximum Deployment Levels

Source: Cambridge Systematics, Inc. 2009, Figure ES. 3

Implementing these bundles without economy-wide pricing could result in annual GHG emissions reductions from 4 percent to 24 percent (see figure above) compared to 2050 projected baseline levels. The most effective strategies were pricing and regulatory strategies that increase the price of single occupancy vehicle travel, regulatory strategies that reduce and enforce speed limits, educational strategies that teach drivers to be fuel efficient, land use and smart growth to reduce travel distances, and multi-modal strategies increasing travel options. Strong economy-wide pricing measures (i.e. additional gas taxes) could add significant GHG emissions reductions. For example, increasing U.S. the fuel tax to a rate similar to European fuel

taxes (starting at $2.40 per gallon in 2015 and increasing to $5.00 per gallon by 2050) could reduce GHG emissions by an additional 28 percent by 2050 (Cambridge Systematics, Inc. 2009).

The bundle that most closely relates to the focus of this thesis is the Land Use/Transit/Nonmotorized Transportation bundle. This bundle focuses on changes to land use that support transit and nonmotorized travel improvements. This results in a reduction of single occupancy vehicle trips and shortens the average length of trips. Included in this bundle are a variety of pricing strategies, land use changes, improvement and expansion of pedestrian and bicycle facilities, public transportation expansion, HOV lanes, car-sharing, urban non-motorized zones, and urban parking restrictions. This bundle is slower to produce results than others, but by 2050 annual reductions in GHGs range from 9 percent to 15 percent with maximum implementation (Cambridge Systematics, Inc. 2009, p.53). This bundle has cumulative implementation costs by 2050 ranging from $1.4 trillion (maximum deployment) to $2.4 trillion (maximum deployment). The cumulative vehicle cost savings for this bundle are $3.3 to $5.7 trillion, and exceed implementation costs. The average annual net included costs of GHG reduction ranges from -$480 to -$530 per ton. This path has the additional benefits of offering more travel options, improvements to public health, and GHG savings from decreased building energy use (Cambridge Systematics, Inc. 2009, p. 52-55).

Moving Cooler also breaks down the GHG reduction by individual strategy. For comparison the U.S. transportation sector produced almost 2,000 mmt of CO_2e annually at the time of the study. The combined pedestrian strategy has a GHG reduction of 74 mmt and the combine bicycle strategy has a reduction of 59 mmt. Grouping certain strategies can create synergies that boost GHG reductions (Cambridge Systematics, Inc. 2009).

The relevant lesson of Moving Cooler is that alterations to the ROW aimed at reducing greenhouse gas emissions are a necessary part of a bigger effort that includes a variety of strategies.

SWITCHING TO ALTERNATIVE TRANSPORTATION

Multiple studies have shown that adding transportation infrastructure for non-motorized transportation modes, especially when combined with other strategies, can induce more people to use alternative forms of transportation (e.g. walking, biking, and taking transit).

A study by Lindsay et al (2011) estimated the effects switching short trips from car to bicycle would have on health, air pollution and greenhouse gas emissions. The study used existing data sources to model these effects in urban New Zealand. The results showed that switching 5% of vehicle kilometres to cycling would conserve approximately 22 million litres of fuel and reduce transport-related greenhouse gas emissions by 0.4% (50,000 tonnes of CO_2). This switch would also save 116 deaths a year because of increased physical activity, reduce 6 deaths from local air pollution, but would increase cyclist fatalities by 5. The study estimated about $200 million per year in savings from the positive health effects.

A 2004 study by Ogilvie et al looked at the success of interventions aimed at promoting a shift from cars to walking and cycling and health effects of the interventions. The study reviewed 22 published and unpublished reports to draw conclusions. It concluded that targeted behavior change programs had an effect on people's behavior, but on balance publicity campaigns, engineering measures, and other interventions had not been effective. (Ogilvie et al 2014)

A later review by Scheepers et al (2014) looked 19 studies to examine the effectiveness of interventions and policies aimed at increasing the mode share of walking and cycling. The interventions reviewed were characterized as work-place-based, architectural and urbanistic adjustments, population-wide, and bicycle-renting systems. 16 of the studies examined revealed a positive effect on mode shift from car to active transport. Mass media campaigns work in combination with other interventions, but evidence that they worked alone was lacking. Reward or penalty systems were effective while active, but there was less evidence that they worked in the long-term. A study of a new neighborhood trail showed a negative effect on mode shift, possibly because there were no corresponding promotional activities. But the opening of a new rail station without promotional activities did show a positive effect. The authors conclude that certain types of architectural and urbanistic interventions may require other intervention tools to be implemented in tandem. They go on to say that combining intervention tools may have more of an impact then using one alone. (Scheepers et al 2014)

A systematic review by Yang et al in 2014 looked at interventions effective in promoting cycling documented in 25 studies from seven countries. They found that four of the six studies directed specifically at promoting cycling were associated with increases. These studies looked at personal interventions in obese women, high quality improvements to a bicycle network, and two cycle promotion initiatives with multiple interventions. 16 studies looked at marketing of environmentally friendly modes of transport to interested households and found small but positive results. The authors concluded that improvements to cycling infrastructure, individualized marketing, and community-wide promotional activities have the potential to produce modest increases in cycling rates.

A review by Pucher et al (2014) assessed 139 studies and 14 case study cities about bicycle promotion interventions including infrastructure, integration with public transport, education and marketing programs, bicycle access programs, and legal issues. This study found many studies demonstrated a positive association between an intervention and bicycling rates. They conclude that public policy plays an important role, and a combination of complementary interventions is necessary for a substantial increase in biking. Complementary interventions include infrastructure improvements, bicycle promotion programs, supportive land use planning, and restrictions on car use.

A review by Handy et al (2002) gives an overview of urban planning concepts, theories, and methods meant to be used as a foundation for research on the connection between the built environment and physical activity. This work reviews new studies to test the hypothesis that policies that affect the built environment and travel behavior can also be used to decrease car travel. The review starts with a background that recounts the evolution of this topic in the urban planning field. The authors note that the urban design literature gives a prescription for making public spaces people will use. The urban design concepts came from a handful of contributors such as Jane Jacobs, Christopher Alexander's 1977 book *A Pattern Language*, Kevin Lynch's book *Good City Form,* William Whyte's observation studies of public plazas, and Donald Appleyard's mapping of neighbor relationships. This literature became the basis for the new urbanism movement, which uses urban design and planning concepts to reduce car use and make great public places. Specifically, that locating daily activities within walking distance and offering an interconnected network of streets, sidewalks, and paths can decrease driving and promote walking.

SEATTLE'S GREENHOUSE GAS EMISSIONS

The "2012 Seattle Community Greenhouse Gas Emissions Inventory" report evaluates the Seattle community's GHG emissions in 1990, 2005, 2008, and 2012. GHG emissions are broken into two categories: "core" emissions and "expanded" emissions (see tables below). "Core" emissions are things the City can have the greatest effect on, like road transportation, building energy use and waste sectors. Seattle's 2013 Climate Action Plan concentrates on "core" emissions.

Table 1 Seattle core greenhouse gas emissions per person, by sector (metric tons CO2e)

Per Person GHG Emissions by Sector	1990	2005	2008	2012	% change 1990-2012	% change 2008-2012
TRANSPORTATION	4.3	4.0	3.8	3.8	-11%	-1%
Road: Passenger	3.0	2.8	2.7	2.6	-13%	-1%
Road: Freight	1.2	1.2	1.1	1.1	-8%	-1%
BUILDINGS	2.8	2.2	2.3	2.0	-31%	-15%
Residential	1.4	1.0	1.0	0.8	-39%	-17%
Commercial	1.4	1.2	1.3	1.1	-23%	-14%
WASTE	0.2	0.2	0.2	0.1	-37%	-23%
Waste Management	0.2	0.2	0.2	0.1	-37%	-23%
TOTAL PER PERSON	7.3	6.5	6.3	5.9	-20%	-7%
GHG OFFSETS		-0.3	-0.2	-0.1		
City Light Offset Purchases		-0.3	-0.2	-0.1		
TOTAL AFTER OFFSETS	7.3	6.2	6.1	5.7	-22%	-6%

Source: Stockholm Environment Institute 2014, p. 3

"Expanded" emissions come from sources that are challenging for the city to influence such as industry, marine, rail and air travel, yard equipment, and wastewater treatment (Stockholm Environment Institute 2014).

