2008 King County Community Greenhouse Gas Emissions Inventory: "Geographic Plus" Methodology

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http://www.kingcounty.gov/climate

climatechange@kingcounty.gov

Stockholm Environment Institute – U.S. Center
for the King County Department of Natural Resources and Parks

Authors: Chelsea Chandler, Peter Erickson, and Michael Lazarus

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Introduction and Methodology

This document presents one of two companion greenhouse gas (GHG) emissions inventories for King County, Washington. The inventory described in this report estimates the release of GHG emissions from cars and trucks, buildings, waste, agriculture, and other sources of emissions within King County in 2008. Because this inventory also includes some emissions that occurred outside King County's borders (notably emissions associated with electricity produced outside the County but used within it), it is called a "geographic plus" inventory.

This inventory is accompanied by the 2008 King County Community Greenhouse Gas Emissions Inventory – Consumption Methodology. That inventory estimates all emissions associated with

consumption of goods and services in King County (including all citizen and government spending), no matter where the emissions occur.

King County and its partners are using the results of these inventories in identifying significant sources of GHG emissions, developing emissions reduction programs and policies, and to assess progress towards community emissions reduction goals. For more information on what the results of the inventories mean and how they fit together, see *Greenhouse Gas Emissions in King County: An Updated Geographic Inventory, a Consumption-based Inventory, and an Ongoing Tracking Framework*, , to which this report is considered an appendix.

To enable comparisons over time, the geographic plus inventory estimates greenhouse gas emissions for both 2003 and 2008 using the same methodology.[1] Results are first presented overall, for all sectors studied, followed by sector-by-sector discussions of results and methodology. Appendices document the sources cited throughout this report and additional data used.[2] For more information about the methodology and data, contact climatechange@kingcounty.gov.

The Seattle office of Stockholm Environment Institute–U.S. compiled this GHG inventory in autumn, 2010 (with minor revisions in 2011) under contract to King County.

Overview of King County Emissions

Total Emissions

Transportation, buildings, industrial, and other activities together released approximately 23.4 million metric tons of greenhouse gases (in terms of carbon dioxide equivalent) in 2008.[3] This represents an increase of 1.0 million metric tons, or 5%, since 2003. As indicated in Figure 1 and Table 1, below, transportation is responsible for half these emissions.

[1] King County's prior community GHG inventory, conducted in 2004 for the year 2003, was based largely on the Puget Sound Clean Air Agency's regional GHG inventory and used a different method. In this inventory, we estimate 2003 emissions using the same methodology as for 2008 to enable comparisons over time. While the 2003 inventory was instrumental in initial stages of King County climate action planning and implementation of climate solutions, emissions methodologies have evolved and the previous inventory is out of date.

[2] Note that this report and inventory follows many (but not all) of the conventions used in the City of Seattle's 2008 Greenhouse Gas Inventory report, available at http://www.seattle.gov/archive/climate/, including data and some of the descriptive text. We thank the City of Seattle Office of Sustainability and Environment, especially Jill Simmons and Hillary Papendick, for making their files and documents available to us and for conducting those Seattle-specific calculations that we reuse here.

[3] In this report, greenhouse gases are reported in metric tons of carbon dioxide equivalent, or $MgCO_2e$. Gases other than carbon dioxide (CO_2), such as methane (CH_4) and nitrous oxide (N_2O), are converted to their CO_2-equivalent global warming potentials using standard factors from the Intergovernmental Panel on Climate Change.

Figure 1. King County Community Greenhouse Gas Emissions by Sector ("Geographic plus" methodology)

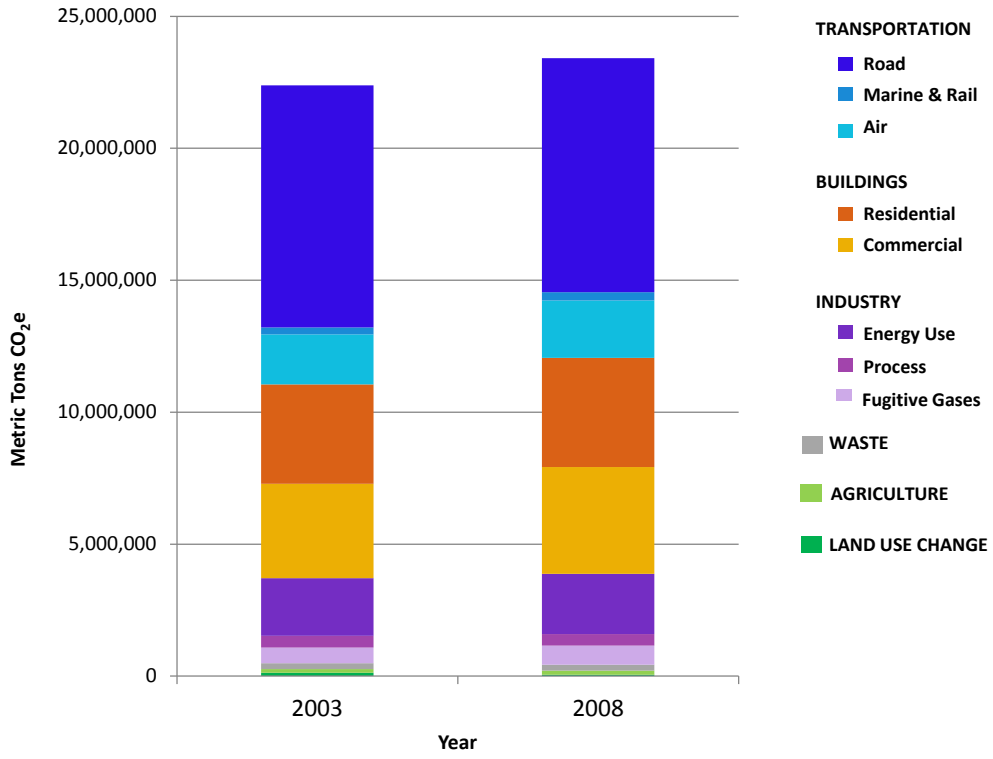


Table 1. King County Greenhouse Gas Emissions by Sector (Metric Tons CO_2e)

