ESTABLISHING A BASELINE: A COMMUNITY GREENHOUSE GAS EMISSIONS INVENTORY FOR THURSTON COUNTY, WA

by

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ABSTRACT

Establishing a Baseline: A Community Greenhouse Gas Emissions Inventory for Thurston County, WA

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Global atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) have increased markedly as a result of human activities since 1750, with CO_2 concentrations now exceeding pre-industrial values determined from ice-cores that span at least 650,000 years. In response, many national and subnational efforts to reduce greenhouse gas emissions have been initiated with the intention of combatting the hazardous effects of climate change. Leaders and community members in Thurston County Washington have identified climate change as a primary concern for the region's future and the Thurston County Planning Department has identified a Community Greenhouse Gas Emissions Inventory as a necessary exercise to identify and reduce greenhouse gas emissions in the region. Utilizing the U.S. Community Protocol for Accounting and Reporting of Greenhouse Gas Emissions, this study estimates the total Metric Tons of Carbon Dioxide Equivalents (MTCDE) emitted from the built environment, on-road vehicles, solid waste, wastewater treatment, and livestock in Thurston County, WA in 2010. Energy consumption in buildings (approximately 1.4 million MTCDE) and fuel usage in on-road vehicles (approximately 1.2 million MTCDE) constitute the largest portion of the total greenhouse gas emissions in Thurston County (approximately 2.8 MTCDE). Further, energy usage in residential buildings (0.8 million MTCDE) and fuel usage in passenger vehicles (0.9 million MTCDE) are the two largest individual sources of greenhouse gas emissions in Thurston County. This information suggests that in order to drastically reduce greenhouse gas emissions from sources and activities in Thurston County, local leadership and community members should focus greenhouse gas emissions reduction efforts on residential buildings and on-road passenger vehicles.

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Introduction

Our planet is a lonely speck in the great enveloping cosmic dark. In our obscurity, in all this vastness, there is no hint that help will come from elsewhere to save us from ourselves.
- Carl Sagan

The Intergovernmental Panel on Climate Change (IPCC) states that global atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) have increased markedly as a result of human activities since 1750 and now CO_2 levels exceed pre-industrial values determined from ice cores that span at least 650,000 years (Siegenthaler et al. 2005). Further, global increases in carbon dioxide concentration are due primarily to fossil fuel use and land use change, while increases in methane and nitrous oxide concentrations are primarily due to agriculture (IPCC 2007). All of these gases are greenhouse gases, and as such have been demonstrated to affect the energy balance of the Earth, with temperatures increasing as the concentration of these gases increase. In response to the conclusions drawn by the Intergovernmental Panel on Climate Change, many national and subnational efforts to reduce greenhouse gas emissions have been initiated as an attempt to combat the hazardous effects of climate change. Complete and accurate greenhouse gas emissions inventories are a critical first step in guiding policy and planning efforts in a direction that will effectively reduce emissions.

Greenhouse gas emissions inventories have been an integral part of local and state greenhouse gas emissions reduction strategies and climate action plans across the United States (Engel 2006). Given that global climate change continues to be addressed at a scale much smaller than the problem itself, the consequences of developing inventories at the state and local level is a first step towards combating climate change regardless of the lack of national leadership on this issue. Further, greenhouse gas emissions inventories have broad applications in scientific and mathematical modeling, policy-making, environmental regulation and compliance, as well as environmental stewardship in business and non-profit endeavors. A community greenhouse gas emissions inventory goes beyond estimating the emissions resulting from a single entity, and instead incorporates estimates from all sources and activities within the community that result in emissions within or outside the community itself (e.g., a power plant that serves a city but is not located within the city limits). As such, these inventories are a useful planning tool in developing effective reduction plans that reduce emissions resulting from sources within the community, as well as activities of the community that generate emissions elsewhere. This thesis investigates the largest sources and quantities of greenhouse gas emissions (reported in metric tons of carbon dioxide equivalents) across Thurston County, and identifies the sources and activities upon which planners, policy-makers, and individuals should focus in order to significantly reduce greenhouse gas emissions resulting from community sources and activities.

The U.S. Community Protocol for the Accounting and Reporting of Greenhouse Gas Emissions, published by the International Council for Local Environmental Initiatives (ICLEI) – Local Governments for Sustainability USA, was used to calculate emission estimates. Given the inherent uncertainty in any emissions estimate, the Community Protocol was selected because it provides methods for estimating emissions with the best available data. Herein is the first iteration of a community greenhouse gas emissions inventory for Thurston County, WA using data for calendar year 2010, including emission estimates for sources and activities associated with: 1) the built environment (i.e., energy usage in residential, commercial, and industrial buildings), 2) on-road transportation, 3) solid waste generation, 4) waste-water treatment, and 5) livestock production within the geopolitical boundary. Thurston County was selected for this study as it is home to the state capitol, Olympia, as well as Thurston Climate Action Team the non-profit organization and proprietor of this inventorying effort.

This thesis is comprised of six chapters. Chapter 1 provides background information on greenhouse gas emissions, their influences on climate change in Washington State and the South Puget Sound, the academic discourse on subnational greenhouse gas emissions inventories, as well as the need for carbon accounting in Thurston County, WA. Chapter 2 details the effective allocation of greenhouse gas emissions as discussed in the academic literature, the methodologies of similar inventorying exercises, as well as the unique aspects of the U.S. Community Protocol for the Accounting and Reporting of Greenhouse Gas Emissions (i.e., the Community Protocol). Chapter 3 discusses the methods used in this study (i.e., the calculation of emissions estimates using the Community Protocol). Chapter 4 provides a detailed summary of the resultant greenhouse gas emissions estimates for Thurston County. Chapter 5 is an in-depth discussion of these results and provides a conclusion to this study.

Chapter 1

The Need for Carbon Accounting

The following chapter provides background information on global climate change, anthropogenic greenhouse gas emissions and their impacts on climate change, the projected impacts of climate change on the United States, Washington State, and Thurston County, as well as the development of policies at the local and regional scale that address climate change. This chapter sets the back-drop for the purpose of this study, and establishes a foundation for further discussion of this study's results and implications related to climate policy development in Thurston County.

Greenhouse Gas Emissions and Global Climate Change: A Human Disturbance

The greenhouse effect is a term used to describe the trapping of ultraviolet solar radiation within the Earth's atmosphere, and the subsequent effect this trapped radiation has on the Earth's climate and natural systems. Approximately one-third of the solar energy that meets the farthest reaches of the Earth's atmosphere is reflected directly back to space, while the remaining two-thirds is absorbed by the surface and atmosphere itself. Short wavelengths of visible light from the Sun pass through the atmosphere and are absorbed. Re-radiated long wavelengths of energy are less efficient in escaping the atmosphere leading to more heating and a higher resultant temperature. The Earth's greenhouse effect warms the surface of the planet, making human and non-human life possible, and trapped thermal radiation is in a constant state of flux between the surface of the Earth, its land and oceans, and the atmosphere where it is radiated and reradiated.

Unfortunately, human activities since the late 18th century, primarily the burning of fossil fuels and the clearing of forests, have accelerated and intensified the natural greenhouse effect causing global warming (i.e., climate change) (Figure 1).

Human activities, beginning in the industrial era and continuing into the present, have made a significant contribution to the concentration of greenhouse gases in the atmosphere, primarily through the burning of fossil fuels and the clearing of forest cover. The Kyoto Protocol and the IPCC have identified carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexaflouride (SF_6) as the six primary atmospheric greenhouse gases whose concentrations have been affected by human activities (IPCC 2007).Since the pre-industrial era, carbon dioxide levels have increased by over 40 percent (Table 1) and stable isotope analyses of Antarctic ice cores show that levels are currently higher than any level in the past 650,000 years (Siegenthaler et al. 2005, Figure 2). The intensity and significance of warming depends on many different mechanisms both human and natural.

Radiative forcing is used to compare how a range of human and natural factors drive warming or cooling influences on global climate (IPCC 2007). It is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system and is an index of the importance of the factor as a potential climate change mechanism. According to the American Chemistry Society, contemporary interest in radiative forcing is mostly concerned with the effects of increasing atmospheric concentrations of greenhouse gases.

Changes in the atmospheric abundance of greenhouse gases and aerosols alter the energy balance of the climate system and threaten human and natural systems.

As greenhouse gas concentrations within the atmosphere increase, the concentration of water vapor within the atmosphere increases due to the inherent warming, compounding the greenhouse effect and thus creating more warming, and more water vapor within the atmosphere. According to the IPCC, "this water vapor feedback may be strong enough to approximately double the increase in the greenhouse effect due to the added CO_2 alone." Further, if current trends continue, carbon dioxide concentrations are projected to reach 600 to 1,000 parts per million by the end of the 21st century (from 278 ppm pre-industrial era), or a rise of approximately 115 to 250 percent (IPCC 2007). Recently, atmospheric CO_2 concentrations were observed to exceed 400 ppm at the National Oceanic and Atmospheric Administration Global Monitoring Division's Mauna Loa Observatory.

Synthesis of data suggests that "eleven of the last twelve years (1995-2006) rank among the twelve warmest years" since 1850, and that the 100-year linear trend highlighted in the AR4 (1906-2005) is larger (0.7 degrees C) in comparison to the trend observed in the Third Assessment Report's 100-year linear trend (1901-2000; 0.6 degrees C). Further, the 50-year linear trend from 1956 to 2005 (0.13 degrees C per decade) is almost two-times that of the 100-year trend from 1906 to 2005. Similarly, decreases in magnitudes of both snow and ice are consistent with warming; satellite data show that annual average Arctic sea ice

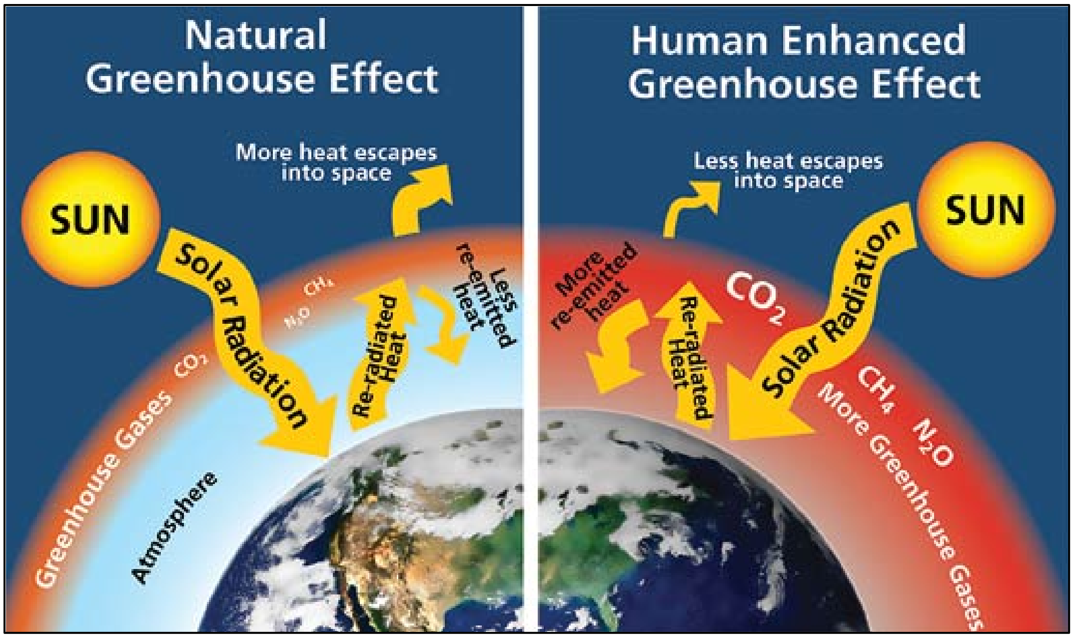

Figure 1: Left - Naturally occurring greenhouse gases—carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)—normally trap some of the sun's heat, keeping the planet from freezing. Right - Human activities, such as the burning of fossil fuels, are increasing greenhouse gas levels, leading to an enhanced greenhouse effect. The result is global warming and unprecedented rates of climate change. Retrieved from "What is Climate Change?," by Will Elder, 2013, National Park Service, http://www.nps.gov/goga/naturescience/climate-change-causes.htm.