Table 2 Seattle community GHG emissions by sector (metric tons CO2e): expanded view

	1990	2005	2008	2012	% change 1990-2012	% change 2008-2012
TRANSPORTATION	**3,412,000**	**3,487,000**	**3,524,000**	**3,542,000**	**4%**	**1%**
Road: Passenger	**1,561,000**	**1,628,000**	**1,578,000**	**1,670,000**	**7%**	**6%**
Cars & Light Duty Trucks	*1,512,000*	*1,572,000*	*1,510,000*	*1,603,000*	*6%*	*6%*
Buses	*47,000*	*54,000*	*66,000*	*64,000*	*36%*	*-3%*
Vanpool	*2,000*	*2,000*	*2,000*	*2,000*	*0%*	*0%*
Road: Freight	**635,000**	**681,000**	**677,000**	**720,000**	**13%**	**6%**
Trucks	*635,000*	*681,000*	*677,000*	*720,000*	*13%*	*6%*
Marine & Rail	**276,000**	**274,000**	**293,000**	**247,000**	**-11%**	**-16%**
Hotelling	*53,000*	*51,000*	*74,000*	*46,000*	*-13%*	*-38%*
Washington State Ferries	*41,000*	*42,000*	*35,000*	*42,000*	*2%*	*20%*
Pleasure Craft	*32,000*	*30,000*	*31,000*	*31,000*	*-3%*	*0%*
Other Ship & Boat Traffic	*65,000*	*62,000*	*64,000*	*64,000*	*-2%*	*0%*
Rail - Freight	*85,000*	*81,000*	*79,000*	*53,000*	*-38%*	*-33%*
Rail - Passenger	*1,000*	*9,000*	*10,000*	*12,000*	*1100%*	*20%*
Air	**940,000**	**904,000**	**976,000**	**905,000**	**-4%**	**-7%**
Sea-Tac Airport	*756,000*	*688,000*	*718,000*	*681,000*	*-10%*	*-5%*
King County Airport	*184,000*	*216,000*	*258,000*	*224,000*	*22%*	*-13%*
BUILDINGS	**1,620,000**	**1,430,000**	**1,545,000**	**1,424,000**	**-12%**	**-8%**
Residential	**741,000**	**587,000**	**625,000**	**557,000**	**-25%**	**-11%**
Electricity	*133,000*	*68,000*	*44,000*	*28,000*	*-79%*	*-36%*
Natural Gas	*259,000*	*371,000*	*432,000*	*420,000*	*62%*	*-3%*
Oil	*329,000*	*131,000*	*131,000*	*89,000*	*-73%*	*-32%*
Yard Equipment	*20,000*	*17,000*	*17,000*	*19,000*	*-5%*	*12%*
Commercial	**879,000**	**843,000**	**920,000**	**867,000**	**-1%**	**-6%**
Electricity	*169,000*	*102,000*	*82,000*	*53,000*	*-69%*	*-35%*
Natural Gas	*281,000*	*351,000*	*401,000*	*402,000*	*43%*	*0%*
Oil	*150,000*	*84,000*	*108,000*	*93,000*	*-38%*	*-14%*
Steam	*144,000*	*160,000*	*177,000*	*156,000*	*8%*	*-12%*
Commercial Equipment	*135,000*	*145,000*	*153,000*	*162,000*	*20%*	*6%*
INDUSTRY	**976,000**	**1,552,000**	**1,503,000**	**1,069,000**	**10%**	**-29%**
Cement	**417,000**	**861,000**	**746,000**	**307,000**	**-26%**	**-59%**
Fuel Combustion	*211,000*	*377,000*	*353,000*	-	-	-
Clinker Calcination	*206,000*	*484,000*	*393,000*	-	-	-
Other - Energy Use	**528,000**	**457,000**	**513,000**	**488,000**	**-8%**	**-5%**
Electricity	*62,000*	*26,000*	*17,000*	*10,000*	*-84%*	*-41%*
Natural Gas	*266,000*	*246,000*	*232,000*	*259,000*	*-3%*	*12%*
Oil	*49,000*	*11,000*	*36,000*	*16,000*	*-67%*	*-56%*
Industrial Equipment	*151,000*	*173,000*	*228,000*	*202,000*	*34%*	*-11%*
Other - Process Emissions	**20,000**	**37,000**	**40,000**	**39,000**	**95%**	**-3%**
Steel & Glass	*20,000*	*37,000*	*40,000*	*39,000*	*95%*	*-3%*
Fugitive Gases	**11,000**	**197,000**	**204,000**	**235,000**	**>100%**	**15%**
ODS Substitutes	*1,000*	*192,000*	*202,000*	*235,000*	*>100%*	*16%*
Switchgear Insulation (SF6)	*10,000*	*5,000*	*2,000*	*1,000*	*-90%*	*-50%*
WASTE	**123,000**	**126,000**	**117,000**	**97,000**	**-21%**	**-17%**
Waste	**123,000**	**126,000**	**117,000**	**97,000**	**-21%**	**-17%**
Waste Management	*122,000*	*124,000*	*115,000*	*95,000*	*-22%*	*-17%*
Wastewater Treatment	*2,000*	*2,000*	*2,000*	*2,000*	*0%*	*0%*
TOTAL EMISSIONS	**6,131,000**	**6,595,000**	**6,689,000**	**6,132,000**	**0%**	**-8%**
Per person	**11.9**	**11.5**	**11.3**	**9.7**	**-19%**	**-14%**
GHG OFFSETS		**-196,000**	**-143,000**	**-91,000**		
City Light Offset Purchases		**-196,000**	**-143,000**	**-91,000**		
TOTAL AFTER OFFSETS	**6,131,000**	**6,399,000**	**6,546,000**	**6,041,000**	**-1%**	**-8%**
Per person	**11.9**	**11.2**	**11.0**	**9.5**	**-20%**	**-14%**

Source: Stockholm Environment Institute 2014, p. 7

In 2012 road transportation accounted for 64% of Seattle's core emissions. Core emissions for Seattle have decreased slightly from 3.8 million tons in 1990 to 3.6 million tons in 2008 and 2012, despite growth 23% population growth and 14% job growth. Per person Seattle's total GHG emissions decreased 22% from 1990 to 2012. The building and waste sectors saw greater decreases in emissions (-31% and -37%) than the transportation sector (-11%). The decrease in vehicle emissions per person is attributed to residents driving more fuel efficient cars fewer miles (Stockholm Environment Institute 2014).

Every 7 to 8 years the Puget Sound Regional Council performs a household travel survey to learn about the demographic characteristics and travel behaviors of the area's residents. The latest 2014 survey showed growth in the share of transit and nonmotorized trips and a decrease in the the share of driving trips. In 1999 travel in personal vehicles accounted for 86% of trips and in 2014 82% of trips took place in a personal vehicle. Although the regional shifts in mode were not large, the urban core of Seattle experienced greater change. 18-24 year olds and 25-35 year olds were more likely to shift from automobiles to other modes. The survey also found that fuel prices and better high-speed transit options would most influence people to take an alternative mode of transport to work (Puget Sound Regional Council 2015).

Table 3 Puget Sound Regional Mode Shares, 1999 To 2014

	1999	2006	2014
Auto	86.0%	84.8%	81.5%
Walk	6.1%	7.7%	11.0%
Transit	2.6%	3.2%	4.2%
Bike	0.9%	1.0%	1.3%
Other	4.4%	3.3%	2.0%

Source: Puget Sound Regional Council 2015, p. 8

The above data shows important shifts in transit and walking. Between 1999 and 2014 transit shares grew by 60%, and walking trips grew by 80%. The increase in walking share is likely exaggerated by changes to methods in the 2014 survey, but the growth in walking trips is still clear. While biking share also increased from 1999 to 2014, the increase is not as dramatic as walking or transit.

2010-2014 American Community Survey data in the table below shows the commute patterns of Seattle's residents. More than half drive alone, and a much smaller percentage (8.4%) carpooled to work. The Seattle rates of public transit (19.6%) are high when compared to the whole Puget Sound. While the percentage of people who bike to work is not large, it is higher than the Puget Sound as a whole.

Table 4 2010-2014 ACS Seattle Commute Info

Means of Transport	Percentage
Drove alone	51.0%
Carpooled	8.4%
Public Transit	19.6%
Walked	9.3%
Biked	3.7%
Other	1.3%
Worked at home	6.7%

Source: 2010-2014 American Community Service

Seattle Regional Growth Centers have very different mode share than the entire Puget Sound region. The table above shows transit and walking trips are a far bigger share and personal vehicles have a smaller share than the region as a whole.

Table 5 2014 Mode Shares to Seattle Regional Growth Centers, All Trips

	Downtown	First Hill/ Capitol Hill	Northgate	South Lake Union	University Community
SOV	16%	23%	56%	28%	22%
HOV	14%	14%	29%	12	16%
Transit	27%	17%	6%	14%	21%
Walk	38%	41%	5%	37%	31%
Other	3%	5%	3%	9%	10%

Source: Puget Sound Regional Council 2015, p. 9

The plans, policies, and goals of Seattle and the Puget Sound support efforts to reduce Greenhouse Gases. In 2011 the Seattle City Council adopted resolution 3132 to pledging to strive to reach net zero greenhouse gas emissions by 2050 and prepare for the likely impacts of climate change. (Seattle City Council 2011).

Seattle's Comprehensive Plan lays out a vision for how the city will grow in the future. The current Comprehensive Plan was meant to guide growth during the years 1994-2004, and the yet to be adopted draft Plan, Seattle 2035, will direct Seattle's growth from 2015 until 2035. The core values in both versions of Seattle's Comprehensive Plan are: race and social equity, economic opportunity and security, environmental stewardship, and community. Seattle 2035 added a focus on carbon neutrality to the environmental stewardship value. The updated plan also has new goals and policies to help achieve carbon neutrality, including a development pattern that reduces vehicle trips, and improvements that encourage walking, biking and transit options (City of Seattle 2015a).

Transportation 2040 is the central Puget Sound region's long range multimodal transportation plan. The plan outlines investments and strategies for the next 30 years aimed

at meeting the transportation demands of the the region's growing population. The strategy to meet these demands is to invest in bike and pedestrian facilities, local and regional transit, auto and passenger ferries, city and county roads, and state highways. This will reduce congestion, increase the mobility of people and freight, and protect the environment (Puget Sound Regional Council 2014).