GHG Emissions by Sector	2003	2008
TRANSPORTATION	**11,330,000**	**11,354,000**
Road	**9,169,000**	**8,868,000**
Cars & Light Duty Trucks	*5,964,000*	*5,633,000*
Trucks	*3,077,000*	*3,115,000*
Buses & Vanpool	*128,000*	*119,000*
Marine & Rail	**266,000**	**309,000**
Ship & Boat Traffic	*167,000*	*200,000*
WA State Ferries	*51,000*	*39,000*
Rail	*49,000*	*70,000*
Air	**1,895,000**	**2,177,000**
Sea-Tac Airport	*1,757,000*	*2,043,000*
King County Airport	*138,000*	*134,000*
BUILDINGS	**7,342,000**	**8,180,000**
Residential	**3,763,000**	**4,136,000**
Electricity	*1,867,000*	*2,057,000*
Natural Gas	*1,565,000*	*1,815,000*
Petroleum (Heating)	*284,000*	*215,000*
Petroleum (Yard Equipment)	*46,000*	*49,000*
Commercial	**3,580,000**	**4,044,000**
Electricity	*2,001,000*	*2,278,000*
Natural Gas (Commercial Equipment)	*36,000*	*39,000*
Natural Gas (Heat and Other)	*832,000*	*952,000*
Petroleum (Commercial Equipment)	*341,000*	*370,000*
Petroleum (Heat and Other)	*209,000*	*227,000*
Steam	*160,000*	*177,000*
INDUSTRY	**3,225,000**	**3,451,000**
Energy Use	**2,181,000**	**2,284,000**
Electricity	*535,000*	*504,000*
Natural Gas (Industrial Equipment)	*49,000*	*52,000*
Natural Gas (Heat and Other)	*523,000*	*511,000*
Petroleum (Industrial Equipment)	*686,000*	*729,000*
Petroleum (Heat and Other)	*85,000*	*134,000*
Coal	*286,000*	*338,000*
Tire	*17,000*	*17,000*
Process	**451,000**	**435,000**
Cement (Calcination)	*411,000*	*395,000*
Steel	*3,000*	*3,000*
Glass	*37,000*	*37,000*
Fugitive Gases	**593,000**	**732,000**
ODS Substitutes	*542,000*	*676,000*
Switchgear Insulation	*51,000*	*56,000*
WASTE	**218,000**	**217,000**
Landfills	*214,000*	*213,000*
Wastewater Treatment	*4,000*	*4,000*
AGRICULTURE	**145,000**	**158,000**
Enteric Emissions from Livestock	*52,000*	*57,000*
Manure Management	*85,000*	*94,000*
Soil Management	*7,000*	*6,000*
LAND USE CHANGE	**123,000**	**53,000**
Residential Development	*123,000*	*53,000*
TOTAL EMISSIONS	**22,382,000**	**23,412,000**

Per Capita Emissions

King County's emissions increased an estimated 5% between 2003 and 2008, during a time when population increased 6%. On a per-capita basis, therefore, King County's emissions are remaining relatively constant.[4] As indicated in Table 2, increases in per-capita emissions from buildings and industry were offset by decreases in per-capita transportation emissions.

Table 2. Per Capita King County Greenhouse Gas Emissions by Sector (Metric Tons CO_2e)

Per Capita GHG Emissions by Sector	2003	2008
TRANSPORTATION	**6.4**	**6.0**
Road	5.2	4.7
Marine & Rail	0.2	0.2
Air	1.1	1.2
BUILDINGS	**4.1**	**4.3**
Residential	2.1	2.2
Commercial	2.0	2.1
INDUSTRY	**1.8**	**1.8**
Energy Use	1.2	1.2
Process	0.3	0.2
Fugitive Gases	0.3	0.4
WASTE	**0.1**	**0.1**
AGRICULTURE	**0.1**	**0.1**
LAND USE CHANGE	**0.1**	**<0.1**
TOTAL EMISSIONS	**12.6**	**12.4**

Readers should take care in making comparisons to GHG inventories in other communities. Since there is no widely accepted standard method for conducting GHG inventories of community emissions, methods can vary across communities, making direct comparisons difficult.

[4] In subsequent sections of this report, readers may notice that some sources of emissions are estimated from one year to another by scaling results from one year to another based on population or employment trends. The total share of this emissions inventory estimated by using such scaling factors is about 10% in both years. For these emissions sources (e.g., pleasure-craft emissions, which are part of *marine* emissions), per-capita emissions are held constant *by definition* and would not warrant a conclusion such as that made in the text here. But because these sources represent such a small share of overall emissions, the conclusion that King County's per-capita emissions are holding relatively constant is not likely to be affected.

Despite these challenges, it is clear that at an estimated 12.4 metric tons CO_2e, King County's per capita emissions in this inventory are lower than the national average of 23.3 metric tons CO_2e per person.[5] Two primary factors help explain this departure. One is that major sources of production (e.g., factories, particularly for emissions-intensive sectors such as petroleum refining or chemical manufacturing, as well farms) are less prevalent in King County (relative to population) than in the nation as a whole. The other is that low-carbon electricity (e.g., hydroelectricity) is a higher fraction of the electricity provided by utilities operating in King County, especially Seattle City Light.

For additional discussion of comparison of both King County's "geographic plus" and consumption-based emissions to national or global totals, please see the *Greenhouse Gas Emissions in King County* document, to which this report is an appendix.

[5] Source: U.S. EPA. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008, http://www.epa.gov/climatechange/emissions/usinventoryreport.html, after making some minor adjustments to facilitate comparisons. For example, the official national inventory does not include international air travel, but these emissions were added back in for the purpose of this comparison since the King County inventory includes fuel loaded at Sea-tac airport for international flights.

Transportation Sector

The transportation sector includes road, marine, rail, and air travel. This sector is the largest source of greenhouse gas emissions within King County, comprising approximately half of the county's total emissions. While total transportation emissions increased slightly from 2003 to 2008, per-capita transportation emissions decreased slightly.

Road Transportation

Road transportation includes the emissions from passenger, commercial, and transit vehicles. Emissions from road transportation dominate King County's transportation-sector emissions, accounting for 7% of the sector's emissions, and 38% of all emissions in King County. The Puget Sound Regional Council (PSRC) modeled and provided an estimate of vehicle miles traveled (VMT) on streets and highways, on which emissions from commercial trucks, cars and light trucks, and van pools were based. Emissions from buses were calculated based on fuel use data provided by King County Metro.