Table 1: Increases in the concentrations of the primary, long-lived anthropogenic greenhouse gases according to the IPCC's Fourth Assessment Report (AR4). These trends indicate that it is very likely that human activities have accelerated and exacerbated global warming trends. Values reflect atmospheric concentrations of greenhouse gases in either parts per million (ppm) or parts per billion (ppb), and are representative of the ratio of the number of greenhouse gas molecules to the total number of molecules of dry air (Petit et al. 1999).

	Carbon Dioxide (CO_2)	Methane (CH_4)	Nitrous Oxide (N_2O)
Pre-industrial	280 ppm	715 ppb	270 ppb
2005	379 ppm	1774 ppb	319 ppb

has shrunk 2.7% per decade since 1978, with decreases of a greater magnitude (7.4% per decade) in summer (Johannessen et al. 1999). Snow-cap and mountain glaciers have similarly declined in both the Northern and Southern hemispheres and surface temperatures of the Arctic's permafrost layer has generally increased since the 1980s by up to 3 degrees Celsius (Johannessen et al. 1999).

Global average sea level rose with an average rate of approximately 1.8 millimeters per year from 1961 to 2003 and with an average rate of approximately 3.1 millimeters per year from 1993 to 2003; however, it is unclear if this is due to decadal variation or an increase in the longer-term trend (Domingues et al. 2008). Further, thermal expansion of the oceans, i.e., warming of the ocean, has contributed about 57% of the total estimated rise in sea level with decreases in glaciers and ice caps contributing about 28% to the total rise, and losses from polar ice sheets contributing the remaining 15% (Domingues et al. 2008). Since 1750, the uptake of anthropogenic carbon in the world's oceans has led to acidification of this precious resource, with an average decrease in pH of 0.1 units, and increasing concentrations of CO_2 in the atmosphere have led to further acidification (Raven et al. 2005).

The Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report (AR4) states that "the warming of the global climate system is unequivocal (AR4)." Further, the report posits that observed changes across all continents and most oceans show the many natural systems being impacted by climate change, particularly temperature changes. The IPCC has asserted anthropogenic greenhouse gas emissions as the primary driver of global climate change, and identifies and outlines observed global trends of climate change, including increases in global average air and ocean temperatures, widespread melting of snow and ice, rising global average sea level, ocean acidification as well as increases in concentrations of greenhouse gases. The effects of these changes are widespread, impacting all of the world's continents and most oceans.

The impacts of climate change to human populations differ from continent to continent, and the IPCC states that "taken as a whole, the range of published evidence indicates that the net damage costs of climate change are likely to be significant and to increase over time." Freshwater availability in Central, South, East, and Southeast Asia is projected to decrease by the 2050s, while coastal areas of the continent will be at risk due to increased flooding and death risks associated with floods and droughts (IPCC 2007). By 2020, between 75 and 250 million people in African countries are projected to be exposed to increased water stress, while yields from rain-fed agriculture could be reduced by up to 50 percent in some regions severely comprising production and food-access (IPCC 2007). Replacement of tropical forest by savannah in the eastern Amazon, widespread biodiversity loss through species extinction, and significant changes in water availability for human consumption, agriculture, and energy generation are expected in Latin America (IPCC 2007). In Europe, increased risk of inland flash floods, more frequent coastal flooding, increased erosion from storms and sea level rise, as well as glacial retreat in mountainous areas and reduced snow cover will threaten human, ecological, agricultural, and economic systems (IPCC 2007). In North America, increased frequency, intensity, and duration of heat waves may threaten productivity of existing agricultural systems, however reports also project a 5 to 20 percent increase in yields of rain-fed agriculture in regions like the Pacific Northwest that are expected to see lengthening of summer growing seasons and seasonal rainfall (IPCC 2007). Unfortunately, the impacts of accelerated warming are not occurring in a timeframe commensurate with the rate at which anthropogenic greenhouse gas emissions are occurring, and as warming effects become noticeable, the most vulnerable locations, like coastal regions, will be the first to experience observable consequences.

Effects of Climate Change on the U.S., Washington State, and Thurston County

Although the threat of climate change is global in nature, climate change impacts to both natural and human systems are best understood at the regional or local scale. The Pew Center on Global Climate Change published a compilation of four case studies on the regional effects of climate change and examined the similar and differing impacts of climate change on different regions of the United States. The Climate Impacts Group at The University of Washington has scaled-down global climate change models to produce two scenarios ("A1B", a moderate emissions scenario, and "B1", a low emissions scenario) that provide projected climate change impacts to the natural systems of the region. These studies and projections tell a story of how climate change is and will continue to impact the region. Understanding the ways in which climate change is and will likely impact Washington State's and the South Puget Sound's natural systems is integral to projecting how those changes will impact humans, environmental, and economic systems of the South Puget Sound, as well as how best to mitigate and adapt to climate change.

In the four case studies examined by the Pew Center (i.e., Bachelet et al. 2007, Boesch et al. 2007, Ebi et al. 2007, Twilley 2007) evidence is presented that climate change is already increasing risks like wildfire, sea-level rise, hypoxia, and extreme weather events in all regions of the United States; these impacts are projected to become more apparent as the climate continues to shift. In the Midwest existing heat waves are likely to become more frequent, longer, and hotter than cities in the region have experienced in the past, potentially leading to droughts and heat-related mortality (Ebi et al. 2007). In addition to increased average temperatures, the coastline of the Gulf of Mexico with its low-lying development, the construction of levees along major rivers that have degraded coastal wetlands, high pollution levels, and extreme weather events will suffer from rising sea-levels and associated human-health concerns (Twilley 2007). Development, higher temperatures, increased regional rainfall and nutrient runoff from farms and communities within the Chesapeake Bay watershed are leading to hypoxic conditions within the Bay, impacting the ecosystem, its fisheries, and recreational capacity (Boesch et al. 2007).

The western United States and the Pacific Northwest are likely to experience many of these impacts. Some examples of impacts include increased wildfire, reduced snowfall, snowpack, and drier summers (Bachelet et al. 2007). Nine key indicators and projections of how climate change will impact Washington and the Pacific Northwest are presented in the Climate Impacts

Group's Washington Climate Change Impacts Assessment Report: increasing carbon dioxide levels, warmer air temperatures, drier summers and reduced snowfall, more frequent and severe extreme weather events, rising sea levels, more acidic marine waters and warmer water temperatures, as well as increasing severity and frequency of wildfires and flooding events.

The State of Washington Department of Ecology projects that climate change will affect many human systems and systems upon which humans are dependent, like forest resources, electricity, municipal water supplies, agriculture, human health, and shorelines. Impacts to forest resources include loss of economic viability of forest lands due to affected tree growth rates, fire, and pests, as well as lost recreational expenditures, and health and environmental costs related to air pollution and other forest changes (Millar et al. 2007). Climate change's impacts on the state's electrical system, which is highly dependent on hydropower, will affect both supply and demand and include shifts in the timing of peak hydropower generation due to increased/decreased seasonal flows, as well as increased electrical demands in the summer months for cooling needs (Elsner et al. 2010). The threat to hydropower generation will likely exacerbate the importation of electrical energy or drive the development of new generation resources. Municipal water supplies will decline and will increase in cost due to projected increases in population as well as declines in snowpack and thus freshwater availability (Miles et al. 2000, Vano et al. 2010). Agriculture in Washington will likely gain longer growing seasons, but with increased aridity and reduced water supply alongside increases in water demands (Elsner et al.

2010). Shorelines will be affected by sea-level rise and armoring, erosion, and inundation, while industry associated with aquaculture and port systems will likely be affected as well (Huppert et al. 2009). Human health will likely suffer due to increases in human vulnerability to water-borne illness from increases in precipitation and sea-level rise, cardiovascular disease and death from declining air quality, aridity and drought, as well as extreme weather events like flooding and inundation of coastal regions (Climate Impacts Group 2009). Clearly, the threat of climate change to Washington State will affect ecological and human systems in Thurston County, particularly shorelines, forests, and human health. Thurston County is particularly vulnerable to climate change due to susceptibility to sea level rise, ocean acidification, and wildfire, in addition to economic dependencies on natural resources, like aquaculture, logging, and hydroelectricity. However, Thurston County is but a small contributor to global greenhouse gas emissions.

Unfortunately, the global commons are not governed by a centralized body and attempts to establish binding international agreements to reduce anthropogenic greenhouse gas emissions, the primary driver of accelerated global warming and climate change, have been largely unsuccessful (i.e. the Kyoto Protocol). But, Washington State and Thurston County are among a growing number of subnational leaders that are taking climate change preparedness into their own hands for the sake of Washingtonians, their environment, and the world.

Greenhouse Gas Emission Inventories at the Subnational Level

The Intergovernmental Panel on Climate Change has declared global CO_2 emissions must be reduced to at least 50% by 2050 to avert the worst threats of climate change, and with the majority of the world's population residing in cities, municipalities and local governments are at the forefront of efforts to reduce greenhouse gas emissions (IPCC 2007). Although many cities and local governments have prioritized greenhouse gas emissions inventorying and climate action planning efforts, there has historically been a lack of both national and international guidelines for conducting an inventory and developing an action plan for a city, though the IPCC has published standards for data collection and estimation of certain emission types. The first international protocol for community greenhouse gas emissions inventorying was released by the International Council for Local Environmental Initiatives (ICLEI) - Local Governments for Sustainability in October of 2012 (ICLEIusa.org). Transnational networks, like ICLEI, are useful for leveraging increased federal attention to climate planning activities.

Despite failure of the U.S. government to ratify the Kyoto Protocol, state and local initiatives to reduce greenhouse gas emissions are bolstering climate change mitigation and adaptation policy, both regionally and nationally (Engel, 2006). Thirty-two states and Puerto Rico have completed or are developing strategies to reduce greenhouse gas emissions. Thirty-three states plus Washington D.C. have enacted Renewable Portfolio Standards that require a certain percentage of energy sales come from renewable technologies, providing guaranteed reductions in greenhouse gas emissions from point-source emitters (Environmental Protection Agency 2013). As of November 2012, one thousand fifty four mayors have adopted the Mayors Climate Action Protection Agreement, urging cities to adopt the greenhouse gas reduction targets on the timetable posited by the Kyoto Protocol - a reduction of 7 percent below 1990 levels by the year 2012 (Engel, 2006).

The benefits of state and local inventorying efforts and climate action plans are rooted in the ideal of states and local governments as laboratories for democracy and innovation in governance. Lutsey et al. 2008 outlines the benefits of these efforts as follows:

- i allowing more experimentation by more policy-makers
- ii local tailoring of specific actions to fit more aptly the environmental preferences of constituents of various states and locales
- iii testing the political response of innovative regulatory and policy actions
- iv and, gaining the benefit of local expertise and experience in enforcing programs and policies.

These sentiments are echoed more generally in the literature (Fleming et al. 2004, Satterthwaite 2008). Additionally, the benefit most often referenced is the potential for state and local initiatives to promote the development of local, state, and federal climate policy through replication and a bottom-up approach (Rabe 2004, Betsill et al. 2006, Engel et al. 2008). The City of Seattle is a featured community in the EPA's Climate Showcase Communities Program and its climate action plan is a model for effective greenhouse gas emissions reductions. Gelderloos 2013 found that the City of Seattle's greenhouse gas emissions reduction strategies were beneficial and that planning at the local level proffered strengths like accounting for regional variations in climate, as well as economic and social patterns, in addition to regional authority in policy areas pertinent to emissions and existing trust of the populace. Similarly, given the rise of global trends and cultural shifts occurring exclusively in cities it makes sense that inventorying efforts and action plans would be developed at the local level to culturally, socially, and politically address climate change.