The goals of Transportation 2040 will be achieved with costs and revenues in balance. In the future revenues will rely less on gas taxes and more on user fee-based approaches (i.e. High Occupancy Toll lanes (HOT), facility and system tolls, and mileage fees). The reason for this switch is the recognition that the gas tax will likely not be a feasible long term source of revenue and because user fees may provide more equity between use and funding. But revenues have decreased while costs have increased. To create a balanced financial strategy this plan moved many projects into the unprogrammed category and prioritizes transportation investments. Prioritization is based on nine measures: Air Quality, Freight, Jobs, Multimodal, Puget Sound Land & Water, Safety and System Security, Social Equity & Access to Opportunity, Support for Centers, and Travel. These measures are applied to four categories of projects: highways, arterials, transit, and bike/pedestrian (Puget Sound Regional Council 2014).

In the next decade the region will focus its limited funds on keeping existing investments in a state of good repair, finishing the planned Link Light Rail extensions, complete the HOV system, implement HOT lanes, replace vulnerable structures, and fill in gaps and add new bicycle and pedestrian connections to transit stations and growth centers (Puget Sound Regional Council 2014).

The Seattle Climate Action Plan (CAP) lays out what the City government should do to reach its goals to be carbon neutral by 2050 and to prepare for the impacts of climate change. The emphasis of the plan is on the areas where the City can be most effective in reducing GHG emissions: road transportation, building energy, and waste. It also looks at actions that can increase resilience to the impacts of climate change in Seattle (City of Seattle Office of Sustainability and Environment 2013)

The actions of the CAP aim to reduce GHG emissions in the passenger transportation and building energy sectors by 62% by 2030 and achieve carbon neutrality by 2050. The Plan recognizes that many of the recommended strategies need a much greater deal of public resources than currently available, particularly the transportation sector strategies. This will require new and sustained funding sources (City of Seattle Office of Sustainability and Environment 2013).

In the next 20 years Seattle is expected to get over 100,000 new residents and 100,000 new jobs. This new growth cannot happen though car-dominated land use and transportation strategies, because not only will GHG emissions increase but there will not be enough physical space to accommodate the new housing and jobs. New growth should be managed through the creation of pedestrian-friendly urban centers and neighborhoods (City of Seattle Office of Sustainability and Environment 2013).

The CAP strategies to reduce road transportation emissions include expanding transportation choices, creating complete communities, and providing economic signals that show the true cost of driving. The increased transportation choices include adding more transit, walking, and bicycling infrastructure and services. Complete communities are created by

placing homes and businesses in walkable neighborhoods. The City has a goal to reduce passenger vehicle transportation emissions 82%, vehicle miles traveled by 20%, and emissions per mile traveled by 75% by 2030 compared to a 2008 baseline. The full package of transportation and land use actions laid out in the CAP would get the city very close to its 2030 goals, and put it on track to be close to carbon neutral in 2050. Economic signals are an important part of this package because road pricing and parking management actions are expected to account for a quarter of 2030 emissions reductions and would be a source of funding for expanding transportation choices (City of Seattle Office of Sustainability and Environment 2013).

The CAP takes its vision for transportation infrastructure and services from the City's existing transportation master plans (Transit, Pedestrian, Bicycle, and Freight), and highlights some of the key actions from those plans. The vision for 2030 is to make walking, biking, or transit the easiest modes of travel in the City. There will also be rail lines, dedicated bus lanes, and cycle tracks that traverse the city. The Frequent Transit Service network is complete, the pedestrian network is complete within ½ mile of high use locations, and every home is within ¼ mile of a bike facility. (City of Seattle Office of Sustainability and Environment 2013).

Transportation Demand Management will complement the new transportation infrastructure. This will include programs that incentivize and encourage transit, walking, and bicycling and expanding the existing Commute Trip Reduction program. The 2030 vision still foresees a need for auto travel, so reducing emissions through cleaner vehicles and fuels is an important factor in the larger transportation equation. The CAP envisions that 15% of

passenger cars will be electric in 2030, so Seattle will need to add more charging stations, possibly in the right-of-way (City of Seattle Office of Sustainability and Environment 2013).

To create complete communities a goal of the CAP is to have 45% of residents and 85% of jobs in Urban Centers and Urban Villages. The suggested actions to implement this goal are to encourage a greater diversity of housing types, create affordable homes and commercial space, and preserve industrial lands (City of Seattle Office of Sustainability and Environment 2013).

In response to the carbon neutral resolution and an update of the City's Climate Action Plan, the Seattle Office of Sustainability and Environment (OSE) commissioned the report "Getting to Zero" to outline how the city could achieve the goal of carbon neutrality. The report presents three broad outcomes that would reduce Seattle's per capital GHG emissions by 30% by 2020, 60% by 2030, and 90% by 2050% compared to 2008 levels. The first strategy envisions switching to travel modes that emit less GHGs like ride sharing, transit, walking and biking. The other strategies are to increase the energy efficiency of buildings and vehicles and to transition to lower carbon energy sources (City of Seattle Office of Sustainability and Environment 2011).

The City can influence many aspects of these strategies, including reducing vehicle miles traveled (VMT), developing alternative transportation modes, energy efficiency of buildings, and creating electric vehicle infrastructure. But federal and international action is necessary for improving vehicle efficiency and developing alternative fuels. Since it could prove difficult or costly to completely stop GHG emissions, the City may need to implement a strategy to offset the remaining emissions. This could include sequestration and credit for selling excess

renewable energy, among other things (City of Seattle Office of Sustainability and Environment 2011).

Getting to Zero lays out two complementary strategies to increase transportation options and reduce vehicle miles travelled by light duty vehicles. The first is to invest in transit, bike, and pedestrian infrastructure. The goal of investing in infrastructure would be to offer quick, easy, and pleasant alternatives to car travel. This would include expanding transit infrastructure and service to induce an increase in the share of passenger miles travelled by transit from 8% to 25% by 2050. Other cities like San Francisco, Boston, Chicago, New York and Washington DC already have transit mode shares at this level. To do this would mean wide geographic coverage, increased frequency and reliability, and decreasing transit travel times. Investing in bike and pedestrian infrastructure would mean giving motorized vehicles, bicyclists, and pedestrians equal access to the street. This would include adding dedicated bike lanes, boulevards, trails, wider sidewalks, narrow pedestrian crossings, convenient transit stops and traffic signals. Building Seattle's existing Pedestrian and Bicycle Master Plans, along other investments would help to expand the City's pedestrian and bicycle infrastructure (City of Seattle Office of Sustainability and Environment 2011).

The second is to create mechanisms that give travelers incentives to reduce single occupancy vehicle travel. These mechanisms include roadway pricing, Pay as You Drive insurance, parking pricing, and trip reduction programs. Together these two transportation strategies have the potential to decrease per capital LDV VMT 34% by 2050. While the main driver of this decrease is the pricing strategies, to provide affordable and convenient transportation alternatives it is necessary to invest in transit, pedestrian, and bike

infrastructure. Under this scenario biking, walking, and transit shares in terms of passenger-miles traveled would triple by 2050. A passenger mile is one mile travelled by one passenger in a specified mode. This scenario of carbon neutrality would also involve developing denser, transit-oriented neighborhoods to aid the travel reduction strategies. This is because people who live in compact developments have been shown to walk, bike, and use transit more and drive less (Ewing and Cervero 2010). Increases in vehicle efficiencies and switching to cleaner fuels is the final factor for decreasing GHG emissions from transportation. All of these transportation efforts together are estimated to reduce road transportation emissions by 90% in 2050 over 2008 levels (City of Seattle Office of Sustainability and Environment 2011).

CHAPTER 3: METHODS

This section will give an explanation of the object of study (Seattle's ROW) and the data used for analysis, and the analysis performed. The first part of the analysis looks and the ROW as it is today, and the second part looks at how greenhouse gas reduction strategies would alter the ROW.

CITY OF SEATTLE RIGHT-OF-WAY

A right-of-way (ROW) is land over which a public road is built, land used by a public utility, or land occupied by a railroad. (Merriam-Webster). The function of the Seattle ROW is to support the movement of people, goods, and services and access to property (City of Seattle 2012). The Seattle Right-of-Way Improvements Manual (ROWIM) is a resource that contains information about the City's design criteria for street right-of-way improvements. It categorizes the different ROW users as pedestrians, non-motorized vehicles, automobiles, transit, and freight. ROWIM traffic classifications are used to describe the roadway network and include interstate freeways, regional, principal, minor and collector arterial streets, commercial and residential access streets and alleys. (City of Seattle 2012)

Seattle is the 23rd most populous city in the US (City of Seattle 2016), and is growing in population every year. According to the decennial census population count there were 608,660 people living in Seattle in 2010, and Washington's Office of Financial Management (OFM) estimated Seattle's population grew to 662,400 by 2015. That is a population increase of almost 54,000 or 8.8% in 5 years. Population growth is projected to continue, and the city is planning to add an extra 70,000 housing units and 115,000 jobs between 2015 and 2035 (City of Seattle

2015). Because right-of-way is difficult to expand, extra demand from population growth will need to be accommodated within the existing space.

DATA COLLECTION & ANALYSIS

The GIS data used to map the right-of-way is from the City of Seattle in June 2015. The layers used include Right of Way (polygon), City Limits, Hansen Street, Traffic Lanes, Sidewalks, and Street Parking by Category.

To analyze Seattle's ROW, I started with the Right of Way (polygon) layer. I clipped the Right of Way polygon layer using the City Limits layer to get a ROW layer that only included land within the Seattle City Limits. I found the area in feet of the clipped Right of Way (polygon) and the City Limits layer by using the summary statistics tool in ArcMap.