The attribution of emissions from road transport to King County is not straightforward, as many vehicle trips by King County residents and employees are not completely contained within the county, and other vehicles pass through the county without stopping within its borders. This inventory employs a method that counts emissions from all trips that occur entirely within King County, half of trips that either begin or end in the county, and no trips that both begin and end outside the county (even if they pass through the county).[6] For example, this "origin-destination pair" method counts half of commuting trips by residents who live in King County and commute out-of-county, but excludes truck or personal trips traveling through the county on I-5. The rationale for this method is that it attempts to count the trips that local policy-makers can best influence through transportation planning and incentives, such as commuting trips, while excluding trips over which the county and its partners have little influence.[7]

[6] A number of jurisdictions throughout the country use this methodology. For further discussion of this method, see: Ramaswami, Anu, Tim Hillman, Bruce Janson, Mark Reiner, and Gregg Thomas. 2008. A Demand-Centered, Hybrid Life-Cycle Methodology for City-Scale Greenhouse Gas Inventories. *Environmental Science & Technology* 42, no. 17: 6455-6461. doi:10.1021/es702992q.

[7] The method counts half of the emissions associated with trips that either begin or end in the county in order to recognize the shared responsibility with the other half of the originating or destination pair, as well as to avoid double counting of trips if other, neighboring jurisdictions were to use the same method. This method of counting VMT (and, in turn, emissions) yields a result that is largely similar (~1 % different) to the VMT occurring within the geographic bounds of King County. While this small difference might suggest that the difference between the two methods is trivial, King County should, in theory, have a greater chance of supporting community reduction in the VMT measured in this origin-destination pair method than in a strict geographic method. Also, significant differences exist for certain vehicle types. For example, the VMT for medium and heavy trucks attributed to King County in this method versus a strictly geographic approach are 26% and 50% higher, respectively, suggesting that

Table 3 presents emissions from road transportation. Road emissions decreased slightly between 2003 and 2008, driven largely by improvements in fuel economy in cars and light trucks that outpaced a slight decline in efficiency of trucks.[8]

Table 3. Road Transportation Emissions (Metric Tons CO_2e)

	2003	2008
Cars & Light Duty Trucks	5,964,000	5,633,000
Trucks	3,077,000	3,115,000
Buses & Vanpool	128,000	119,000
Totals	**9,169,000**	**8,868,000**

the method may do a better job of capturing the emissions associated with transporting goods consumed in King County.

[8]This inventory uses national average fuel economy figures. Some jurisdictions (e.g., New York City) use local vehicle registration data to estimate a local fuel economy, but defining a local coefficient was beyond the scope of this project. An average rate for King County could be calculated by matching EPA combined fuel economy values by vehicle type with Department of Licensing registration data. Though time-consuming to develop, this value would be useful in tracking improvements in vehicle efficiencies in King County over time. Total vehicle miles travelled (VMT) declined slightly (1%) between 2003 and 2008, per the Highway Performance Monitoring System (see *Source Notes* box). Lower VMT in 2008 may partly be explained by high gas prices, as the summer of 2008 saw the highest gas prices of the decade.

Source Notes

Road transportation emissions were predominately calculated from daily average vehicle miles traveled (VMT) modeling results for calendar year 2006, provided by PSRC **(KC08-11-2_TripsVMT-KC)**, for cars and light trucks, Metro VanPool, and trucks (medium and heavy duty). To estimate VMT for years 2003 and 2008, PSRC's modeled VMT results were scaled by a ratio of 2008 and 2003 (to 2006) VMT from the Highway Performance Monitoring System (HPMS), which records yearly data on average daily VMT by county. VMT results were also scaled by 95% to correct for the fact that the PSRC-provided figures were based on weekday-only traffic, which is higher than average traffic, including weekends **(KC08-11-9_VMTcorr)**.

The table below categorizes total average weekday VMT from all vehicles traveling entirely in, starting in, or ending in King County in 2006. The shaded area depicts the VMT that are counted according to the origin-destination pair method (and totaling 44,330,479 miles): 100% of trips contained within King County, 50% of trips with an origin or destination in King County, and 0% of trips that both start and end outside King County.

Destination / *Origin*	King County	Outside King County
King County	32,298,529	11,726,485
Outside King County	12,337,415	

Finally, in order to calculate emissions, annual VMT were multiplied by emissions factors derived from national average fuel efficiencies (miles per gallon) and fuel-specific (gasoline or diesel) carbon contents.

Emissions from bus travel were calculated through fuel use data provided by King County Metro and the National Transit Database (NTD). King County Metro bus fuel use was provided by King County Metro **(KC08-11-3_KCM-Motorbus)**, and annual revenue miles were collected from the NTD **(KC08-11-5_NTD-KCMetro08** and **KC08-11-6_NTD-KCMetro03)**. Sound Transit fuel use for 2008 was also downloaded from NTD **(KC08-11-4_NTD-T17EnergyCons)**. Calculation steps and data sources are listed in **KC08-00-1_MasterSpreadsheet_053111 'Trans- Road'.**

Key Drivers and Uncertainties

The principal drivers of road transport emissions are how much people drive (vehicle miles travelled, or VMT) and how efficiently their vehicles consume fuel (miles per gallon, or mpg). Uncertainty exists in each of these factors. VMT is modeled, not measured, and each model has its strengths and weaknesses. For example, the Puget Sound Regional Council's current trip-based model allows for sophisticated calculations of trips according to origins and destinations, but a "trip" in their model ends with each stop, limiting the ability to track travel activity with multiple stops, e.g., a commuting trip that starts in the City of Snohomish and stops in Everett for gas before continuing to Seattle would be considered two separate trips in

PSRC's model, one before the gas-station stop and one after[9]. Furthermore, emission rates from fuel consumption are based on national averages, rather than King County-specific rates.