Purpose

The threat of global climate change is of international concern, and the impacts of climate change have been identified by the scientific community as one of the primary threats to humanity and Earth. In addition, the Intergovernmental Panel on Climate Change's Fourth Assessment Report (AR4), published in 2007, indicates that humans are "very likely" the leading cause of accelerated warming of the atmosphere in the last century. However, the United States has not implemented comprehensive policies addressing climate change or its impacts on the global community. Subnational governments in Washington State are taking progressive actions to not only reduce greenhouse gas emissions, but to prepare for climate change and its effects. The purpose of this study is to provide a baseline dataset of emissions estimates for Thurston County, WA, so that local and regional leadership, as well as the community, might begin to prepare, plan, and measure the effectiveness of greenhouse gas emissions reductions strategies. The effective allocation of greenhouse gas emissions is essential to the development of feasible and effective emission reduction plans.

Chapter 2

Effectively Allocating Emissions

This chapter builds the case for the selection of the U.S. Community Protocol for the Accounting and Reporting of Greenhouse Gas Emissions by reviewing the academic literature relative to the effective allocation of greenhouse gas emissions and the uncertainty in emissions estimates, the methodologies of similar inventorying efforts, and outlining the significant attributes of the Community Protocol that set it apart from existing inventorying methodologies.

Current Issues in Allocating Emissions

Hoornweg et al. 2011 posit that in order to accurately assign responsibility to cities or regions it is important to consider the fundamental role of the modern city in the global context: that cities are not only more environmentally efficient than suburban and rural living at similar levels of affluence, but cities are drivers of human activity (the primary of global climate change). For this reason, many scholars have investigated local climate action and posited global climate change as a global issue that can be addressed through careful and concise "local action" in cities and other denominations of local government (Kousky et al. 2003, Fleming et al. 2004, Gupta et al. 2007, Lutsey et al. 2008, Satterthwaite 2008, Sippel et al. 2009, Larsen et al. 2009). The International Energy Agency reports in the World Energy Outlook of 2008 that 71% of energy derived CO_2 emissions come from cities in the United States. However, differing estimation methodologies present a significant level of uncertainty in the comparability of inventories.

There are several methodologies for greenhouse gas emissions inventories; inventories that are consumption- or production-based, specific to a given temporal and geographic or organizational boundary, as well as inventories that incorporate "sinks" of emissions (i.e., the quantity of emissions removed by natural systems like forests or bodies of water). The selection of a particularly accounting or estimation methodology is dependent upon the goal of the project and the intended outcomes of the accounting process. For example, a corporation may estimate emissions associated with the worldwide operations of the business, a local government might wish to account for emissions associated with government operations, while the federal government wonders the quantity of greenhouse gases emitted versus the quantity stored in natural systems. A community inventory accounts for all sources and activities that generate emissions within a given boundary with the goal of facilitating a community-wide discourse on appropriate avenues for reducing emissions resulting from these sources and activities.

Assigning responsibility for anthropogenic greenhouse gas emissions seems to be a tedious task fraught with doubts regarding who should be held responsible for what emissions. A production versus consumption based inventory will provide starkly different results (Dodman 2009), one amassing emissions for which the consumer is accountable the other the producer. For example, a large fossil-fueled power plant located just outside a city's limits might provide electricity to the city, but the actual emissions from the power plant are occurring outside the city limits. Thus, in a production-based inventory, the city would not be held responsible for the emissions generated at the power plant that in fact support activities within the city that are dependent on those emissions.

Neither a consumption or production-based inventory is necessarily superior to the other, however, the geographic or organizational boundary used to conduct the inventory is a determinant of which methodology is used; at the national or state level a production-based inventory makes sense as the majority of the energy produced within the state or country is used within the state or country. The Washington State Greenhouse Gas Emissions Inventory and the Inventory for U.S. Greenhouse Gas Emissions and Sinks use a production-based, while smaller scale inventories utilize a consumption-based methodology. King County, WA utilized a consumption-based accounting approach for their GHG emissions inventories. However, these differing methodologies focus on similar emission source types, like the built environment, transportation, solid waste, wastewater treatment, and livestock and agricultural emissions.

Ramaswami et al. 2008 propose the need for methodologies that allocate emissions to the consumer of the good or service provided by the emissions source to more appropriately allocate emissions from surface and airline travel across co-located cities in larger metropolitan regions and to quantify the embodied energy of key urban materials, like food, water, fuel, and concrete enabling cities to separately report the greenhouse gas impact associated with direct end-use of energy by cities. The difficulties associated with assigning responsibility for anthropogenic greenhouse gas emissions might be alleviated by standardization across reporting frameworks to minimize double-counting and unallocated emissions. The result of double-counting emissions is an inventory that over-reports emission estimates and thus limits the applicability of the inventory to a reduction strategy or modeling and forecasting effort. Similarly, unallocated emissions result in an inventory that under-reports emission estimates further limiting effective reduction strategizing.

Rypdal and Winiwarter 2001 discuss difficulty in GHG reduction strategizing in terms of the level of uncertainty in inventory estimates. According to Rypdal and Winiwater 2001, uncertainty in emissions estimates range from 5 to 20% in well-developed inventories from the five countries they examined. Further they state that this range reflects differences in source mix with CO_2 typically having less uncertainty relative to emissions from CH_4 and N_2O. For example, uncertainty in nitrous oxide emissions from agricultural soils and uncertainties in CO_2 emissions are a few percent in all countries, whereas uncertainty for CH_4 ranges between 20–40%. They conclude that in any inventorying effort a keen discussion or estimate of uncertainty in data or calculation is important, given the inherent uncertainty in an estimation methodology and the possibility of needed recalculations or expansion of an inventories scope (i.e., including more sources and activities generating emissions).

U.S. Community Protocol for the Accounting and Reporting of Greenhouse Gas Emissions

For this greenhouse gas emissions inventorying effort ICLEI's U.S. Community Protocol for the Accounting and Reporting of Greenhouse Gas Emissions was selected as a guide as it establishes requirements and recommends best practices for developing community GHG emissions inventories. The Community Protocol is designed to:

- enable local governments to estimate and report on GHG emissions associated with their communities in order to measure progress toward GHG emission reduction goals
- use best practice methods that align, where possible, with nationally and internationally recognized GHG accounting and reporting principles, as well as with emerging reporting processes or registries
- provide local governments with an assessment of GHG emissions associated with their communities so that they – and others – can make more informed decisions about where and how to pursue GHG emissions reduction opportunities
- help local governments engage with residents, businesses, and other stakeholders about opportunities in their communities for reducing GHG emissions
- advance consistent, comparable, and relevant quantification of GHG emissions and appropriate, transparent, and policy-relevant reporting

of GHG emissions to allow communities to compare their baseline emissions.

In particular the Community Protocol includes many innovations that are different from existing accounting and reporting methodologies, including:

- the drawing of distinctions between emission sources that may be located in a community and activities of the community that result in GHG emissions elsewhere
- five required Basic Emissions Generating Activities for all communities: the built environment, on-road transportation, solid waste generation and disposal, wastewater treatment, and livestock-related emissions
- a focus on a required process that helps communities achieve their emissions management goals in a variety of contexts
- detailed accounting guidance to aid data collection and emission calculations
- emphasis on line item reporting of emissions numbers with guidance on aggregation where appropriate and how to avoid double counting
- inclusion of life cycle accounting methods of upstream emissions from: electricity use, stationary fuel use, transportation fuels, and materials and services used in the community

In contrast to GHG emissions reports that might be developed for individual organizations or projects (e.g., by a company reporting on its own emissions to a carbon registry), community GHG emissions inventories convey information about emissions associated with entire geopolitically defined communities. They are neither exclusive of emissions separately reported by organizations in the community, nor simply the sum of emissions reported by individual organizations or households. Rather, community inventories provide new ways of understanding the collective GHG emissions stories associated with a community. They are primarily created from community-wide data sets (e.g., total energy use, total miles driven, total waste produced). While no community inventory is fully comprehensive (some emissions cannot be estimated due to a lack of valid methods, a lack of emissions data, or for other reasons), community inventories often aim to provide as complete a picture of GHG emissions associated with a community as is feasible.

Chapter 3

Methodology

Site Description

Thurston County is located at the southern-most point of Puget Sound in western Washington and is one of the smallest counties in Washington State. The county covers a total of 736 square miles, approximately 14% of which is incorporated in cities and towns. Topographically, the area ranges from coastal lowlands to prairie flatlands and the foothills of the Cascade Range. The county neighbors Mason, Pierce, Lewis, and Grays Harbor counties to the north, east, south, and west, respectively.

Boasting a population of roughly 252,264 in 2010, and an average annual population growth of 2%, Thurston County has been one of the fastest-growing counties in the state since the 1960s. Most of the observed population growth in Thurston County is a result of in-migration, or the movement of individuals from outside the region into the region. Further, Thurston Regional Planning Council estimates the county population will continue to grow to 400,000 residents by 2040. The potential impacts of such population growth and associated development on the environment and greenhouse gas emissions are cause for concern, further justifying the need for regular carbon accounting in order to coordinate and measure impact reduction plans.

Selection of Estimation Methodology

Given the many ways that communities contribute to greenhouse gas emissions and the many methodologies available to estimate emissions, the U.S. Community Protocol for Accounting and Reporting Greenhouse Gas Emissions (i.e., Community Protocol, http://www.icleiusa.org/tools/ghg-protocol/community-protocol) was selected as the primary guide for estimating community-wide greenhouse gas emissions within the geopolitical boundary of Thurston County Washington. The Community Protocol is a national standard developed by ICLEI-USA (International Council for Local Environmental Initiatives), now known as Local Governments for Sustainability USA, to inspire and guide U.S. local governments to account for and report on greenhouse gas emissions associated with the communities they represent. The development of the Community Protocol was funded by Pacific Gas and Electric Company, the State of Oregon Department of Environmental Quality, and through a National Science Foundation grant from the Research Coordination Network led by Dr. Anu Ramaswami at University of Colorado Denver. The Community Protocol was vetted by industry experts working in local, state, and federal governments, as well as universities, non-governmental organizations, and private corporations across the United States and Canada. By addressing six internationally recognized greenhouse gases regulated under the Kyoto Protocol (CO_2, CH_4, N_2O, Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), and Sulfur hexafluoride (SF_6)) across five basic emission types (built environment, transportation and other mobile sources, solid waste, water and wastewater, and agriculture), the protocol can be used to estimate the quantity of GHG emissions associated with community sources and activities during a chosen analysis year using a consumption based methodology.

Data Allocation

The quantities of CO_2, $CH_{4,}$ and N_2O emitted for each of the five basic emission types were estimated for 2010 based on the best available data. Data for this inventory was allocated during the months of January and February of 2013, in partnership with Thurston Climate Action Team, Thurston County, and Thurston Regional Planning Council. Aggregate use of natural gas and electricity in residential, commercial, and industrial units within the geopolitical boundary of Thurston County were obtained from Puget Sound Energy. Additionally, estimates for a small percentage of residential on-site fuel usage not served by Puget Sound Energy (i.e., fuel oil, propane, liquefied petroleum gas, and wood) were obtained utilizing the Energy Information Administration's State Energy Data System (SEDS). Values for the amount of fuel oil, propane, liquefied petroleum gas, and wood were obtained by scaling-down consumption estimates from the Energy Information Administration's (EIA) State Energy Database System (SDES). Thurston County Solid Waste provided aggregate solid waste volumes generated within the geopolitical boundary and collected at county-owned sites. Estimates for livestock production (i.e., dairy and beef cows, swine, and sheep) were obtained from the United States Department of Agriculture's

Agricultural Census of 2007. Emissions from the operation of wastewater treatment facilities located within the community were estimated based on data provided by the Lacey, Olympia, Tumwater, Thurston (LOTT) Clean Water Alliance and Thurston Regional Planning Council's Profile 2012. Emissions from on road vehicles operating within the community were estimated based on Vehicle Miles Traveled (VMT) data supplied by Thurston Regional Planning Council's Travel Demand Model and Annual Vehicle Miles Traveled data from the Highway Performance Monitoring System (HPMS) database.