Next I added a column titled "Category" to the Right-of-Way (polygon) attribute table and assigned each feature one of the following categories: Agency Property, Alley, Arterial, Highway & State Route, Non-Designated, Railroad and Other. I chose these categories based on how ROW parcels and streets are classified in the attribute tables of the Right of Way (polygon) layer and the Hansen Street layer.

The Right of Way (polygon) layer classifies ROW parcels under the L_FEA_SYM field as RW, RW adjustment (ordinance), RW adjustment (deed), agency property, easement, court cause (scc), RW (alley), and RW (railroad). For this study parcels classified as RW (railroad), RW (alley) and agency property (if it was not part of the roadway) did not need to be analyzed any further. The categories agency property, alley, and railroad were assigned using the calculate field tool and the corresponding L_FEA_SYM field classifications.

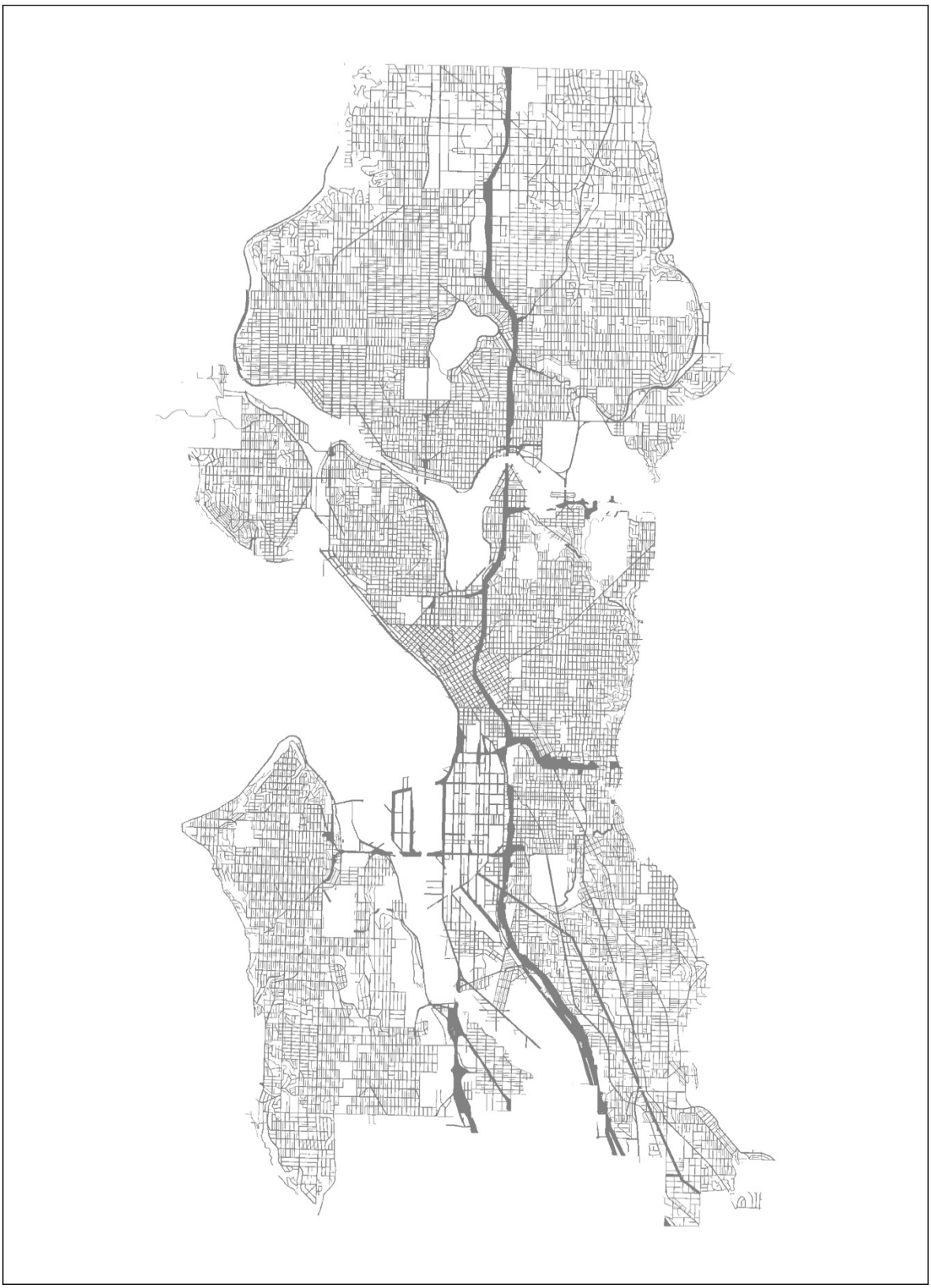


Figure 5 City of Seattle right-of-way GIS layer

The remaining parcel types needed to be broken down further because they represented streets with uses that take place in discrete spaces (sidewalks, bike lanes, traffic lanes, etc). The Hansen Street layer classifies streets under the artdescript field as principal arterial, collector arterial, county arterial, minor arterial, not designated, interstate/freeway, state route/freeway. I used the principal arterial, collector arterial, and minor arterial values to create the arterial value in the Right of Way (polygon) category field. I grouped those values together because the process for breaking down streets is the same for all arterials. There were no county arterials within the city limits so they were not included. I combined the interstate/freeway and state route/freeway values to assign the "freeway" value in the Right of Way (polygon) category field because this these road types are similar and don't require further analysis. The "not designated" artdescript value was used to assign the "not designated" category value.

To use the Hansen Street layer to assign values to the Right of Way (polygon) layer I created 70 foot buffers around the different groups of street types, selected by location the ROW parcels that had centers within each buffer, and assigned the appropriate category to the selected parcels using the field calculator. In cases where parcels covered more than one type of street, the parcel was assigned to the category of more intense use (e.g. Freeway over Arterials, Arterials over non-designated). I made this decision because it would have been too time intensive to fix these problems on a case by case basis.

At this point there were still some parcels that were used as not designated or arterial streets, but whose centers were not within the not designated or arterial buffer layers. To

correct this, I selected parcels by location that shared a line segment with the not designated or arterial buffers and assigned the selected parcels to a category.

The process of assigning parcels to a category was not accurate in all cases, mostly due to parcels that were oddly shaped and/or fell under multiple categories. Because of this I made some fixes, including visually checking and making changes to standout problem areas. The areas around the Freeways were particularly problematic because of large and unusually shaped parcels, so I manually corrected those issues using the cadastral annotation layer, 2013 aerials, and the Hansen Street layer as a guide. The Freeway category included on & off ramps, and had parcels missing in a few areas.

Parcels left uncategorized were assigned as other. These parcels were mostly unimproved and/or covered in vegetation. At this point the parcels categorized as "Arterial" and "Not Designated" required more analysis and breakdown because different areas of those parcels are devoted to different uses. The parcels categorized as agency property, railroad, other, and alleys did not require more analysis. While these categories might have more than one use, the different uses all happen in the same space.

Figure 6 Example of Right-of-way categories in South Seattle

To understand how the space in arterial and not designated parcels is allocated, I used a combination of the Traffic Lanes, Sidewalks and Street Parking by Category layers. I started with

the traffic lanes layer and used lane type column to calculate the area of different types of street lanes on arterial streets by multiplying lane width and lane length. The lane type column of the Traffic Lanes layer breaks street lanes into 41 types, which I grouped into driving, parking, median, bike only, and bus lanes.