Marine & Rail Transportation

Marine and rail transportation comprise a small share (1%) of total emissions in King County. Emissions from marine transportation were calculated based on estimates of fuel used by boat traffic in the waters in and around King County. Specifically, boat traffic includes pleasure craft, Washington State Ferries, cruise ships, cargo vessels, and other commercial boat traffic, such as tug boats. Emissions that occur near shore (maneuvering) and on-shore (hoteling) are included as well, based on estimates conducted by the Port of Seattle. Freight rail transportation includes emissions from locomotive use at the Port of Seattle, as well as the movement of Port of Seattle-related cargo in the county. Through rail (e.g., a train from Portland to British Columbia that passes through but does not originate or end in King County) is therefore not included in this inventory. Furthermore, passenger rail (i.e., Amtrak and Sounder commuter trains) is not considered due to lack of available data and the minor contribution to overall emissions in the county. Emissions from marine and rail transportation are presented in Table 4.

Table 4. Marine & Rail Transportation Emissions (Metric Tons CO_2e)

	2003	2008
Ship & Boat Traffic	167,000	200,000
WA State Ferries	51,000	39,000
Freight Rail	49,000	70,000
Totals	**266,000**	**309,000**

[9] This limits the ability of the VMT method employed here to fully capture the VMT associated with commuting trips. Transportation models continue to evolve and improve over time, and the models available to PSRC a few years from now will likely be better able to assess the origins and destinations of travel trips.

Source Notes

Ship & Boat Traffic (Cruise and other): 2008 and 2003 emissions were calculated from 2005 ship and boat emissions reported in the *Puget Sound Maritime Air Emissions Inventory* **(KC08-12-1_PS05MaritimeInv)**. Maneuvering emissions were scaled by tonnage for freight and by number of calls for cruise ships. Hoteling emissions were scaled by number of calls for freight and by number of calls (minus calls where the ship was connected to electrified shore power) for cruise ships **(C08-12-2_POS-Tonnage)**. King County pleasure craft fuel use was estimated by the Puget Sound Clean Air Agency using EPA's NONROAD2008 model. PSCAA provided these estimates (reformatted and summarized in **KC08-41-1_NONROAD-EquipCalcs**). 2003 emissions were estimated by scaling 2008 emissions by King County population.

WA State Ferries: Emissions from Washington State Ferries were calculated from fuel consumed by ferries on routes servicing King County. Seattle route data, previously used in the 2008 Seattle inventory and provided by WSDOT **(08-12-0)**, was updated in 2010 by WSDOT to include an additional route outside of Seattle but within King County **(KC08-12-3_FerryRoutes)**. Routes were then matched with fuel usage data **(08-12-1 CY2008 fuel)**. The Fauntleroy-Vashon-Southworth route was weighted by a fraction reflecting distance of each leg and county limits **(KC08-12-4_FVS-weight)**. 2003 emissions were approximated by multiplying 2005 Seattle emissions by the ratio of King County to Seattle ferry emissions from 2008.

Rail: Freight rail emissions were calculated based on the 2005 emissions presented in the Puget SoundMaritime Air Emissions Inventory **(KC08-12-1_PS05MaritimeInv)**. Emissions for other years of interest were scaled by the change in cargo throughput, using annual container tonnage as a proxy **(KC08-12-2_POS-Tonnage)**.

Calculation steps and data sources for marine and rail transportation are listed in **KC08-00-1_MasterSpreadsheet_053111 'Trans- Marine Traffic'** and **'Trans-Rail'**, respectively.

Key Drivers and Uncertainties

A key driver of maritime and freight rail emissions is the level of trade activity at the Port. Greenhouse gas emissions associated with the Port of Seattle have fluctuated significantly in recent years, as a function of cargo tonnage.

Generally speaking, emissions from marine sources are highly uncertain, and as such, few greenhouse gas inventories consider them. While the marine and rail emissions are included in this inventory, it is important to note that this subsector is very small compared to other sources in the county. Pleasure craft emissions, in particular, are likely underestimated.

Pleasure craft emissions were estimated with the EPA's NONROAD2008 model for King County in calendar year 2008. To scale down from the state to the county level, NONROAD allocates recreational boat population and activity using county-level water surface data from the U.S. Census Bureau, adjusting for typical variation in boat type by distance from shore. However, this method does not reflect factors such as proximity of water to high population areas or recreational quality of the body of water **(KC08-12-5_GeogAllocNONROAD)**. Both of these

elements are pertinent to the King County area, and therefore it is likely that the NONROAD model underestimates emissions from this source.[10]

The rail calculation method assumes that freight emissions scale directly with freight throughput at the Port. Other factors could affect this relationship, such as alterations in operations (e.g., transporting varying loads), or equipment retrofits or rebuilds (e.g., introducing hybrid locomotives). These factors are accounted for, to some extent, in the Port inventory. However, as comprehensive port inventories are currently not calculated on an annual basis, using the most recent inventory figures available (2005) and scaling based on throughput at the Port of Seattle was the methodology used for this estimate, using tonnage data available for 2003 and 2008. Accordingly, this estimate assumes that freight rail emissions scale directly with tonnage entering the port.

Air Transportation

Emissions from air transportation include a share of emissions associated with passenger travel at Seattle-Tacoma International Airport, as well as take-off and landing emissions at King County Airport in Seattle. Together, these sources represent 9% of King County's total emissions. Emissions attributed to King County Airport are those associated with landing and take-offs at (not the full flights in and out of) the airport and are primarily associated with Boeing activities.[11] By contrast, emissions attributed to King County from Sea-Tac airport are the estimated share of all the emissions from trips in and out of Sea-Tac that are associated with residential and business activities in King County. King County's share of Sea-Tac traffic (47%) is determined by the relative share of King County's population (representing personal travel) and employment (representing business travel) in the region, based on Census Bureau and Washington Employment Security Department sources. Emissions from air transport are shown in Table 5.

Table 5. Air Transportation Emissions (Metric Tons CO_2e)

	2003	2008
Sea-Tac Airport	1,757,000	2,043,000
King County Airport	138,000	134,000
Totals	**1,895,000**	**2,177,000**

[10] In the future, another possible data source for estimating activity (and, by extension, emissions) from pleasure craft could be boat registration statistics.

[11] There is no commonly accepted method for attributing air travel emissions. Counting the landing and take-off emissions at King County airport is consistent with prior treatment in King County's 2003 inventory, Puget Sound Clean Air Agency's 2005 inventory, and the City of Seattle's 2008 inventory. Emissions from SeaTac, the region's major passenger airport, are counted differently to reflect King County's share of the emissions from the entire flight (not just the landing and take-off cycles).