Estimate Calculation Methodology

Microsoft Excel was used to create a calculator that incorporated estimation methods provided by the Community Protocol (Table 3) and user inputs (Table 4). Metric Tons of Carbon Dioxide Equivalents (MTCDE) were calculated either directly with an equation supplied by the Community Protocol or by converting individual estimates for each of the three greenhouse gases (provided in units of metric tons of the particular gas) into Carbon Dioxide equivalents using 100 year Global Warming Potential (Table 2) and summing.

$$MTCDE = [(mt\ CO_2 \times GWP_{CO_2}) + \left(mt\ CH_4 \times GWP_{CH_4}\right) + \left(mt\ N_2O\ \times GWP_{N_2O}\right)]$$

Where the variable in metric tons (e.g., mt CO_2) represents the value obtained from the estimation methodology and the variable Global Warming Potential (GWP) represents the value obtained from Table 2.

Table 2: One-hundred year Global Warming Potentials (GWP) for greenhouse gases. Carbon Dioxide (CO_2) has a GWP of 1 since it is the baseline unit to which all other greenhouse gases are compared.

Greenhouse Gas	**100 year GWP**
Carbon Dioxide (CO_2)	1
Methane (CH_4)	21
Nitrous Oxide (N_2O)	310

The Community Protocol provides equations that a user can input community-based variables in order to calculate individual greenhouse gas values or MTCDE for a given emission source or activity. The following tables detail which equations were used (with specific equation numbers referring to equations found within the Community Protocol) to calculate emissions associated with a particular source or activity (Table 3), and the user inputs used within those equations (Table 4).

Table 3: Emissions sources and related estimation method used to calculate greenhouse gas emission based on the Community Protocol. The right column details which equations were used (with specific equation numbers referring to equations found within the Community Protocol) to calculate emissions associated with a particular source or activity listed in the column on the left.

Emission Source	**Estimation Method Used**
Built Environment Emission Activities and Sources	
Emissions from stationary combustion of natural gas in residential, commercial, and industrial units	BE.1.1, Equations BE.1.1.1, BE.1.1.2, BE.1.1.4, BE.1.1.6
Emissions from stationary combustion of fuel oil, propane/LPG, and wood in residential units	BE.1.2, BE.1.1

Emissions from use of electricity in residential, commercial, and industrial units	BE.2.1, Equation BE.2.2
Emissions from electricity transmission and distribution losses	BE.4.1, Equation BE.4.1.1
Upstream emissions from energy use	BE.5.1, Equation BE.5.1.1; BE.5.2A
Transportation and Other Mobile Emission Activities	
Emissions from passenger vehicles	TR.1.B, Equations TR.1.B.2, TR.1.B.3
Emissions from freight and service trucks	TR.2.A, Equations TR.2.A.1, TR.2.A.2
Solid Waste Emission Activities and Sources	
Methane emissions from community-generated waste sent to landfills	SW.4.1
Process emissions associated with landfilling	SW.5
Collection and transportation emissions	SW.6
Agricultural Livestock Emission Activities and Sources	
Methane emissions from enteric fermentation	A.1
Wastewater and Water Emission Activities and Sources	
Stationary methane emissions from combustion of digester gas	WW.1.a
Stationary nitrous oxide emissions from combustion of digester gas	WW.2.a
Stationary carbon dioxide emissions from digester gas combustion	WW.3
Process methane emissions from wastewater treatment lagoons	WW.6
Process nitrous oxide emissions from wastewater treatment plants with nitrification or denitrification	WW.7
Process carbon dioxide emissions from the use of fossil-fuel-derived methanol for biological nitrogen removal	WW.9

Table 4: List of user input descriptions, values, and related emission source/activity. These values were the user inputs utilized to calculate emission estimates for the various emission sources and activities.*Values are obtained by scaling-down consumption estimates from the Energy Information Administration's (EIA) State Energy Database System (SDES)

Input Description	Input Value	Emission Source/Activity
Built Environment		
Use of electricity in residential units	1,266,273,211 (kWh)	Consumption of electricity, Transmission and Distribution Losses, Upstream emissions from electricity use
Use of electricity in commercial units	920,512,299 (kWh)	Consumption of electricity, Transmission and Distribution Losses, Upstream emissions from electricity use
Use of electricity in industrial units	136,413,709 (kWh)	Consumption of electricity, Transmission and Distribution Losses, Upstream emissions from electricity use
Use of electricity in street lighting	4,419,884 (kWh)	Consumption of electricity, Transmission and Distribution Losses, Upstream emissions from electricity use
Use of natural gas in residential units	31,268,416 (therms)	Onsite combustion of fuel, Upstream emissions from fuel use
Use of fuel oil in residential units	248,428* (MMBtu)	Onsite combustion of fuel, Upstream emissions from fuel use
Use of propane/LPG in residential units	26,169* (MMBtu)	Onsite combustion of fuel, Upstream emissions from fuel use
Use of wood in residential units	125,965* (MMBtu)	Onsite combustion of fuel, Upstream emissions from fuel use
Use of natural gas in commercial units	15,994,387 (therms)	Onsite combustion of fuel, Upstream emissions from fuel use
Use of natural gas in industrial units	4,007,881 (therms)	Onsite combustion of fuel, Upstream emissions from

Input Description	Input Value	Emission Source/Activity
		fuel use
Transportation and Other Mobile Units		
Vehicle Miles Traveled estimate	2,341,013,000	Use of fuel in passenger cars
Vehicle Miles Traveled estimate	2,341,013,000	Use of fuel in heavy-duty freight vehicles
Solid Waste		
Tons of waste sent to landfill	165,191 tons	Methane emissions from community-generated waste sent to landfills
Tons of waste sent to landfill	165,191 tons	Process emissions associated with landfilling
Tons of waste sent to landfill	165,191 tons	Collection and transportation emissions
Agricultural Livestock		
Quantity of beef cows	5,165 individuals	Methane emissions from enteric fermentation and manure, direct and indirect nitrous oxide emissions from manure
Quantity of dairy cows	5,451 individuals	Methane emissions from enteric fermentation and manure, direct and indirect nitrous oxide emissions from manure
Quantity of swine	777 individuals	Methane emissions from enteric fermentation and manure, direct and indirect nitrous oxide emissions from manure
Quantity of sheep	1,838 individuals	Methane emissions from enteric fermentation and manure, direct and indirect nitrous oxide emissions from manure
Wastewater Treatment		
Digester annual average daily Biogas	138,369 ft^3	LOTT Digester emissions
Fraction of CH4 in biogas	70%	LOTT Digester emissions
BOD_5	23,162 lbs	LOTT Process emissions
BOD_5 removed	11,544 lbs	LOTT Process emissions
Population served by LOTT	102,000	LOTT Process emissions
Annual methanol consumption	31,029 gallons	LOTT Emissions from methanol use in biological treatment of wastewater

Emission sources and activities associated with the built environment include the consumption of electricity, electricity transmission and distribution losses, onsite combustion of fuel, and upstream emissions (i.e., emissions from production/extraction) from electricity and fuel usage. Aggregate values for the consumption of electricity in residential, commercial, industrial, and street lighting units were used to calculate emissions associated with the generation of the electrical energy consumed (Figure 2) as well as transmission and distribution losses (Figure 3) and upstream emissions resulting from the use of electricity (Figure 4). Aggregate values for the consumption of fuel in residential, commercial, and industrial units were used to calculate associated emissions (Figure 5) and upstream emissions resulting from the use of fuel (Figure 6).

Equation BE.2.2 Calculating Electricity GHG Emissions Using Separate CO_2, N_2O, and CH_4 Emission Factors

Annual CO_2e emissions (metric tons/year) =

$$\frac{electricity}{2204.6} \times \begin{pmatrix} CO_2 \ emission \ factor \\ +21 \times CH_4 \ emission \ factor \\ +310 \times N_2O \ emission \ factor \end{pmatrix}$$

Where:

- electricity is the community's annual electricity use in MWh from Step 1,
- the CO_2 emission factor is the individual CO_2 emission factor from Step 2 (lb/MWh),
- the CH_4 emission factor is from Step 2 (lb/MWh),
- the N_2O emission factor is from Step 2 (lb/MWh),
- Use the CH_4 global warming potential[11] (GWP) to convert from pounds of CH_4 to CO_2e
- Use the N_2O global warming potential[12] (GWP) to convert from pounds of N_2O to CO_2e, and
- 2204.6 is the conversion factor to convert from pounds to metric tons.

Figure 2: Method for estimating individual GHG emissions from the use of electricity, where "electricity" represents the use of electricity in residential, commercial, or industrial units from Table 4 and "emission factor" represents the emission factor listed for the NWPP sub-region for the particular gas in Table B.10 of Appendix C of the Community Protocol. Retrieved from "U.S. Community Protocol for Accounting and Reporting Greenhouse Gas Emissions," Developed by ICLEI Local Governments for Sustainability – USA, 2012.

Equation BE.4.1.1 Calculating Electricity GHG Emissions Using a CO_2e Emission Factor

Annual CO_2e emissions (metric tons/year) =

$$\frac{\text{Community electricity use} \times \text{grid loss factor} \times CO_2\,\text{e emission factor}}{2204.6}$$

Where:

- Electricity is the community's annual electricity use in MWh from Step 1,
- the CO_2e emission factor is the combined carbon dioxide *equivalents* emission factor from Step 2 in lbs/MWh,
- the grid loss factor is from Step 3, and
- 2204.6 is the conversion factor to convert from pounds to metric tons.

Figure 3: Method for estimating GHG emissions resulting from transmission and distribution losses, where "community electricity use" represents the use of electricity in residential, commercial, or industrial units from Table 4, "grid loss factor" represents the value listed for the western region in Table B.12 of Appendix C of the Community Protocol, and "CO_2e emission factor" represents the value listed for the NWPP sub-region for CO_2e in Table B.10 of Appendix C of the Community Protocol. Retrieved from "U.S. Community Protocol for Accounting and Reporting Greenhouse Gas Emissions," Developed by ICLEI Local Governments for Sustainability – USA, 2012.

***Equation BE.5.2.A* - Upstream emissions associated with electricity used within a community.**

Total upstream emissions= (Total Electricity Use x Regional Upstream Emissions Factor Conversion Factor)

Where:

Description		
Annual CO_2e	= Total annual CO_2e emitted by upstream activities ($mtCO_2e$)	User Input
Total Electricity Use	= Total annual electricity used in a community including transmission and distribution losses	User Input
EF_{region}	= Regionally appropriate upstream emissions factor from Table B.18	User Input
Conversion Factor	= Conversion from kg to metric ton (mt/kg)	10^{-3}

Figure 4: Method for estimating upstream GHG emissions associated with electricity used within a community, where "total electricity use" represents the use of electricity in residential, commercial, or industrial units from Table 4 and "regional upstream emissions factor" represents the value listed for the western region in Table B.18 of Appendix C of the Community Protocol. Retrieved from "U.S. Community Protocol for Accounting and Reporting Greenhouse Gas Emissions," Developed by ICLEI Local Governments for Sustainability – USA, 2012.

Equation BE.1.1.1	**Calculating CO_2 Emissions From Stationary Combustion (gallons)**
Fuel A CO_2 Emissions (metric tons) = Fuel Used (gallons) × Emission Factor (kg CO_2/gallon) ÷ 1,000 (kg/metric ton)	
Fuel B CO_2 Emissions (metric tons) = Fuel Used (gallons) × Emission Factor (kg CO_2/gallon) ÷ 1,000 (kg/metric ton)	
Total CO_2 Emissions (metric tons) = CO_2 from Fuel A (metric tons) + CO_2 from Fuel B (metric tons)	
Note that Equation BE.1.1.1 expresses fuel use in gallons. If fuel use is expressed in different units (such as short tons, cubic feet, MMBtu, etc.), replace "gallons" in the equation with the appropriate unit of measure. Be sure that your units of measure for fuel use are the same as those in your emission factor.	