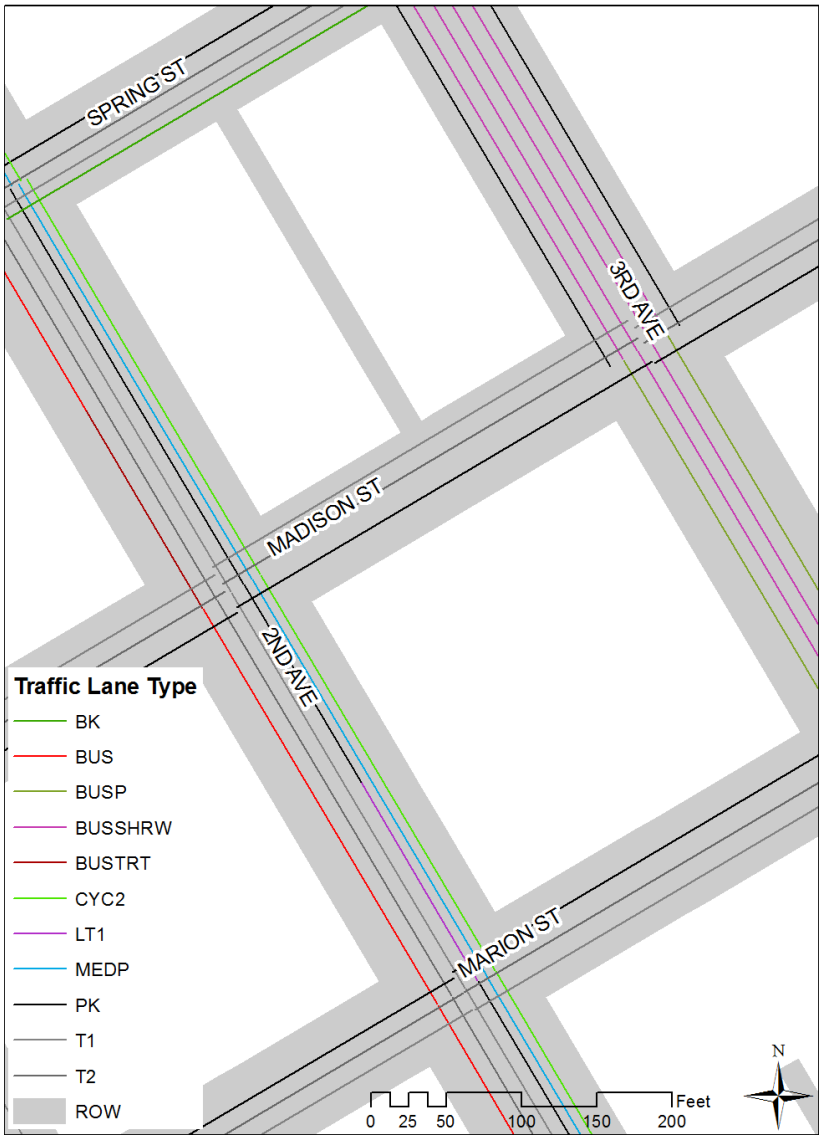


Figure 7 Downtown Traffic Lane Types

(BK: Bike Lane; BUS: Bus Only Lane; BUSP: Bus PM; BUSSHRW: Bus only w/ sharrow; BUSTRT: Bus Only Thru, Right Turn Lane; CYC2: Protected Bike Lane Two-Way; LT1: Left Turn 1; MEDP: Median Painted; PK: Parking; T1: Travel Lane 1; T2: Travel Lane 2)

To find the area devoted to those different groups I had to make some assumptions. For the "Bike Lane and Parking" lane type I assumed that parking took up 7 feet and the bike lane took up whatever was left over.

The Traffic Lanes layer did not include data on sidewalks, so I used the Sidewalk layer to find the area of sidewalks on arterial and not designated streets. I created a buffer using the width measurement given in the SW_Widths column and dissolved the buffer so that overlapping areas would not be counted twice. The data included in the Sidewalk layer has a few errors, including widths that are clearly too small or too big.

The Traffic Lanes layer had data for all arterials but only a few not designated streets, so I did not use Traffic Lanes data to breakdown the not designated streets. I used the Street Parking by Category layer to find the area used for parking on not designated streets. First I selected the Street Parking by Category lines on not designated streets using the 70 foot not designated buffer and then used the Parking_Category column to select all categories except "no parking allowed". Then I exported a table of the selected Street Parking by Category features and multiplied the blockface_length column by 7 feet to find the area.

To find the area of the not designated streets (which does not include paved sidewalks, landscape/furniture or frontage zones) I used the surfacewidth column from the Hansen Street layer. Width data was not available for all streets, so where it was missing I assumed a width of 25 ft because that is the mode of the not designated street that have data. I created a buffer

based on the not designated street widths, and then subtracted the parking area to find the driving lane area. To find the area of the Landscape/Furniture & Frontage Zones I subtracted the Pedestrian Zone (Paved Walkway) area and street area from the total ROW area.

"Moving Cooler" offers three levels of intensity of greenhouse gas reductions. This thesis uses the most intense version of GHG reductions, Level C to calculation ROW changes. Level C means a range of things would happen within 5 years and 10 years of implementation. Within 5 years all new construction would have buffered sidewalks on both sides of the street. New construction would also have marked or signalized pedestrian crossings at collector and arterial intersections. Reconstructed streets in denser neighborhoods (>4,000 persons/square mile) and business districts would have extensive traffic calming measures. These measures include bulb-outs and median refugees to shorten street-crossings. State and local transportation agencies would also adopt "complete streets" policies.

In 10 years there would be evaluation and retrofits of existing streets within one-half mile of business districts, transit stations, and schools. These streets would be evaluated for pedestrian friendliness and of curb ramps, sidewalks, and crosswalks would be added were needed.

The part of the "Moving Cooler" pedestrian strategy that would have the most impact on ROW allocation is adding sidewalks in the vicinity of business districts, transit stations, and schools. While adding curb ramps would alter the ROW, it would not change ROW allocation. The space taken up by crosswalks in Seattle was not calculated in this analysis because it is not exclusively pedestrian. The addition of curb bulbs and median refuges would change the ROW allocation, but would be difficult to calculate and are not included in this analysis.

The Seattle Municipal Code requires sidewalks in many, but not all cases. The dedication of new streets requires sidewalks and curbs. In urban centers and urban villages sidewalks are required when new lots are created or whenever development is proposed abutting an existing street without a sidewalk. Outside of Urban Centers and Urban Villages sidewalks are only required in certain circumstances. There are several exceptions to these requirements, such as the construction of a single family dwelling on a lot with no existing pedestrian improvements within 100 feet.

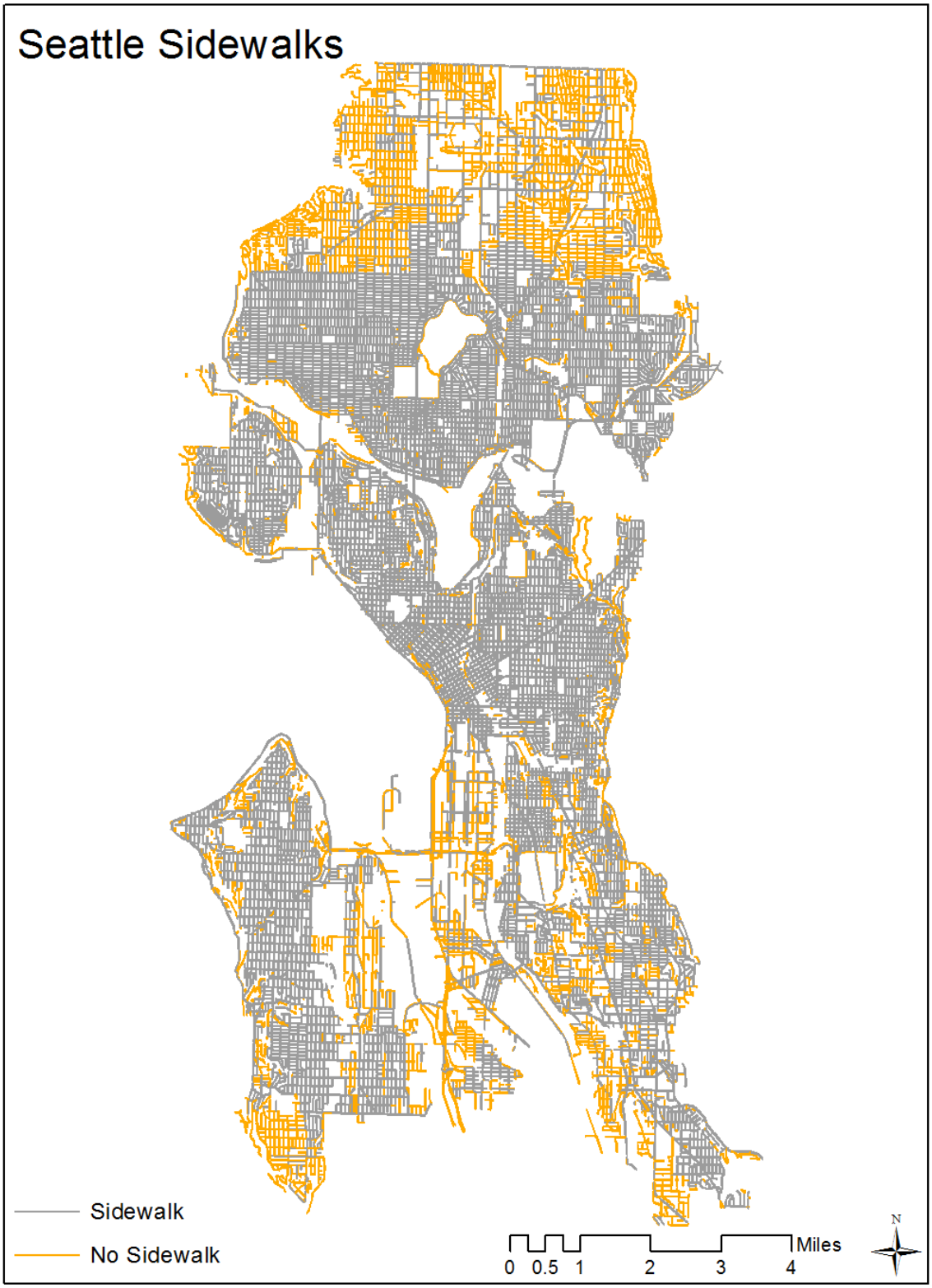


Figure 8 Seattle Sidewalks

This analysis will calculate how the ROW would change if sidewalks were added in all business districts, transit stations, and schools. Urban villages (excluding manufacturing industrial) are used as a stand in for business districts. A public school GIS point layer was used for schools to find the area in Seattle around schools. For transit stations I used Link station points, Sounder station points, and Streetcar station points. The final GIS layer used in this part of the analysis was the Seattle sidewalks layer.

To begin I created a one-half mile buffer around the urban villages, schools, and transit layer. I then used those buffers to clip the sidewalk layer. From the selected sidewalk layer, I found how many feet of unimproved sidewalks were in these buffered areas. Next I multiplied the length of unimproved sidewalk by 6 feet (the minimum pedestrian zone width listed in the ROWIM). This area was then subtracted from the landscape/furniture/frontage zone.