Source Notes

Sea-Tac International Airport: The fraction of emissions attributable to King County was estimated with a composite of population and employment in the county, and origin within the region **(KC08-14-1_SeaTacRatio)**. Both domestic and international flights were included, though only passenger flights were considered in these calculations (i.e., no cargo-only flights were included). The Port of Seattle provided total jet fuel consumed at Sea-Tac Airport **(08-14-13)**.

King County International Airport: 2008 emissions from King County International Airport were calculated from fuel used by jets during landing and take-off. KCIA provided fuel use data (**08-14-5)** and PSCAA provided the landing and take-off fraction (51%) of fuel burned **(05-047)**.

Calculation steps and data sources are listed in **KC08-00-1_MasterSpreadsheet_053111 'Trans- Air Traffic'.**

Key Drivers and Uncertainties

The main drivers of passenger air transport emissions are personal vacation preferences and business cycles. A choice to take a trip to a far-off destination or the decision to fly instead of taking an alternative mode of transportation (such as a train, bus, or car) impact the number of flights out of Sea-Tac. Similarly, a decision to take a work-related trip, as opposed to telecommuting or taking an alternative transportation mode, contributes to the number of flights. While planes solely transporting cargo were not considered in these calculations, it is worth noting that some cargo is loaded on most passenger flights. Therefore, one could argue that a portion of the fuel used in Sea-Tac flights could be ascribed to the consumption of goods. Emissions from King County International Airport are largely impacted by Boeing operations.

From the standpoint of policy relevance, emissions associated with air travel are somewhat difficult to influence. While the population and employment allocation method is implemented in this methodology, these factors are policy insensitive, and therefore future progress in air travel emissions could be measured through surveys tracking the impact of particular programs.

Buildings Sector

Building emissions account for 35% of greenhouse gas emissions in King County, and include the energy consumed by King County's residential and commercial buildings for lighting, appliances, heat, hot water, and building equipment. Emissions include those associated with electricity consumption (i.e., from generation of electricity by SCL and PSE). Residential and commercial buildings contribute approximately equally. Emissions in 2008 were higher than in 2003 in every category but petroleum for heating in homes, as residences switched residential heating fuels from oil to natural gas.

Residential Buildings

Residential building emissions are from single-family homes, apartment buildings, and other residential buildings in King County. The vast majority of building emissions are generated by the energy used for home heating, appliances, and hot water, though the emissions reported here also include fuel used for landscaping equipment like lawnmowers. Emissions from residential buildings are shown in Table 6.

Table 6. Residential Building Emissions (Metric Tons CO_2e)

	2003	2008
Electricity	1,867,000	2,057,000
Natural Gas	1,565,000	1,815,000
Petroleum (Heating)	284,000	215,000
Petroleum (Yard Equipment)	46,000	49,000
Totals	**3,763,000**	**4,136,000**

Emissions from electricity production are associated primarily with electricity sold by Puget Sound Energy, as the other electric utility operating in King County, Seattle City Light, relies almost exclusively on low-carbon hydroelectricity.[12]

[12] For discussion of Seattle's City Light's purchases of greenhouse gas offsets, see the *Supplemental Emissions Calculations* report.

Source Notes

Electricity: Seattle City Light provided SCL-serviced (Seattle and some King County) residential building electricity consumption using total kWh and a breakdown of residential and non-residential electricity usage **(KC08-60-1_SCLkWh95-08)**. PSE provided the remaining King County residential electricity consumption **(KC08-61-1_PSE08** and **KC08-61-2_PSE03)**. Utility emission rates for King County were calculated by multiplying fuel mix percentages by fuel-specific emissions factors **(KC08-63-1_FuelMixPSE-SCL)**. Utility emissions for Seattle City Light were as reported in their GHG inventory **(08-60-2).**

Natural Gas: PSE provided 2008 and 2003 natural gas use by King County residences **(KC08-61-1_PSE08** and **KC08-61-2_PSE03)**.

Petroleum (Heating): King County residential oil use was estimated from 2008 Washington State home oil use, which is reported by the U.S. Energy Information Administration **(KC08-21-0_EIA_DistFuel-WA)**, according to the ratio of King County homes with oil heat to Washington State homes with oil heat. The number of King County homes with oil heat was obtained from the 2008 American Community Survey (ACS) **(KC08-20-1_ACS08HeatFuel)**.

Petroleum (Yard Equipment): King County yard equipment fuel use was estimated by the Puget Sound Clean Air Agency using EPA's NONROAD2008 model. PSCAA provided these estimates (reformatted and summarized in **KC08-41-1_NONROAD-EquipCalcs**).

Calculation steps and data sources for electricity, natural gas and petroleum (heating) and petroleum (yard equipment) are listed in **KC08-00-1_MasterSpreadsheet_053111 'Electricity', 'Res- Heat & Hot Water',** and

Key Drivers and Uncertainties

The main cause of residential GHG emissions is personal energy use at home. Heat, hot water, lighting, and use of appliances drive emissions in this subsector.

While natural gas data was available for King County, heating oil, on the other hand, was not available at this scale. Heating oil was taken from Energy Information Administration (EIA) data on a state level, which was then scaled by the ratio of houses with oil heat in King County to those in Washington State. This approximation assumes that the amount of fuel used per Washington household is typical of King County. Uncertainties in the residential buildings sector are believed to be lower than for most other sectors, since data for the major sources of GHG emissions (natural gas and electricity) were provided by sales data from the utilities PSE and SCL.

Commercial Buildings

Commercial building emissions are from the energy consumed by businesses, office buildings, and institutional facilities (such as government buildings and schools). Like residential building emissions, the majority of these emissions are generated by lighting, space heating, and hot water. Many downtown Seattle buildings are heated by steam generated by Seattle Steam

Company, and the emissions associated with steam heat are reported on a separate line. Commercial buildings also include emissions from small equipment associated with commercial operations. Greenhouse gas emissions from commercial buildings are shown in Table 7.