Equation BE.1.1.2	**Calculating CH_4 Emissions From Stationary Combustion (MMBtu)**
Fuel/Sector A CH_4 Emissions (metric tons) = Fuel Use (MMBtu) × Emission Factor (kg CH_4/MMBtu) ÷ 1,000 (kg/metric ton)	
Fuel/Sector B CH_4 Emissions (metric tons) = Fuel Use (MMBtu) × Emission Factor (kg CH_4/MMBtu) ÷ 1,000 (kg/metric ton)	
Total CH_4 Emissions (metric tons) = CH_4 from Type A (metric tons) + CH_4 from Type B (metric tons)	

Equation BE.1.1.4	**Calculating N_2O Emissions From Stationary Combustion (MMBtu)**
Fuel/Sector A N_2O Emissions (metric tons) = Fuel Use (MMBtu) × Emission Factor (kg N_2O/MMBtu) ÷ 1,000 (kg/metric ton)	
Fuel/Sector B N_2O Emissions (metric tons) = Fuel Use (MMBtu) × Emission Factor (kg N_2O/MMBtu) ÷ 1,000 (kg/metric ton)	
Total N_2O Emissions (metric tons) = N_2O from Type A (metric tons)+ N_2O from Type B (metric tons)	

Figure 5: Method for estimating emissions from on-site combustion of fuels in residential, commercial, and industrial units, where "fuel use" represents the use of the particular fuel in residential, commercial, or industrial units from Table 4 and "emissions factor" represents the value listed for the particular fuel in Tables B.2 and B.3 of Appendix C of the Community Protocol. Retrieved from "U.S. Community Protocol for Accounting and Reporting Greenhouse Gas Emissions," Developed by ICLEI Local Governments for Sustainability – USA, 2012.

***Equation BE.5.1.1* Upstream emissions associated with stationary fuel use within a community. Note: this is for primary fuels only and also applies to primary fuels combusted outside of the community for generating electricity used by the community.**		
Annual CO_2e *emissions =Σ(Total Fuel Use*$_{Fuel\ Type}$ *x Conversion Factor x Upstream EF) x* 10^{-3} Where:		
Description		Value
Annual CO_2e	= Total annual CO_2e emitted by upstream activities ($mtCO_2e$)	Result
Total Fuel Use$_{Fuel\ Type}$	= Total annual fuel of each type used in a community and sector	User Input
Conversion Factor	= Conversion factor to obtain the same units of fuel used in Table B.13	User Input
Upstream EF	= Fuel specific upstream emissions factor from Table B.13	User Input
10^{-3}	= Conversion from kg to metric ton (mt/kg)	10^{-3}

Figure 6: Method for estimating upstream emissions associated with on-site fuel use in residential, commercial, and industrial units, where “total fuel use” represents the use of natural gas in residential, commercial, or industrial units from Table 4, “conversion factor” represents the factor used to match the units used in Table B.13 of Appendix C of the Community Protocol, and “upstream EF” represents the fuel-specific value listed in Table B.13 of Appendix C of the Community Protocol. Retrieved from “U.S. Community Protocol for Accounting and Reporting Greenhouse Gas Emissions,” Developed by ICLEI Local Governments for Sustainability – USA, 2012.

Emissions activities and sources associated with on-road transportation and other mobile units include the use of fuel in on-road passenger and freight vehicles, as well as the use of fuel in public transit vehicles. On-road passenger and freight vehicle emissions were calculated by using the formula:

$$\sum\left(\frac{VMT \times \%_{vehicle\ type}}{Average\ MPG_{vehicle\ type}} \times Emission\ Factor_{fuel\ type}\right)$$

Where VMT represents the Vehicle Miles Traveled estimate for passenger or heavy-duty vehicles listed in Table 4, $\%_{\text{vehicle type}}$ represents the default vehicle mix value listed in Table TR.1.3 in Appendix D of the Community Protocol, $\text{Average MPG}_{\text{vehicle type}}$ represents the default fuel efficiency by vehicle type listed in Table TR.1.5 in Appendix D of the Community Protocol, and $\text{Emission Factor}_{\text{fuel type}}$ represents the fuel-specific value listed in Table TR.1.6 in Appendix D of the Community Protocol. Emissions from public transit vehicles were obtained from InterCity Transit's 2010 greenhouse gas emissions inventory.

Emission sources and activities associated with the generation and disposal of solid waste include methane emissions from community-generated waste sent to landfills (Figure 7), process emissions associated with landfilling waste (Figure 8), and rail transportation emissions (Figure 9).

Equation SW.4.1 Methane Emissions

$$CH_4\ Emissions\ = GWP_{CH4} * (1-\ CE) * (1-OX) * M * \sum_i P_i\ * EF_i$$

Where:

Term	Description	Value
CH_4 emissions	= Community generated waste emissions from waste M ($mtCO_2e$)	Result
GWP_{CH4}	= CH_4 global warming potential	
M	= Total mass of waste entering landfill (wet short ton)	User Input
P_i	= Mass fraction of waste component i	User Input
EF_i	= Emission factor for material i ($mtCH_4$/wet short ton)	Table SW.5
CE	= Default LFG Collection Efficiency	No Collection, 0 Collection, 0.75
OX	= Oxidation rate	0.10

Source: As developed by ICLEI staff and Solid Waste Technical Advisory Committee. Emissions factors from U.S. EPA Municipal Solid Waste Publication (2008) available at http://www.epa.gov/epawaste/nonhaz/municipal/pubs/msw2008data.pdf

Figure 7: Method for estimating methane emissions from community-generated waste sent to landfills, where GWP_{CH4} represents the global warming potential value of methane (i.e., 21), M represents the tons of waste sent to the landfill listed in Table 4, P_i represents the default value of 1 for landfilled waste (i.e., all waste included in M is landfilled), CE represents the default Landfill Gas collection efficiency factor of 0.75 ,and EF_i represents the default emissions factors for mixed municipal solid waste listed in Table SW.5 of Appendix E of the Community Protocol. Retrieved from "U.S. Community Protocol for Accounting and Reporting Greenhouse Gas Emissions," Developed by ICLEI Local Governments for Sustainability – USA, 2012.

Equation SW.5 Process Emissions			
*PE_{LF} = M*EFP*			
Where:			
Term	Description	Value (Diesel)	Value (CNG)
PE_{LF}	= Total landfill process emissions ($mtCO_2e$)	Result	Result
M	= Total mass of solid waste that enters the landfill in the inventory year (wet short ton)	User Input	User Input
EFP	= Emissions factor for landfill process emissions (mtCO2e/wet short ton)	0.0164	0.011
Source: U.S. EPA, Waste Reduction Model (WARM), Version 12 and Model Documentation			

Figure 8: Method for estimating process emissions from community-generated waste sent to landfills, where M represents the tons of waste sent to the landfill listed in Table 4 and EFP represents the diesel value for fuel (i.e., 0.0164). Retrieved from "U.S. Community Protocol for Accounting and Reporting Greenhouse Gas Emissions," Developed by ICLEI Local Governments for Sustainability – USA, 2012.

Equation SW.6 Collection and Transportation Emissions			
*CE = M*EFC*			
*TE = M*MT*EFT*			
Where:			
Term	Description	Value (Diesel)	Value (CNG)
CE	= Total collection emissions ($mtCO_2e$)	Result	Result
TE	= Total transportation emissions ($mtCO_2e$)	Result	Result
M	= Total mass of solid waste collected and transported in the inventory year (wet short ton)	User Input	User Input
MT	= Miles traveled to disposal site	User Input	User Input
EFC	= Emissions factor for collection emissions ($mtCO_2e$/ wet short ton)	0.020	0.014
EFT	= Emissions factor for transport emissions ($mtCO_2e$/ wet short ton/mile)	0.00014	0.00010

Figure 9: Method for estimating rail transportation emissions from community-generated waste sent to landfills, where M represents the tons of waste sent to the landfill listed in Table 4, MT represents the estimated 200 miles waste travels by rail to the landfill, and EFT represents the default value of 0.00014 for diesel locomotives. Only rail transportation emissions are estimated as collection emissions are captured in the on-road vehicle estimate. Retrieved from "U.S. Community Protocol for Accounting and Reporting Greenhouse Gas Emissions," Developed by ICLEI Local Governments for Sustainability – USA, 2012.

Emissions sources and activities associated with domesticated animal production include methane emissions from enteric fermentation. In this inventory, only emissions from enteric fermentation are reported as the availability of data related to manure management practices in Thurston County is not readily available. Beef cows, dairy cows, swine, and sheep populations were included in methane emissions estimates resulting from enteric fermentation (Figure 10).

Equation A.1
Methane Emissions due to Enteric Fermentation from Domesticated Animal Production

CH_4 Emissions =Σ (Animal Population x EF x (1/1000) x GWP)$_{animal\ type}$

Where:

		Description	Value
CH_4 Emissions	=	Methane emissions due to enteric fermentation ($MTCO_2e$)	Product of equation A.1
Animal Population	=	Average annual animal population (head)	User input (or as calculated in A.0)
EF	=	Emissions Factor (kg CH_4/head/year)	Varies by animal type, see tables A.1.1 and A.1.2
1/1000	=	Conversion of kg CH_4 to metric tons	1/1000
GWP_{CH4}	=	Global Warming Potential; conversion from metric tons of methane into metric tons of CO_2 equivalents (CO_2e)	GWP[1]

Source: US Environmental Protection Agency's *2011 Inventory of US Greenhouse Gas Emissions and Sinks* Annex 3 Section 3.9 Methodology for Estimating CH_4 Emissions from Enteric Fermentation

Figure 10: Method for estimating methane emissions from enteric fermentation, where "animal population" represents species-specific population estimates listed in Table 4, EF represents the species-specific emissions factor listed in tables A.1.1 and A.1.2 in Appendix G of the Community Protocol, and GWP_{CH4} represents the global warming potential for methane (21). Retrieved from "U.S. Community Protocol for Accounting and Reporting Greenhouse Gas Emissions," Developed by ICLEI Local Governments for Sustainability – USA, 2012.

Emission sources and activities associated with wastewater treatment at the LOTT Clean Water Alliance Budd Inlet Treatment Plant include digester operation (Figure 11, 12, 13), lagoon (Figure 14, 15) and biological (Figure 16) wastewater treatment processes.

***Equation WW.1.a* Emissions from Devices Designed to Combust Digester Gas, with CH_4 Content Known**

Annual CH_4 emissions =

(Digester Gas xfCH_4x BTU_{CH4}x 10^{-6}x EF_{CH4}x 365.25 x 10^{-3}) x GWP

Where:

Description		Value
Annual CH_4 emissions	= Total annual CH_4 emitted by incomplete combustion ($mtCO_2e$)	Result
Digester gas	= Standard cubic feet of digester gas produced per day (std ft^3/day)	User Input
fCH_4	= Fraction of CH_4 in gas	User Input
BTU_{CH4}	= Default BTU content of CH_4, higher heating value (BTU/ft^3)	1028 (nation-wide average)
10^{-6}	= Conversion from BTU to 1 MMBTU	10^{-6}
EF_{CH4}	= CH_4 emission factor (kg CH_4/MMBTU)	3.2 X 10^{-3} kg CH_4 per MMBTU
365.25	= Conversion factor (day/year)	365.25
10^{-3}	= Conversion from kg to mt (mt/kg)	10^{-3}
GWP_{CH_4}	= Global Warming Potential; conversion from mt of CH_4 into mt of CO_2 equivalents	GWP^5

***Equation WW.1.a* Emissions from Devices Designed to Combust Digester Gas, with CH_4 Content Known**

Source: In 40 CFR Part 98, Mandatory Reporting of Greenhouse Gases; Final Rule, Table C-2, page 79154 of the Federal Register / Vol. 75, No. 242 / Friday, December 17, 2010 / Rules and Regulations, is referenced an emission factor for digester gas combustion: 3.2 X 10^{-3} kg CH_4 per million BTU. See: http://edocket.access.gpo.gov/2010/pdf/2010-30286.pdf

Figure 11: Method for estimating methane emissions from devices designed to combust digester gas, where "digester gas" represents the average daily biogas production listed in Table 4, and fCH_4 represents the fraction of CH_4 contained in each unit of biogas (0.70). Retrieved from "U.S. Community Protocol for Accounting and Reporting Greenhouse Gas Emissions," Developed by ICLEI Local Governments for Sustainability – USA, 2012.