The most intensive Moving Cooler bicycle strategy (Level C) involved implementing bicycle stations and bicycle networks. The strategy called for bicycle stations in all major activity centers, transit hubs, and center business districts within 5 years. It also calls for implementing a bicycle network (bicycle lanes, bicycle boulevards, and shared use paths) at one quarter mile spacing in areas with a population of >2,000 persons per square mile. This translates to eight miles of bicycle network per square mile. This network would consist of half bicycle lanes, one-quarter bicycle boulevards, and one-quarter shared use paths. In Seattle this would mean 664 miles of bicycle network within 40 years. The minimum width for a bicycle lane in Seattle is 4 feet adjacent to the curb and 5 feet adjacent to parking.

To find the physically separated bicycle lanes planned for the Seattle ROW I used the BMP Citywide Network GIS layer and the Local Connector Network GIS layer. From the BMP

Citywide Network started by selecting lines that were “not existing” and were either “cycle track” or “off street”. I excluded the lanes that overlapped with the bicycle lanes listed in the Traffic Lanes GIS layer (which only happened in a few cases).

From the Local Connector Network I selected lines that were not existing, and cycle track or in street minor separation, or off street. The Shared Street and Neighborhood Greenways were not included because they do not have a physically separate space for bicycle use.

From the previously selected, next I selected the BMP Citywide Network and Local Connector Network lines using a 70-foot buffer around Seattle streets. This excluded bike lanes not in the ROW GIS layer. For example, there are no ROW parcels in Seward Park, but there is a bicycle lane.

To calculate the area of the planned bicycle lanes I assumed that the minimum width of a bike lane was 4 feet (the minimum width of a bicycle lane listed in the Seattle ROWIM). While this minimum width applies only to bicycle lanes adjacent to the curb, I do not currently know how streets will be rearranged in the future to accommodate bicycles. So the added bicycle lane area represents the minimum amount needed to implement the BMP, although after implementation this area could be bigger. I am not breaking down these numbers between arterials and local streets because for at least some of these lanes the exact routes are yet to be determined.

A regulatory measure in Moving Cooler that would alter the ROW would be to create Urban Nonmotorized Zones. Level C of this strategy would mean that with a 10-year period, 6

percent of the central business district and regional employment and retail centers centerline miles would be converted to transit malls, linear parks, or other nonmotorized zones.

To find the ROW area required to fill this strategy in Seattle I used urban villages as a stand in for the central business district and regional employment and retail centers. I selected the ROW parcels with their centroid in the urban village layer (excluding manufacturing industrial).

The approach used for analysis is limited in several ways. The some of the datasets used in have incomplete or inaccurate entries, and in some of these cases I made assumptions to correct for these issues. I was also limited by the datasets that were available, and some information that would have improved this analysis was not available. For example, it would have been useful to have more information about the landscaped areas of the ROW.

CHAPTER 4: FINDINGS

This section discusses the results of the ROW analysis. It begins with an overview of the ROW as it exists today, including the different categories of ROW parcel and the different uses that take place in the ROW. The second part of this section looks at how greenhouse gas reduction strategies would change the ROW, and what the reductions in emissions would be.

ROW ANALYSIS RESULTS

Table 6 Right-of-way and Seattle area

Seattle right-of-way	23 square miles
Seattle land with water bodies	84 square miles
Percent of Seattle that is ROW	28%

Source: Seattle Right of Way (polygon) GIS layer and City of Seattle GIS layer

Seattle classifies streets in several different ways, including by traffic classifications. The traffic classifications are based on how a street features traffic movement versus direct access to property. The American Association of State Highway and Transportation Officials (AASHTO) standards provide the definitions for this classification. For example, freeways focus on traffic movement and limit access to adjacent land, and local streets prioritize access to adjacent land uses (City of Seattle 2012). The Seattle street classifications were used to create the ROW categories for this analysis. The table below shows the breakdown of the right-of-way by the category assigned to each parcel.

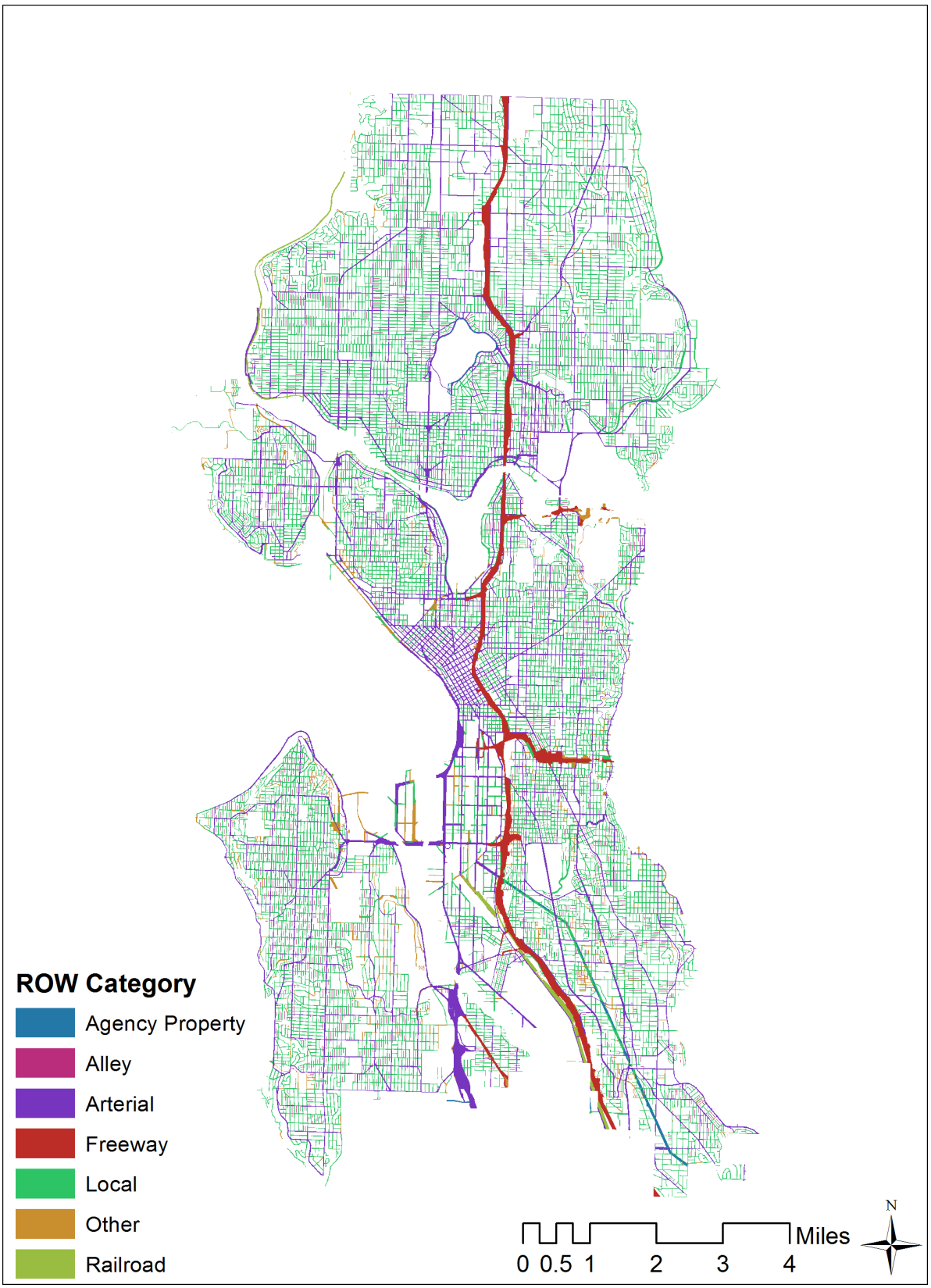


Figure 9 Right-of-way parcels by category

Table 7 Right-of-way category results

Category	Square Miles	Percentage of right-of-way
Local Streets	12.81	55%
Arterials	6.42	28%
Freeways	1.57	7%
Undeveloped	0.99	4%
Alley	0.9	4%
Railroad	0.27	1%
Agency Property	0.15	0.64%

Figure 10 Local Street in Wallingford

Photo: Author

Local streets make up over half (55%) of land devoted to the right-of-way. The purpose of local streets is to provide access to adjoining properties and they are not meant for through traffic (USDOT 2012). Adjacent uses can be residential or industrial and manufacturing.

Figure 11 23rd Ave (Principal Arterial) at E Cherry St

Photo: Author

Arterials make up the second biggest piece of the right-of-way at almost 28%. Arterial Street serve high-speed and high volume traffic movements for travel between major locations (USDOT 2012). Seattle further breaks these streets into principal, minor, and collector arterials. Principal arterials are the main routes for moving traffic through the city. They connect urban centers and urban villages to one another or to the regional transportation network. Minor Arterials deliver traffic from principal arterials to collector arterials and access streets. Collector Arterials can either offer direct access to destinations or collect and move traffic from principal and minor arterials to local access streets (SDOT 2005).

Freeways allow for the unimpeded flow of large amounts of traffic and have tightly controlled access (USDOT 2012). The land devoted to freeways makes up close to 7% of the right-of-way. Not all of this space is used for traffic lanes, however. Some of this land is vegetation and buffer space.

Source: (of background image)ESRI

Figure 12 Undeveloped ROW near 19th Ave S and S Juneau St

Parcels that fall into the undeveloped category are mostly unimproved right-of-way covered in vegetation. An example of this can be seen below in a picture of the Maple School Natural Area. This category makes up a little over 4% of the right-of-way.