Table 7. Commercial Building Emissions (Metric Tons CO_2e)

	2003	2008
Electricity	2,001,000	2,278,000
Natural Gas (Commercial Equipment)	36,000	39,000
Natural Gas (Heat and Other)	832,000	952,000
Petroleum (Commercial Equipment)	341,000	370,000
Petroleum (Heat and Other)	209,000	227,000
Steam	160,000	177,000
Totals	**3,580,000**	**4,044,000**

Source Notes

Electricity: Seattle City Light provided SCL-serviced (Seattle and some King County) building electricity consumption using total kWh and a breakdown of residential and non-residential electricity usage **(KC08-60-1_SCLkWh95-08)**. A further breakdown of non-residential kWh into commercial and industrial sectors was calculated from the Seattle City Light 2008 Annual Report **(08-60-4)**. PSE provided the remaining King County commercial electricity consumption **(KC08-61-1_PSE08** and **KC08-61-2_PSE03)**. Utility emission rates were calculated by multiplying fuel mix percentages by fuel-specific emissions factors **(KC08-63-1_FuelMixPSE-SCL)**.

Natural Gas (Commercial Equipment): Compressed natural gas (CNG) fuel use of commercial equipment in King County was estimated by PSCAA using EPA's NONROAD2008 model. PSCAA provided these estimates (reformatted and summarized in **KC08-41-1_NONROAD-EquipCalcs**).

Natural Gas (Heat and Other): PSE provided commercial building natural gas consumption for 2008 and 2003 **(KC08-61-1_PSE08** and **KC08-61-2_PSE03)**.

Petroleum (Commercial Equipment): Petroleum fuel use of commercial equipment in King County was estimated by PSCAA using EPA's NONROAD2008 model. PSCAA provided these estimates (reformatted and summarized in **KC08-41-1_NONROAD-EquipCalcs**).

Petroleum (Heat and Other): King County commercial oil use was estimated from 2008 Washington State home oil use, which is reported by the U.S. Energy Information Administration **(KC08-21-0_EIA_DistFuel-WA)**, scaled by the ratio of commercial employees in King County and Washington State.

Steam: PSCAA provided natural gas and back up oil use from the Seattle Steam and the University of Washington Steam Plant **(KC08-40-1_00-08ProcessData)**.

Calculation steps and data sources for electricity, natural gas (commercial equipment) and petroleum (commercial equipment), and natural gas (heat and other), petroleum (heat and other) and steam are listed in **KC08-00-1_MasterSpreadsheet_053111 'Electricity', 'Commercial- equip',** and **'Commercial- Heat & Hot Water'**, respectively.

Key Drivers and Uncertainties

The main driver of emissions from the commercial sector is energy use by businesses and public facilities. Specifically, demand for lighting, heat, and hot water drive these emissions.

Uncertainties in this sector are believed to be lower than for most other sectors, since data for the major sources of GHG emissions (natural gas and electricity) were provided by sales data from the utilities PSE and SCL.[13] Uncertainty in emissions from oil combustion are much higher, since these estimates rely largely on statewide data from the EIA scaled to King County by the relative number of commercial employees in the county to the state. This approximation assumes that the fuel used by commercial buildings is relatively constant across these scales, and would not necessarily account for benefits such as more efficient or larger buildings in the county. The alternative source of oil consumption data, PSCAA, is incomplete, as PSCAA only maintains data for facilities that are required to report emissions for years when reporting thresholds for other (non-GHG) pollutants are exceeded.

[13] However, note that some natural gas customers are known to purchase their natural gas directly from wholesalers, even though PSE delivers it. We assume that quantities purchased by these customers (which are sometimes referred to by PSE as "transport" customers since PSE only transports, but does not directly sell, the gas) are included in the natural gas consumption totals provided to us by PSE, but this could not be confirmed. Accordingly, it is possible that our estimates of emissions associated with natural gas are low throughout.

Industrial Sector

The industrial sector accounts for 15% of greenhouse gas emissions in King County. This sector includes emissions from industrial operations, the manufacturing of cement, steel, and glass, and fugitive gases associated with industrial equipment. Emissions include those associated with electricity consumption (i.e., from generation of the electricity by SCL and PSE), for which generation largely occurs outside King County.

Industrial Energy Use

Industrial operations include emissions from energy consumed by industrial facilities located in King County. Industrial operations are dominated by emissions from energy used to fuel manufacturing or other industrial equipment, rather than space heating and hot water as in the residential and commercial sectors. Industrial operations also include fuel use and greenhouse gas emissions from construction equipment, material handling, HVAC equipment, and other off-road machinery. Emissions from industrial operations are shown in Table 8.

Table 8. Industrial Energy Use Emissions (Metric Tons CO_2e)

	2003	2008
Electricity	535,000	504,000
Natural Gas (Industrial Equipment)	49,000	52,000
Natural Gas (Heat and Other)	523,000	511,000
Petroleum (Industrial Equipment)	686,000	729,000
Petroleum (Heat and Other)	85,000	134,000
Coal	286,000	338,000
Tire	17,000	17,000
Totals	**2,181,000**	**2,284,000**

Source Notes

Electricity: Seattle City Light provided SCL-serviced (Seattle and some King County) building electricity consumption using total kWh and a breakdown of residential and non-residential electricity usage **(KC08-60-1_SCLkWh95-08)**. A further breakdown of non-residential kWh into industrial and commercial sectors was calculated from the Seattle City Light 2008 Annual Report **(08-60-4)**. PSE provided the remaining King County industrial electricity consumption **(KC08-61-1_PSE08** and **KC08-61-2_PSE03)**. Utility emission rates were calculated by multiplying fuel mix percentages by fuel-specific emissions factors **(KC08-63-1_FuelMixPSE-SCL)**.

Natural Gas (Industrial Equipment): CNG fuel use of industrial equipment in King County was estimated by the Puget Sound Clean Air Agency using EPA's NONROAD2008 model. PSCAA provided these estimates (reformatted and summarized in **KC08-41-1_NONROAD-EquipCalcs**).

Natural Gas (Heat and Other): PSE provided industrial natural gas consumption for 2008 and 2003 **(KC08-61-1_PSE08** and **KC08-61-2_PSE03)**.

Petroleum (Industrial Equipment): Petroleum fuel use of industrial equipment in King County was estimated by PSCAA using EPA's NONROAD2008 model. Leslie Stanton at PSCAA provided these estimates (reformatted and summarized in **KC08-41-1_NONROAD-EquipCalcs**).