Box WW.2.a	Example Calculation of N_2O Emissions from the Combustion of Anaerobic Digester Gas when fraction of CH_4 is known	
A wastewater facility generates 1,000,000 ft^3 per day of digester gas containing 65% CH_4. The BTU content of the digester gas is not available. Based on this scenario the N_2O emissions from the combustion of digester biogas can be calculated as follows		
Description		Value
N_2O emissions	= Total N_2O emitted by combustion ($mtCO_2e$)	Result
Digester gas	= Measured standard cubic feet of digester gas produced per day (std ft^3/ day)	1,000,000
fCH_4	= Fraction of CH_4 in biogas	0.65
BTU_{CH4}	= Default BTU content of CH_4, higher heating value (BTU/ft^3)	1028
10^{-6}	= Conversion from BTU to 1 MMBTU	10^{-6}
EF_{N2O}	= N_2O emission factor (kg N_2O/MMBTU)	6.3 X 10^{-4} kg N_2O per MMBTU
365.25	= Conversion factor (day/year)	365.25
10^{-3}	= Conversion from kg to mt (mt/kg)	10^{-3}
GWP_{N_2O}	= Global Warming Potential; conversion from mt of N_2O into mt of CO_2 equivalents	GWP[9]
Sample Calculation:		
Annual N_2O *emissions* = $(1,000,000 \times 0.65 \times 1028 \times 10^{-6} \times (6.3 \times 10^{-4}) \times 365.25 \times 10^{-3}) \times 310$ = 47.7 $mtCO_2e$		

Figure 12: Example method for estimating nitrous oxide emissions from the combustion of digester gas, where "digester gas" represents the average daily biogas production listed in Table 4, and fCH_4 represents the fraction of CH_4 contained in each unit of biogas (0.70), all other values as listed in this figure. Retrieved from "U.S. Community Protocol for Accounting and Reporting Greenhouse Gas Emissions," Developed by ICLEI Local Governments for Sustainability – USA, 2012.

Equation WW.3 **CO_2 Emissions from Digester gas Combustion**		
*Annual CO_2 emissions = Digester gas * BTU_{CO2} * EF_{CO2} * 365.25 * 10^{-3}*		
Where:		
Description		Value
CO_2 emissions	= Total annual biogenic CO_2 emitted by combustion of biogas ($mtCO_2e$)	Result
Digester gas	= Standard cubic feet of digester gas produced per day (std ft^3/day)	User input
BTU_{CO2}	= BTU content of biogas (MMBTU/scf)	User input or 0.000841
EF_{CO2}	= Emission factor for CO_2 (kg CO_2/ MMBTU)	52.07
365.25	= Conversion factor (day/year)	365.25
10^{-3}	= Conversion factor kg to mt	10^{-3}
Source: Table G.2 of the Local Government Operations Protocol version 1.1 May, 2010		

Figure 13: Method for estimating carbon dioxide emissions from digester gas combustion, where "digester gas" represents the average daily biogas production listed in Table 4 and BTU_{CO2} represents the default value of 0.000841. Retrieved from "U.S. Community Protocol for Accounting and Reporting Greenhouse Gas Emissions," Developed by ICLEI Local Governments for Sustainability – USA, 2012.

Equation WW.6 **Methane Emissions from Lagoons**		
Annual CH_4 emissions = (BOD_5 load × (1-FP) × Bo × MCF_a × 365.25 × 10^{-3}) × GWP		
Where:		
Description		Value
Annual CH_4 emissions	= Total annual CH_4 emitted by lagoon ($mtCO_2e$)	Result
BOD_5 load	= Amount of BOD_5 treated per day ($kgBOD_5$/day)	User input
FP	= Fraction of BOD_5 removed in primary treatment	User input
Bo	= Maximum CH_4 producing capacity for domestic wastewater (kg CH_4/kg BOD_5 removed)	0.6
MCF_a	= CH_4 correction factor for anaerobic systems	0.8
365.25	= Conversion factor (day/year)	365.25
10^{-3}	= Conversion from kg to mt (mt/kg)	10^{-3}
GWP_{CH_4}	= Global Warming Potential; conversion from mt of CH_4 into mt of CO_2 equivalents	GWP[16]
Source: As listed in LGO protocol Equation 10.3 from EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007, Chapter 8, 8-7 (2009)		

Figure 14: Method for estimating methane emissions from wastewater treatment lagoons, where "BOD_5load" represents BOD_5 listed in Table 4 and "FP" represents BOD_5 removed listed in Table 4. Retrieved from "U.S. Community Protocol for Accounting and Reporting Greenhouse Gas Emissions," Developed by ICLEI Local Governments for Sustainability – USA, 2012.

Equation WW.7 **N_2O Process Emission from Wastewater Treatment Plants (or aeration basin) that Uses Nitrification or Denitrification**

Annual N_2O emissions $= ((P \times F_{ind\text{-}com}) \times EF \times 10^{-6}) \times GWP$

Where:

Description		Value
Annual N_2O emissions	= Total annual N_2O emitted by WWTP processes ($mtCO_2e$)	Result
P	= Population served by the WWTP adjusted for industrial discharge (if applicable)	User input
$F_{ind\text{-}com}$	= Factor for high nitrogen loading of industrial or commercial discharge	1.25
$F_{ind\text{-}com}$	= Factor for insignificant industrial or commercial discharge	1
EFnit/denit	= Emission factor for a WWTP with nitrification or denitrification (g N_2O/ person equivalent/year)	7
		10^{-6}
10^{-6}	= Conversion from g to mt (mt/g)	
GWP_{N_2O}	= Global Warming Potential; conversion from mt of N_2O into mt of CO_2 equivalents	GWP^{21}

Source: *As listed in LGO protocol Equation 10.7 from EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1890-2007, Chapter 8, 8-13 (2009)*

Figure 15: Method for estimating emissions from denitrification, where P represents population served by LOTT listed in Table 4. Retrieved from "U.S. Community Protocol for Accounting and Reporting Greenhouse Gas Emissions," Developed by ICLEI Local Governments for Sustainability – USA, 2012.

Equation WW.9 **CO2 Emission from Methanol Use**		
*Annual CO_2 emissions = Methanol Load *F *(44.01/32.04) *GWP *365.25*		
Where:		
Description		Value
Annual CO_2 emissions	= Total annual CO_2 emitted ($mtCO_2e$)	Result
Methanol load	= Amount of neat chemical used per day (mt CH_3OH/day)	User Input
F	= Factor to be applied based on WWTP's sludge treatment type: • Raw Solids Disposal 80% • Anaerobic Digestion 90% • Solids Combustion 100%	0.80, 0.90, 1.0
44.01/32.04	= Molecular weight ratio of 44.01 (for CO_2) to 32.04 (for CH_3OH)	1.37
GWP	= Global Warming Potential for CO_2	1
365.25	= Conversion factor from days to year	365.25

Figure 16: Method for estimating carbon dioxide emissions from methanol usage in the biological treatment of wastewater, where "methanol load" represents annual methanol consumption listed in Table 4. Retrieved from "U.S. Community Protocol for Accounting and Reporting Greenhouse Gas Emissions," Developed by ICLEI Local Governments for Sustainability – USA, 2012.

Chapter 4

Results

In calendar year 2010 sources and activities producing greenhouse gas emissions in Thurston County, WA emitted roughly 2.78 million metric tons of carbon dioxide equivalents (MTCDEs) (Table 5, Figure 17), including emissions from the built environment, on-road vehicles (i.e., passenger, heavy-duty, and public transit vehicles), the generation and disposal of solid waste, wastewater treatment, and livestock production. The built environment was the largest emission source type generating approximately 1.44 million MTCDE (52%), whereas on-road vehicles were the second largest emission source type producing approximately 1.23 million MTCDE (44%). The generation and disposal of solid waste by the community emitted approximately 54,000 MTCDE (2%), whereas emissions related to the primary wastewater treatment facility within the county was approximately 31,000 MTCDE(1%), and livestock produced the least amount of emissions, roughly 21,000 MTCDE (1%).

Table 5: Emission source type quantities, and percentage of total emissions. Values are in Metric Tons of Carbon Dioxide Equivalents (MTCDE).

Emission Source Type	**MTCDE**	**%**
Built Environment	1,444,406	52%
On-Road Vehicles	1,230,054	44%
Solid Waste	54,166	2%
Livestock	21,289	1%
Wastewater Treatment	31,508	1%
Total	2,781,423	100%
Per Capita Emissions	11.03	

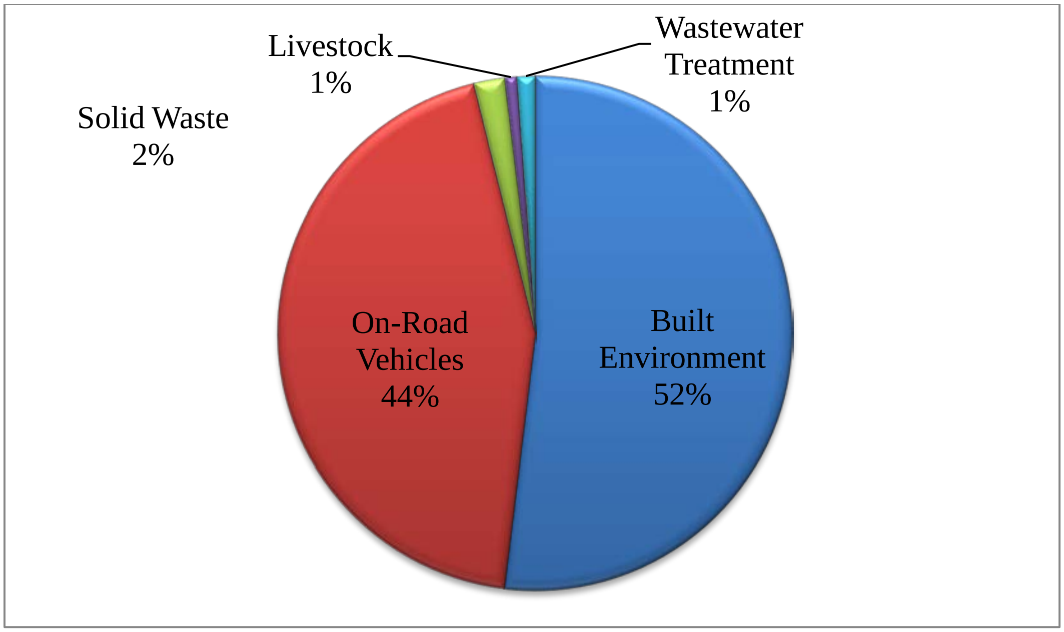

Figure 17: Distribution of percentages of metric tons of carbon dioxide equivalents emitted in 2010 from community sources and activities in Thurston County, WA. Thurston County produced approximately 2.78 million metric tons of carbon dioxide equivalents in calendar year 2010, including emissions from the built environment, on-road transportation, solid waste, water and wastewater treatment, and livestock production.

Built Environment Emissions

Emissions resulting from the use of fuel and electricity in the built environment account for the largest portion of emissions in the county (Figure 17). Diving further into the distribution of emissions within the built environment reveals that the residential sector accounts for the most built environment emission and the second largest single source of emissions count-wide (Figure 18).