Figure 13 Residential Alley in Queen Anne

Photo: Author

Alleys offer access to the back of residences and businesses and are not meant for through trips. Alleys are multipurpose spaces that can be used for parking, trash collection, commercial uses, and community activities. Alleys make up almost 4% of the right-of-way.

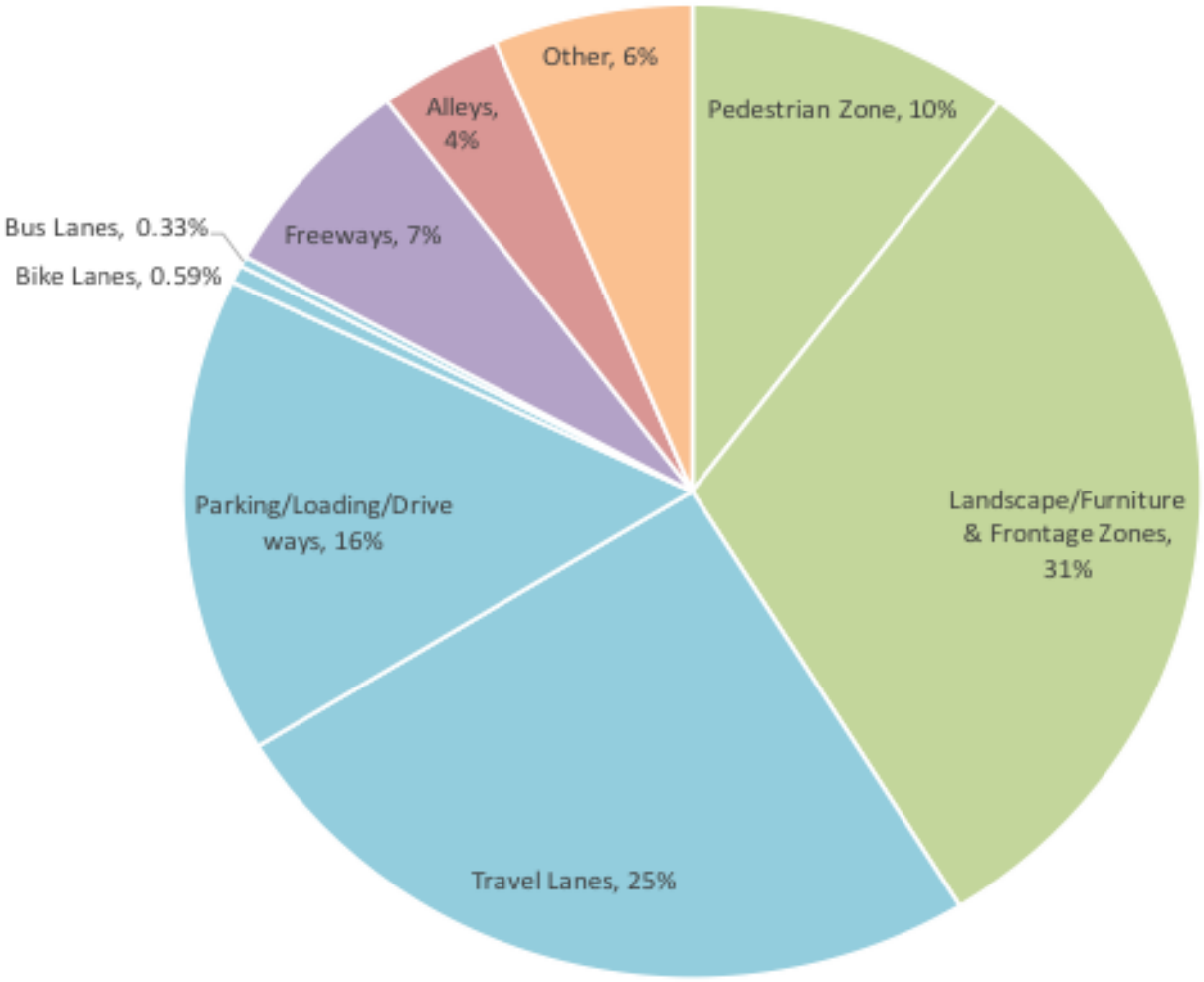


Figure 14 Right-of-way by use

The right-of-way can also be broken down the by use in the ROW parcels. The next section provides a deeper look at the activities that happen within the separated spaces of local and arterial streets. These activities include walking, biking, driving, taking transit and socializing.

Table 8 Right-of-way by use

Right-of-Way Use	Square Miles	Percent of Right-of-Way
Sidewalk Corridor		
Landscape/Furniture & Frontage Zones	7.14	31%
Pedestrian Zone	2.38	10%
Roadway		
Driving Lanes	5.79	25%
Parking	3.66	16%
Bike Lanes	0.14	0.59%
Bus Lanes	0.08	0.33%
Other		
Freeways	1.57	7%
Alleys	0.9	4%
Undeveloped	0.99	4%
Railroad	0.27	1%
Agency Property	0.15	0.64%
Arterial Medians	0.05	0.22%

Figure 15 Frontage, Pedestrian, and Furniture zone on Ballard Ave

Photo: Author

41% of the right-of-way is devoted to pedestrian activities. This area is made up of the land between property lines and curbs, otherwise known as the sidewalk corridor. The sidewalk corridor is made up of a frontage zone, a pedestrian zone, and landscape/furniture zone (City of Seattle 2012). The pedestrian zone accounts for 11% of the right-of-way. The landscape/furniture & frontage zones make up nearly 31% percent of the ROW. It is not possible to separate out the percentage of landscape/furniture zone from the percentage of frontage zone with the data available for this analysis.

Figure 16 Landscape zone in Ballard

Photo: Author

The frontage zone is the area between the property line and pedestrian zone. This area can be used for sidewalk cafes, store entrances, retail display, or landscaping. Where there is sufficient right-of-way the frontage zone is required to be a minimum of 2 feet. The pedestrian zone is the section of the sidewalk corridor that is reserved for pedestrian travel. The minimum required width of the pedestrian zone is 6 feet, with the exception of areas in high and intermediate capacity transit stations. The landscape/furniture zone is the area between the pedestrian zone and the curb. It buffers pedestrians from from the roadway and can be used

for street furniture, art, landscaping, and waiting areas for transit customers. The minimum required width of the landscape/furniture zone is 5 ½ feet, with the exception of areas in high and intermediate capacity transit stations (City of Seattle 2012).

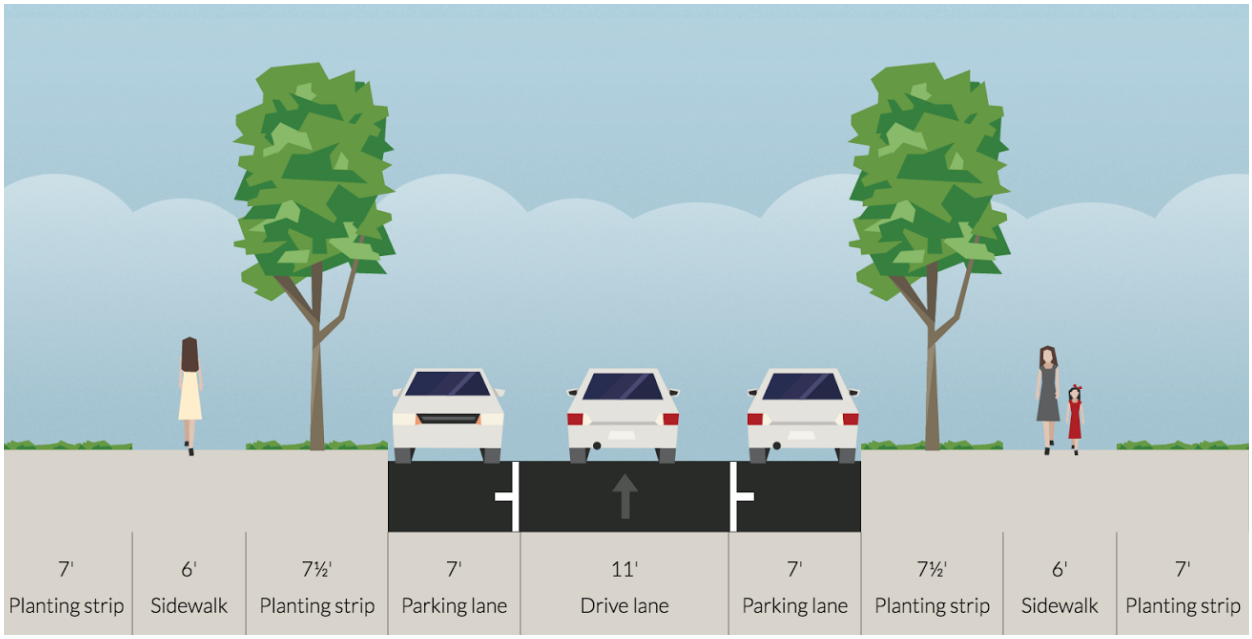


Figure 17 Residential Street Diagram - Modeled after Bagley Ave N.
Source: Created by author using Streetmix.net

While it may seem like an overly large percentage of the ROW devoted to the sidewalk corridor, looking at a diagram of a typical residential street shows how this could be the case. The diagram above was modeled on a fairly typical residential street. The roadway width is 25 feet, and the curb to property line width is 41 feet for a total ROW width of 66 feet. The roadway makes up about 38% of the right-of-way width and the sidewalk corridor makes up the additional 62%. The pedestrian zones are about 18% and the landscaped sections are about 43% of the ROW width.