Petroleum (Heat and Other): King County industrial oil use was estimated from 2008 Washington State industrial oil use, which is reported by the U.S. Energy Information Administration **(KC08-21-0_EIA_DistFuel-WA)**, scaled by the ratio of industrial employees in King County and Washington State.

Coal: Coal-derived fuel is used in cement production. PSCAA provided point source data for Ash Grove **(KC08-40-1_00-08ProcessData)**. Lafarge cement provided self-reported data from their operations **(KC08-40-4_LafargeFuel03-09)**.

Tire: Tire-derived fuel is used in cement production. Ash Grove provided self-reported data from their operations **(08-41-0)**, as did Lafarge **(KC08-40-4_LafargeFuel03-09)**.

Calculation steps and data sources for electricity, natural gas (industrial equipment) and petroleum (industrial equipment), and natural gas (heat and other), petroleum (heat and other), coal, and tire are listed in **KC08-00-1_MasterSpreadsheet_053111 'Electricity', 'Ind- Small Equipment**, and **'Ind- Operations',** respectively.

Key Drivers and Uncertainties

Notable drivers of these emissions include demand for cement (which can vary substantially from year to year depending on construction activity) and other industrial products made in the region, including steel, glass, and aerospace equipment.

Industrial oil (petroleum) use is relatively uncertain, as estimates for oil use for heat and other applications was scaled from Washington State data from the EIA to King County by the relative number of industrial employees. This approximation assumes that the fuel used by industrial installations is relatively constant across these scales. Estimates of industrial fuel use for

equipment are based on the EPA's NONROAD 2008 model and are also uncertain.[14] As a result of these uncertainties, emissions from industrial energy consumption are less certain than some other sectors.

Industrial Processes & Fugitive Gases

Industrial process emissions include greenhouse gases that are emitted directly from production of cement, steel, and glass, as well as the emissions from fugitive gases from electric switchgear equipment. With two cement plants in the City of Seattle in 2008, cement production is a significant contributor to the county's greenhouse gas emissions.[15] Additional sources of emissions associated here with industry are ozone-depleting substance (ODS) substitutes (mainly hydrofluorocarbons) used largely in refrigeration and air-conditioning equipment and sulfur hexafluoride released from electric switchgear insulation.[16] Industrial process and fugitive gas emissions totals are presented in Table 9 and Table 10, respectively.

Table 9. Industrial Process Emissions (Metric Tons CO_2e)

	2003	2008
Cement (Calcination)	411,000	395,000
Steel	3,000	3,000
Glass	37,000	37,000
Totals	**451,000**	**435,000**

Table 10. Industrial Fugitive Gas Emissions (Metric Tons CO_2e)

	2003	2008
ODS Substitutes	542,000	676,000
Switchgear Insulation	51,000	56,000
Totals	**593,000**	**732,000**

[14] It is worth noting that industrial equipment considered here includes equipment that could be considered the responsibility of other sectors. For example, airport, rail, and agriculture equipment are all considered in this emission source.

[15] Cement production ceased at one of the plants, the Lafarge cement plant, at the end of 2010.

[16] Emissions from substitutes for ozone-depleting substances (ODS) are assigned here to industry but include emissions that could be considered the responsibility of other sectors, such as releases of hydrofluorocarbons found in commercial and residential air conditioning and refrigeration equipment.

Source Notes

Cement: Cement process emissions were calculated by multiplying tons of clinker produced by the calcination factors. PSCAA provided the tons of clinker **(KC08-40-1_00-08ProcessData)**. Lafarge and Ash Grove provided the calcinations factors **(08-41-0** and **05-134)**.

Steel: Steel emissions are from Seattle's two manufacturers, Jorgensen (a forge) and Nucor (an electric arc furnace that produces crude steel). PSCAA provided production data from these facilities **(KC08-40-1_00-08ProcessData)**. To calculate emissions, the production data was multiplied by the nominal IPCC emission factor associated with electric arc furnaces, 1.25 $kgCO_2$/Mg steel. Nucor uses entirely recycled stock and Jorgensen is a forge (which shapes, not produces, steel), so there are no emissions associated with carbon lost from pig iron as there would be in a basic oxygen furnace **(05-127).**

Glass: Glass operations are from Seattle's Saint-Gobain Containers. PSCAA provided production data from this facility **(KC08-40-1_00-08ProcessData)**. To calculate emissions, tons of glass pulled were multiplied by the default emission factor for glass manufacturing **(KC08-40-2_IPCCGuide-MinIndust)** and adjusted by the ratio of recycled cullet used by Saint-Gobain **(KC08-40-3_RecyMatKC).**

ODS Substitutes: Emissions associated with substitutes for ozone-depleting substances were estimated with the EPA's State Inventory and Projection Tool **(KC08-42-1_SIT-IP-WA-ODS)** and scaling by the relative populations in Washington state and King County.

Fugitive Gases: Seattle City Light (SCL) provided fugitive SF_6 emissions for 2008 (**08-60-1).** 2003 emissions were scaled by SCL electricity totals for each year. PSE SF_6 emissions were estimated by multiplying total King County fugitive emissions from the 2005 PSCAA inventory **(KC08-102-0_PSCAA05Inventory)** by the fraction of electricity provided by PSE in the county.

Calculation steps and data sources for cement, steel and glass, and ODS substitutes and fugitive gases are listed in **KC08-00-1_MasterSpreadsheet_053111 'Ind- Process'** and **'Ind- Fug. Gases'**, respectively.

Key Drivers and Uncertainties

Demand for cement, and to a lesser degree, demand for steel and glass, are the dominant drivers of emissions from this subsector.

The emission factors for glass and steel production are defaults from IPCC guidelines, though more specific factors could be calculated if more were known about practices at the glass container (St. Gobain Containers) and steel (Nucor Steel, Jorgenson Forge) facilities. Yet while these emission factors have some uncertainty, both sources of process emissions are relatively small. Uncertainty in process emissions from cement is relatively low, as the production of each ton of cement clinker (the key component of cement) involves a chemical reaction that releases a fixed quantity of CO_2. Lastly, uncertainty in estimates of ODS substitutes and switchgear insulation is relatively high in both cases. For example, it would be beneficial to have a local estimate of ODS, rather than scaling down from statewide emissions.