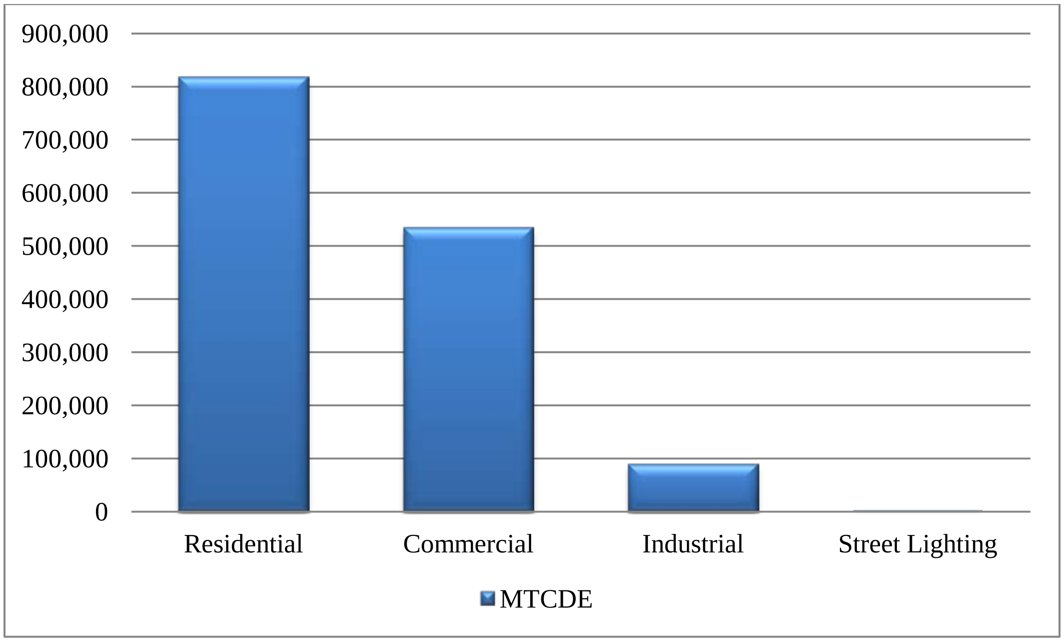

Figure 18: Distribution of built environment emissions in metric tons of carbon dioxide equivalents among residential, commercial, industrial and street lighting units. Emissions associated with the built environment in Thurston County were largest in residential buildings.

The use of electricity within the county accounts for sixty percent of built environment emissions (Table 6), while the use of fuel, primarily natural gas, accounts for roughly twenty percent (Table 6). Upstream emissions involved in the generation of the electricity consumed by the community account for approximately ten percent (Table 6) of built environment emissions. Emissions from electricity transmission and distribution losses and upstream emissions associated with the production and distribution of natural gas account for five and four percent of the built environment total, respectively (Table 6).

Table 6: Emission source quantities and percentage of total for emissions from the built environment. Values are in Metric Tons of Carbon Dioxide Equivalents (MTCDE).

Emissions Source	**MTCDE**	**%**
Use of Electricity	869,353	60%
Use of Fuel	293,597	20%
Upstream Electricity Use	145,476	10%
Transmission and Distribution Losses	71,373	5%
Upstream Fuel Use	64,606	4%
Total	1,444,406	100%

On-road Vehicle Emissions

On-road vehicle emissions account for approximately 44% of total emissions in Thurston County, WA in 2010, and are the second largest emission source type county-wide (Table 7). Emissions resulting from on road vehicles operating within the county boundary were larger in passenger vehicles (962,360 MTCDE) than in heavy-duty freight vehicles (258,696 MTCDE), and public transit emissions were the smallest source (8,997 MTCDE). Passenger vehicles account for seventy-eight percent of emissions from on-road transport and are the largest single-source of emissions county-wide, while heavy-duty freight vehicles account for twenty-one percent of on-road transportation emissions, and public transit accounts for approximately 1% of on-road transportation emissions.

Table 7: Emission source quantities and percentage of total for emissions from on-road vehicles. Values are in Metric Tons of Carbon Dioxide Equivalents (MTCDE).

Emission Source	**MTCDE**	**%**
Passenger vehicles	962,361	78%
Heavy Duty Freight vehicles	258,697	21%
Public Transit (Gasoline)	1,842	>1%
Public Transit (Diesel)	7,154	>1%
Total	1,230,054	100%

Solid Waste Emissions

Eighty-six percent of solid waste emissions are a result of methane emissions from the community-generated waste that is landfilled (Table 8). Emissions associated with the landfilling process (i.e., biological decomposition) and equipment account for 5% of emissions (Table 8). Rail and truck emissions, separate from on-road vehicle emissions, from transporting waste from the Thurston County Waste and Recovery Center to the Roosevelt Regional Landfill in Roosevelt, WA (4,625 MTCDE) makeup the remaining 9% of solid waste emissions (Table 8).

Table 8: Emission source quantities and percentage of total for emissions from the generation and disposal of solid waste. Values are in Metric Tons of Carbon Dioxide Equivalents (MTCDE).

Emission Source	**MTCDE**	**%**
Methane emissions	46,831	86%
Process emissions	2,710	5%
Transportation emissions	4,625	9%
Total	54,166	100%

Wastewater Treatment Emissions

Emissions from the operation of the primary wastewater treatment facility within the county (Lacey Olympia Tumwater Thurston (LOTT) Clean Water Alliance Budd Inlet Treatment Plant) were comprised of process emissions, emissions from burning methane gas from the onsite digesters, and emissions resulting from the use of methanol to biologically treat waste (Table 5). Process emissions account for 62% of emissions at the primary wastewater treatment plant, 37% of emissions were from the onsite burning of captured methane gas, and approximately 1% of emissions were a result of methanol use in the biological treatment of waste (Table 9).

Table 9: Emission source quantities and percentage of total for emissions from wastewater treatment at the LOTT Clean Water Alliance Budd Inlet Treatment Plant. Values are in Metric Tons of Carbon Dioxide Equivalents (MTCDE).

Emission Source	**MTCDE**	**%**
Digester Emissions	11,759	37%
Process Emissions	19,623	62%
Methanol Emissions	124	1%
Total	31,506	100%

Livestock Emissions

Methane emissions resulting from domesticated animal production within the county-boundary were divided among beef cows, dairy cows, sheep, and swine (Table 6). Fifty-one percent of emissions from domesticated animal production were from beef cows, 48% from dairy cows, 1% from sheep, and less than 1% from swine (Table 10).

Table 10: Emission source quantities and percentage of total for emissions from livestock production. Values are in Metric Tons of Carbon Dioxide Equivalents (MTCDE).

Emission Source	**MTCDE**	**%**
Dairy Cows	10,196	48%
Beef Cows	10,760	51%
Swine	24	<1%
Sheep	309	1%
Total	21,289	100%

Chapter 5

Discussion & Conclusion

Emissions in Thurston County Relative to Washington State and King County, WA

In 2010, Thurston County emitted roughly 2.78 million metric tons of carbon dioxide equivalents, roughly 2.5% of the total emissions in Washington State for the same year (i.e., Washington State emitted roughly 103 million metric tons of carbon dioxide equivalents in 2010, Washington State Department of Ecology 2007). Given the population of Thurston County (252,264) and the total estimated emissions for the county (2,781,423 Metric Tons of Carbon Dioxide Equivalents (MTCDE)), per capita CO_2 emissions in 2010 are roughly 11 MTCDE. The Washington State Department of Ecology reported in 2007 that on a per capita basis, Washington residents emit about 15 MTCDE annually; much lower than the national per capita average for 2012 of 25 MTCDE (EPA 2013), largely due to the state's abundant hydroelectricity. Further, emission estimates for King County, WA, the nearest county in Washington that has completed a similar inventory, are estimated at roughly 16% of total emissions in Washington State (roughly 16.6 million MTCDE), with a per capita estimate of approximately 8.6 MTCDE (Erickson and Chandler 2012).

Thurston County is on par with the state for both per capita emissions and the proportion of emissions resulting from transportation (approximately 44%). The principal source of Washington's GHG emissions is transportation, accounting for roughly 47% of total state gross GHG emissions in 2005 (Washington State Department of Ecology 2007). Although transportation does make up a large fraction of both Washington's emissions and Thurston County's emissions – again largely as a result of the state's abundant hydroelectricity – on a per capita basis, both produce emissions that are similar to the US average for transportation (Washington State Department of Ecology 2007) roughly 5 MTCDE per capita (EPA 2013).

Per capita emissions in Thurston County are slightly higher than those reported in King County, WA (approximately 8.6 MTCDE per capita). Emissions in Thurston County in 2010 from fuel consumption in residential, commercial, and industrial units are a small proportion of total emissions (approximately 11%) in comparison to Washington State (20%), and the consumption of electricity comprises a greater proportion of total emissions (approximately 31% to the State's 20%) (Washington State Department of Ecology 2007). Thurston County per capita emissions from the built environment are higher (roughly 5.6 MTCDE per person) than that of King County (roughly 4 MTCDE per person) (Erickson and Chandler 2012). Further, per capita transportation emissions in Thurston County are higher (4.7 MTCDE per person) than that of King County (4 MTCDE per person). These differences may be explained in part by per-person decreases in vehicle travel and residential energy that have been observed in King County since 2003, suggesting that regional efforts to create pedestrian and transit-oriented communities and more energy-efficient buildings may be beginning to yield results (Erickson and Chandler 2012).

Agricultural related emissions in Thurston County differ significantly from the state average. Agricultural activities (i.e., manure management, fertilizer use, and livestock) in Washington account for 6% of state emissions (Washington State Department of Ecology), while in Thurston County they account for 1% of emissions. This difference is likely due to the sources and activities included at the state level that are excluded from the county-level analysis (i.e., manure management and fertilizer use), as well as the relatively larger proportion of agricultural land in the eastern region of Washington than that of western Washington. Further, farmland in Thurston County accounts for only 17% of land-use (TRPC 2012), while it accounts for 33% of land-use state-wide (USDA 2009).

Implications of Results

The estimated greenhouse gas emissions values obtained using the Community Protocol indicate the most significant sources of greenhouse gas emissions in Thurston County, WA in 2010 were the use of fuel in on-road transportation operating within the geopolitical boundary and energy usage in residential, commercial, and industrial buildings and properties. The use of fuel in on-road passenger vehicles represents the largest single source of emissions. The results obtained suggest both local governments and community members in Thurston County, WA should focus greenhouse gas emissions reduction efforts on sources and activities associated with on-road transportation and the built environment.

Given the limitations of local government's ability to impact emissions associated with on-road vehicles themselves (i.e., fuel efficiency), GHG reduction efforts in the transportation realm should focus on reducing the quantity of vehicles on the road through increased access and prevalence of public transit options as well as pedestrian options like greenbelts. King County has achieved steady reductions in transportation related emissions by increasing availability and access to public transit options (Erickson and Chandler 2012). One opportunity would be the provision of public transit options that extend the reach of existing public transit infrastructure in the cities of Olympia, Lacey, and Tumwater to connect incorporated and unincorporated portions of Thurston County.

Increased attention should also be paid to residential energy efficiency opportunities. Emissions resulting from the built environment are largely attributable to the use of electricity and fuel in residential units. Both governmental and individual efforts to reduce greenhouse gas emissions should focus on residential units, specifically on efficient use of electricity among residential units. King County has observed successes in reducing emissions related to energy consumption in buildings through ongoing efforts to increase energy performance of existing buildings, as well as encouraging fuel switchinig from less-efficient oil to more-efficient natural gas. Further increased urbanization in King County and the growing fraction of residents that live in less energy-intensive multifamily housing may contribute to decreases in energy consumption in buildings (Erickson and Chandler 2012). These options are feasibility for Thurston County, and provide basic opportunities to reduce emissions from buildings.

Emissions resulting from generation and disposal of solid waste, as well as wastewater treatment may be relatively fixed in Thurston County given existing efforts to reduce landfilled waste and minimize the environmental impact of wastewater treatment processes. Wastewater treatment processes at the Budd Inlet Treatment Plant, the primary wastewater treatment facility in Thurston County, already utilizes anaerobic digestion of solids and methane capture to heat and power its facilities, which is an extremely effective way to reduce GHG emissions associated with wastewater treatment. Dissimilarly, there may be opportunities for reductions in methane emissions from livestock production on farms in Thurston County, given the rise of anaerobic digester technologies and improved methodologies for manure management. However, the relatively small proportion of emissions resulting from livestock production and the economic challenge presented by low rates for electricity limit the applicability of these expensive technologies on farms in Washington State (Redfern 2013).