Looking at the average numbers of all local streets shows that the sidewalk corridor makes up 54% of local street right-of-way width and roadway accounts for 46%. The average of arterial right-of-ways has a slightly different division, with sidewalk corridor making up 40% of the right-of-way width and roadway making up 60%. The local street right-of-way and arterial right-of-way makes up 55% and 28% of the total right-of-way, respectively.

Table 9 Sidewalk corridor and roadway breakdown

	Square Miles	% of ROW	% of Local ROW	% of Arterial ROW
Local Streets	12.81	55%	100%	N/A
Sidewalk Corridor	6.96	30%	54%	N/A
Roadway	5.84	25%	46%	N/A
Arterial Streets	6.42	28%	N/A	100%
Sidewalk Corridor	2.55	11%	N/A	40%
Roadway	3.87	17%	N/A	60%

Figure 18 23rd Ave Traffic Lanes

Photo: Author

The roadway section of the right-of-way is used for vehicular travel (cars, trucks, bicycles and transit) and on-street parking. The roadway can also contain medians, crossing islands,

traffic circles, and utility access points. The standard roadway widths for non-arterial streets range from 25 feet to 40 feet, and required arterial roadway widths range from 30 feet to 360 feet (City of Seattle 2012).

For this analysis traffic lanes are the section of the roadway used for moving car traffic, bus and bike traffic. This excludes the areas devoted to parking, bus lanes, bike lanes, and medians. Travel lanes make up about 25% of the ROW.

Figure 19 Parking Lane on Ballard Ave

Photo: Author

The area of the roadway used for parking, loading zones, and curb cut access to driveways makes up about 16% of the total right-of-way.

Figure 20 NE 40th St green bike lane

Photo: Author

Bike lanes only make up 0.59% of the right-of-way. This number includes buffered, green, protected one-way, and protected two-way bike lanes. It does not, however, include sharrows because they share the same space as travel lanes.

Figure 21 Westlake Ave N bus only lane

Photo: Author

Bus lanes make up an even smaller percentage of the right-of-way at 0.33%. This number includes lanes that are exclusive to buses fulltime and only at peak hours.

Table 10 below shows the breakdown of arterial ROW by use. It shows that arterials are more roadway (60%) than sidewalk corridor (40%), and that bike and bus lanes still make up a very small percentage (2% and 1%) of the arterial ROW.

Table 10 Arterial right-of-way by use

Right-of-Way Use	Square Miles	Percent of Right-of-Way	Percent of Arterial ROW
Sidewalk Corridor			
Landscape/Furniture & Frontage Zones	1.77	7.68%	27.65%
Pedestrian Zone	0.78	3.36%	12.10%
Subtotal	*2.55*	*11.05%*	*39.75%*
Roadway			
Driving Lanes	2.96	12.83%	46.19%
Parking	0.65	2.82%	10.14%
Bike Lanes	0.13	0.58%	2.09%
Bus Lanes	0.07	0.29%	1.04%
Median	0.05	0.22%	0.79%
Subtotal	*3.87*	*16.74%*	*60.25%*
Total	**6.42**	**27.79%**	**100.00%**

Table 11 shows the breakdown of local streets by use. It shows that local streets have a higher percentage of sidewalk corridor than arterial streets. It also shows that parking on local streets is a relatively large percentage (23%) compared to arterial parking (10%).

Table 11 Local street right-of-way by use

Right-of-Way Use	Square Miles	Percent of Right-of-Way	Percent of Local Right-of-Way
Sidewalk Corridor			
Landscape/Furniture & Frontage Zones	5.36	23.22%	41.88%
Pedestrian Zone	1.60	6.93%	12.50%
Subtotal	*6.96*	*30.15%*	*54.38%*
Roadway			
Driving Lanes	2.83	12.24%	22.08%
Parking	3.00	13.00%	23.46%
Bike Lanes	0.00	0.01%	0.02%
Bus Lanes	0.01	0.04%	0.07%
Subtotal	*5.84*	*25.29%*	*45.62%*
Total	**12.81**	**55.44%**	**100.00%**

HOW GHG REDUCTION STRATEGIES ALTER THE ROW

Completing the sidewalk system in the vicinity of Seattle business districts, transit stations, and schools would mean constructing and additional 0.58 square miles of sidewalk.

Implementing the strongest bicycle strategy outlined in Moving Cooler would mean a number of things. Putting bike stations in all major activity centers, transit hubs, and the CBD. Bicycle network at one quarter mile spacing in areas with a population density of >2,000 persons per square mile (Seattle has a population density of 7,920 persons per square mile) (OFM 2015). The assumption is that half of the bicycle network would be one half bicycle lanes,

one-quarter bicycle boulevards, and the last one-quarter shared-use paths. Seattle's Bicycle Master Plan (City of Seattle 2014) recommends creating the following bicycle network over the next 20 years (2014-2034):

Table 12 Seattle Bicycle Master Plan Recommended Network

	Total Network	Percent of Total Network
Off Street	78.9	13%
Cycle Track (protected bicycle lane)	104.8	17%
Neighborhood Greenway	248.9	41%
In Street, Minor Separation	137.9	23%
Shared Street	37.8	6%
Total	**608.3**	**100%**

Planned network does not line up exactly with Moving Coolers assumptions. The Seattle BMP plans for more bicycle boulevards (neighborhood greenways) and for less shared use paths (off street) than Moving Cooler. However, 53% of the planned bicycle network would have at least minor separation (off street, cycle track, and in street minor separation), and 41% is planned for quiet streets (neighborhood greenways).

The area required for the physically separated bicycle lanes planned for the Seattle ROW in the BMP but not yet built is outlined in the table below:

Table 13 Physically separated bicycle lanes planned for the Seattle

	Length (Miles)	Area (Sq. Miles)	Percent of ROW
Citywide Network	58.19	0.04	0.19%
Local Connector Network	78.10	0.06	0.26%
Total	136.28	0.10	0.45%

The new 0.10 square miles of separated bicycle lanes would be in addition to the existing 0.14 square miles of separated bicycle lanes. This means that over 1% of the ROW will be dedicated to bicycle use in the future.

According to "Moving Cooler" implementing the combined pedestrian and bicycle infrastructure and policies at a national level would lead to a cumulative reduction of 0.2 percent to 0.5 percent in baseline emissions. Cumulative reductions include all of the greenhouse gas reductions over the 40-year period of the "Moving Cooler" study. "Moving Cooler" assumes that a 1% of VMT will create a 1% reduction in GHGs, or a 1:1 ratio between VMT reduction and GHG reduction (Cambridge Systematics, Inc. 2009, p.B-7). "Getting to Zero" estimates that the bicycle and pedestrian infrastructure strategy will reduce light duty vehicle VMT by 6.0% in 2050, which would lead to a 6.0% reduction in GHG emissions (City of Seattle Office of Sustainability and Environment 2011, technical appendix p. 22). The baseline scenario for Seattle's core GHG Emissions is 4.0 million tCO2e in 2050, and a 6% reduction of emissions that would mean 0.24 million tCO2e (City of Seattle Office of Sustainability and Environment 2011).

If 6 percent of the ROW in Seattle's urban villages was converted to transit malls, linear parks, or other nonmotorized zones it would equal 4.9 square miles. Moving Cooler assumes a 5 percent effectiveness rate for light-duty vehicle trip reduction to/from the nonmotorized zone. It also assumed that 15 percent of the total metropolitan area VMT is trips to CBDs and other major retail/employment activity centers. The maximum annual VMT reduction of total metropolitan VMT is 0.03 percent. So based on Moving Cooler's assumptions, this could reduce GHG Emissions by 0.03 percent annually after implementation, which is assumed to happen

over a period of 10 years (Cambridge Systematics, Inc. 2009). In 2050 that would mean a 1200 tCO2e reduction.

CHAPTER 5: CONCLUSIONS AND FUTURE RECOMMENDATIONS

To reduce greenhouse gas emissions Seattle will need to implement multiple complementary strategies in the transportation, building, and waste sectors. Changes to the right-of-way will be just one part of a larger strategy create a more climate friendly transportation system. A comprehensive transportation strategy will consist of developing dense transit-oriented neighborhoods, implementing pricing strategies that reduce single occupancy vehicle travel, increasing transit service, creating programs that encourage and incentivize climate friendly transportation, increasing vehicle and fuel efficiency, and investing in pedestrian, bicycle, and transit infrastructure.

Investing in this new infrastructure would mean adding dedicated bike lanes, boulevards, trails, wider sidewalks, narrow pedestrian crossings, convenient transit stops and traffic signals. It also means giving motorized vehicles, bicyclists, and pedestrians equal access to the street. Empirical studies have shown that infrastructure interventions can be effective in increasing the mode share of walking and cycling, especially in tandem with other interventions such as educational and marketing campaigns, incentive programs, and supportive land use planning.

Making the changes to the right-of-way discussed in the methods and findings sections would change 0.98 square miles or 4.2% of Seattle's ROW and has the potential to annually reduce greenhouse gas emissions by over 6% annually after implementation. These results show that strategies that reduce greenhouse gases by altering the distribution of a city's streets will only alter a small percentage of the right-of-way. This information can be used to inform city residents about how GHG reduction strategies will alter the right-of-way. These strategies

should be implemented as quickly as possible and with other complimentary strategies to maximize greenhouse gas reductions.

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