Limitations of Estimation Methodology

Although the observed results are based on a vetted and accepted greenhouse gas emissions estimation methodology, these results are constrained by a number of factors. There are three primary sources of uncertainty that need to be addressed due to the methodology chosen in this study, and a discussion of these sources is presented below. Uncertainty arises from 1)the use of emission factors for the Northwest sub-region of the Emissions & Generation Resource Integrated Database (eGRID) in the estimation of emissions from electricity usage in place of utility-specific emissions factors, 2) the estimation of upstream emissions, and 3) the estimation of passenger vehicle emissions all present challenges to the accuracy of aggregate emission estimates as well as per capita emissions estimates.

The eGRID is a comprehensive source of data on the characteristics of resource mixes for all electric power generated in the United States, and is a source for estimating greenhouse gas emissions from electricity using eGRID subregion emission factors for the northwest (i.e., the Western Electricity Coordinating Council (WECC) Northwest (NWPP)). The Community Protocol prefers the use of utility-specific emission factors; however, this data is not readily available from Puget Sound Energy (PSE), which is the source of the energy data used in this study. However, the WECC eGRID sub-region average emission factors do provide adequate results as the fuel mix proportions between PSE and the NWPP do not significantly differ (Table 11). The most significant difference in estimates based upon the NWPP versus a utility-specific emission factor would be an underestimation of emissions.

Upstream emissions refer strictly to the process of producing fuels. Upstream emissions do not include GHG emissions associated with construction, maintenance, and decommissioning of infrastructure, or the emissions associated with management of wastes, such as spent nuclear fuels. The Community Protocol recommends using the Department of Energy's National Renewable Energy Laboratory (NREL) average emissions factors derived from its Fuels and Energy Pre-combustion Life Cycle Inventory (LCI) database, which was the procedure followed in this study. The uncertainty associated with this

Table 11: Electricity resource mix for the eGRID WECC Northwest Sub-region in relation to Puget Sound Energy.

Sub-region or Utility	Sub-region / Utility Name	2009 Generation Resource Mix (%)										
		Coal	Oil	Gas	Other Fossil	Biomass	Hydro	Nuclear	Wind	Solar	Geothermal	Other
NWPP	WECC Northwest	29.8	0.3	15.2	0.15	1.09	46.5	2.46	3.8	-	0.55	0.12
PSE	Puget Sound Energy	32	-	30	-	-	36	1	-	-	-	1*

*Biomass, landfill gas, petroleum, waste and wind.

methodology is inherent in the application of these average values to any particular locality. These factors, while widely applicable as national averages do not allow the user to account for differences that could exist if the exact source of a fuel, and technologies and processes used to extract and refine it, is known. The recent increase in unconventional extractions methods (i.e., hydrolic fracturing, or “fracking”) complicates this matter further. “Fracking” for natural gas is known to increase methane leakage, causing higher upstream emissions as compared to other forms of natural gas extraction. Similarly, gasoline and other petroleum products derived from tar sands or other “heavy oil” deposits require significantly more energy inputs to extract and refine than is the case with traditional liquid deposits. This increases the amount of secondary fuels required to produce each unit of primary fuel that was refined from one these unconventional deposits. The Community Protocol does not account for energy-intensive extraction methods, and thus may underestimate emissions from the use of natural gas that may be derived from these sources. Further, due to a lack of available data, upstream emissions from some fuel types are not considered in this method, such as biomass. Also, data on secondary fuel use associated with the production of many fuel types beyond the most common (natural gas, coal, and fuel oil) are not widely available and not currently included in the Community Protocol.

The Community Protocol provides a framework for estimating emissions from on-road transit, however, local estimates of GHG emissions from vehicles differs from state-level and national-level accounting because of the high proportion of cross-boundary travel, and the unique authority and influence local governments possess over transportation and land use. Typically, state and national estimation methods utilize the aggregate amount of fuel dispensed, which does not serve local entities well as vehicles typically travel between multiple jurisdictions on a single tank of fuel (Ramaswami et al. 2008) . Similarly, methods based solely on vehicle travel within the community's geographic boundaries also produce inaccurate results also due to the high proportion of cross-boundary traffic. This inventory attempts to address this issue by using Thurston Regional Planning Council's Travel Demand Model, and excluding all modeled trips that do not originate or terminate within the Thurston County geopolitical boundary. However, local variations in vehicle fuel efficiency and fuel type further complicate emission estimates, and adjustments based on known local data are difficult to obtain as state departments that manage the registration of motor vehicles do not produce it; for this reason the national traffic mix proportions provided by the Community Protocol were applied to the modeled regional Vehicle Miles Traveled (VMT) estimate.

Future Research and Interdisciplinary Statement

Future efforts related to greenhouse gas emission estimates for Thurston Climate Action Team and Thurston County should focus on producing an inventory for the 1990 calendar year in order to establish reduction targets that are in line with existing targets for state agencies outlined in RCW 70.235.020 – the law defining Greenhouse gas emissions reduction targets for Washington State. In addition, subsequent inventories should be completed on an annual basis to track progress and trends over time. Further, future iterations of this study should strive to incorporate utility-specific emission factors for Puget Sound Energy and regionally accurate vehicle fuel types and efficiencies and traffic mix proportions. These provisions will result in an inventory with greater accuracy and completeness for the region.

These future efforts are significant to and highlight the interdisciplinary nature of this study. Community greenhouse gas emissions inventories are an important component of subnational greenhouse gas emissions reduction strategies, and this inventory is a first-step in developing plans and policies that will truly reduce emissions. The estimates herein provide a basis from which planners and policymakers can plan, initiate, and measure emission reduction efforts.

Conclusion

Thurston County is particularly vulnerable to climate change due to susceptibility to sea level rise, ocean acidification, and wildfire, in addition to economic dependencies on natural resources, like aquaculture, logging, and hydroelectricity. Climate change is projected to affect many human systems and systems upon which humans are dependent in Washington State, like forest resources, electricity, municipal water supplies, agriculture, human health, and shorelines. Climate change’s impacts on the state’s electrical system, which is highly dependent on hydropower, will affect both supply and demand and include shifts in the timing of peak hydropower generation due to increased/decreased seasonal flows, as well as increased electrical demands in the summer months for cooling needs (Elsner et al. 2010). The threat to hydropower generation will likely exacerbate the importation of electrical energy or drive the development of new generation resources, likely increasing greenhouse gas emissions in the region. Agriculture in Washington will likely gain longer growing seasons, with increased aridity and reduced water supply alongside increases in water demands driving further increases in emissions.

Greenhouse gas emissions inventories are an integral part of local and state greenhouse gas emissions reductions plans across the United States as global atmospheric concentrations of carbon dioxide are reaching unprecedented levels. However, Thurston County is but a small contributor to global greenhouse gas emissions. In relation to global climate change, the importance of community greenhouse gas emissions inventories on a much broader scale involves the development of plans and policies that will result in marked reductions of greenhouse gas emissions locally, but also reduction strategies that are applicable and replicable on a national, and even global, scale.

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Appendix A: Table of Emission Estimates

Thurston County

Emission Source Type	MTCDE	%
Built Environment	1,444,406	52%
On-Road Vehicles	1,230,054	44%
Solid Waste	54,166	2%
Agriculture/Livestock	21,289	1%
Wastewater Treatment	31,508	1%
Total	2,781,423	100%
Per Capita Emissions	11.03	

KEY	user input range	estimated values
	calculating range	do nothing
	bold type for source totals	

BUILT ENVIRONMENT

Use of fuel in residential, commercial, and industrial stationary combustion equipment

	Natural Gas (therms)	Natural Gas (MMBtu)	Fuel Oil (MMBtu)	Propane/LPG (MMBtu)	Wood (MMBtu)	mt CO2	mt CH4	mt N2O	MTCDE
Residential	31,268,416	3,126,842	248,428	26,169	125,965	197,583	58	1.01	187,307
Commercial	15,994,387	1,599,439				84,802	8	0.16	85,020
Industrial	4,007,881	400,788				21,250	0.40	0.04	21,271
								Total	293,597

Upstream emissions from use of natural gas in residential, commercial, and industrial stationary equipment

	Natural Gas (therms)	Natural Gas (ft^3)	Natural Gas (m^3)	mt CH4	mt N2O	MTCDE
Residential	31,268,416	3,126,841,600	88,542,148			39,401
Commercial	15,994,387	1,599,438,700	45,290,986			20,154
Industrial	4,007,881	400,788,100	11,349,036			5,050
					Total	64,606

Use of electricity in lighting(ext), residential, commercial, and industrial buildings

	Electricity (kWh)	Electricity (MWh)	mt CO2	mt CH4	mt N2O	MTCDE
Lighting (ext)	4,419,884	4,419.88	3,620,813	67.58	55.25	1,650.80
Residential	1,266,273,211	1,266,273.21	1,037,343,677	19,361.32	15,828.42	472,946.15
Commercial	920,512,299	920,512.30	754,092,880	14,074.63	11,506.40	343,806.33
Industrial	136,413,709	136,413.71	111,751,475	2,085.77	1,705.17	50,949.78
					Total	869,353.05

Electricity Transmission and Distribution Losses emissions from the use of electricity in lighting(ext), residential, commercial, and industrial buildings

	Electricity (kWh)	Electricity (MWh)	mt CO2	mt CH4	mt N2O	MTCDE
Lighting (ext)	4,419,884	4,419.88				135.53
Residential	1,266,273,211	1,266,273.21				38,828.59
Commercial	920,512,299	920,512.30				28,226.29
Industrial	136,413,709	136,413.71				4,182.95
					Total	71,373.36

Upstream Emissions from the use of electricity in lighting(ext), residential, commercial, and industrial buildings

	Electricity (kWh)	mt CO2	mt CH4	mt N2O	MTCDE
Lighting (ext)	4,419,884				276.24
Residential	1,266,273,211				79,142.08
Commercial	920,512,299				57,532.02
Industrial	136,413,709				8,525.86
				Total	145,476.19

SOLID WASTE

Generation and disposal of solid waste by the community using total volume of waste generated in Thurston County

	Tons	mt CO2	CH4 in MTCDE	N2O in MTCDE	MTCDE
Methane emissions from community-generated waste sent to landfills	165,191.00		46,831.65		46,831.65
Process emissions associated with landfilling	165,191.00				2,709.13
Transportation emissions	165,191.00				4,625.35
				Total	54,166.13

AGRICULTURE/LIVESTOCK

Domesticated animal production, using USDA Agricultural Census 2007 figures

	Quantity	mt CO2	mt CH4	mt N2O	MTCDE
Dairy Cows (individuals)	5,165		485.5100		10,195.71
Beef Cows (individuals)	5,451		512.3940		10,760.27
Swine (individuals)	777		1.17		24.48
Sheep (individuals)	1,838		14.70		308.78
				Total	21,289.24

WASTEWATER TREAMENT

Emissions from operation of primary wastewater treatment facility located in the community

	Volume	MTCDE	CH4 in MTCDE	N20 in MTCDE	Total MTCDE
LOTT - Digester Annual Average Daily Gas (ft^{3})	138,369				
LOTT - Fraction of CH_4 in biogas (annual average)	70%				
LOTT - Digester Emissions		2,213.16	2,443.93	7,102.68	11,759.78
LOTT - lbs BOD/day	23,162				
LOTT - kg BOD/day	10,506				
LOTT - lbs BOD/day removed	11,544				
LOTT - kg BOD/day removed	5,236				
LOTT - Fraction kg BOD/day removed	0.49840				
LOTT - Population Served	102,000				
LOTT - Process Emissions			19,402.0453	221.3	19,623.3853
LOTT - Annual Methanol consumption (gallons)	31,029				
LOTT - Emissions from Methanol Use	100.84425	124.3410			124.3410
				Total	31,507.50

ON-ROAD VEHICLES

On road vehicles operating within the community, excluding public transit

	VMT	kg CO2	g CH4	g N2O	MTCDE
Emissions from Passenger vehicles	2,341,013,000	938,155,810.87	63,272,899.36	73,793,411.79	962,360.50
Emissions from Heavy Duty Freight vehicles	2,341,013,000	258,656,133.75	129,201.40	121,601.32	258,696.54
Emissions from Public Transit (Gasoline)					1,842.75
Emissions from Public Transit (Diesel)					7,154.29
				Total	1,230,054.08