Waste Sector

The waste sector includes emissions associated with one active landfill, ten closed landfills, and two wastewater treatment facilities in King County. Waste sector emissions represent less than 1% of GHG emissions in this King County Geographic Plus inventory.

Two distinct methodologies can be used to estimate emissions associated with landfills and waste disposal. This "geographic plus" inventory estimates waste-related fugitive landfill emissions using a "waste in place" methodology. Fugitive landfill emissions result from the unintended release of landfill gas from the decomposition of organic materials at a landfill or combustion or treatment of landfill gas in flares. This approach estimates the fugitive landfill gas emitted in the year 2008 as a result of all materials currently in landfills (no matter the year they were disposed) that are located within King County's geographic border.

The other common method, called "waste commitment", estimates fugitive landfill gas emissions associated with all waste generated from within King County in 2008 (and only 2008), regardless of when or where those emissions occur. This "waste commitment" methodology includes emissions even if they occur outside the King County geography. For example, it includes emissions from waste, generated by Seattle residents, that is hauled by train to a landfill in Arlington, Oregon. Estimating future emissions associated with waste generated in the present may align better with the policy choices available today (e.g., waste and recycling programs and infrastructure) than would counting the actual current emissions of in-region landfills as this Geographic Plus inventory does. For estimates of waste-related emissions using the "waste commitment" methodology, please see the companion *Supplemental Emissions Calculations* document. The consumption-based inventory also uses a waste commitment approach.

For more information on recommendations related to interpreting and using these results, see the summary report, *Greenhouse Gas Emissions in King County: An Updated Geographic Inventory, a Consumption-based Inventory, and an Ongoing Tracking Framework*..

Landfills & Wastewater Treatment

In landfills, organic materials decompose and generate landfill gas, which includes a mixture of methane and carbon dioxide. Landfills continue to generate landfill gas long after closing, although the quantity generated drops significantly over time. This GHG inventory includes estimates of landfill gas emitted at a number of closed landfills within King County[17], as well as from the active Cedar Hills Landfill.

[17] We were not able to collect sufficient data to estimate landfill gas emissions from the following closed landfills in King County: Bow Lake, Corliss, Duvall, Houghton, Puyallup; nor from the following closed landfills under the

King County operates two large regional wastewater treatment plants, West Point, located adjacent to Discovery Park within the Seattle city limits, and South Plant, located in Renton. King County also operates two other very small local treatment plants in the City of Carnation and on Vashon Island. Wastewater treatment generates methane and nitrous oxide.

Most of the GHGs generated at landfills and wastewater facilities are captured and flared (creating carbon dioxide and water) or used as renewable energy. GHGs emitted from landfills and wastewater treatment are estimated in Table 11.

Table 11. Waste Sector Emissions (Metric Tons CO_2e)

	2003	2008
Cedar Hills Landfill	108,000	111,000
Closed Landfills	106,000	102,000
Wastewater Treatment	4,000	4,000
Totals	**218,000**	**217,000**

Source Notes

Landfills:

Fugitive landfill emissions from King County's Cedar Hills landfill, the only significant active landfill in King County, were calculated based on landfill gas collection data provided by King County Solid Waste Division **(KC08-50-9_Cedar_Hills_CH4)**. It was estimated that the flaring system at the landfill combusted 98% of the methane collected **(KC08-50-11),** that the collection system recovered at least 90% of the total landfill gas generated **(KC08-50-10_Collection_Efficiency)**, and that 10% of methane not captured was oxidized to CO_2 **(KC08-50-2_LGOP)**. According to "Landfill Gas Management Definitions & Collection Efficiency" provided by King County Solid Waste Division **(KC08-50-10_Collection_Efficiency)** the 90% collection efficiency is conservative, and so this inventory may overstate the landfill gas emissions from Cedar Hills landfill. See the *Key Drivers and Uncertainties* section that follows the source notes for details.

Fugitive landfill emissions from four closed landfills in King County outside Seattle were taken from a report by AMEC Geomatrix Inc. **(KC08-50-3_Closed_Landfills)**.

Fugitive landfill emissions from six closed landfills within the City of Seattle were taken directly from the City of Seattle's 2008 GHG Inventory **(08-09-00)**.

Wastewater Treatment: King County calculated wastewater treatment emissions according to the Local Government Operations Protocol methodology **(KC08-50-2_LGOP)**, and provided these 2008 emissions for West Point and South Plant facilities **(KC08-50-1_WWT)**. Note that Carnation and Vashon emissions estimates are included in the South Plant calculations, as solids from these treatment plants are processed at South Plant.

Calculation steps and data sources for landfills and wastewater treatment are listed in **KC08-00-1_MasterSpreadsheet_053111 'Waste- Landfills'** and **'Waste- Wastewater'**, respectively.

jurisdiction of Seattle: Midway, Kent-Highlands. However, these closed landfills are small and old enough that the landfill gas emissions are likely very small.

Key Drivers and Uncertainties

For older, closed landfills, data on actual measurement of landfill gas or the quantity and type of waste disposed was not always available, requiring other estimation methodologies (e.g., based on landfill area). Emissions from the closed landfills are therefore highly uncertain.[18]

A key driver of emissions from any landfill is the current landfill gas capture practices in place at each landfill, especially the Cedar Hills landfill, the only significant currently operating landfill in King County. According to King County Solid Waste Division analysis, at least 90% of the landfill gas generated at Cedar Hills is captured. This estimate is based on several considerations: (1) surface level concentrations of landfill gas are below the best available equipment detection limit of 100 ppm, (2) fugitive landfill gas emissions from the active cell are assumed to be minimal, since decomposition occurs mainly in semi-aerobic condition (since the active cell is not yet completely capped) and where King County uses a unique surface landfill gas horizontal collector system, minimizing any fugitive landfill gas, and (3) research by the Solid Waste Association of North America[19] indicates that for a landfill using comparable landfill gas collection technology, with landfill gas collection systems compliant to the standards the Cedar Hills system meets, landfill gas collection efficiency ranges between 84 percent to 98 percent with an average efficiency of 91.1%. Based on these points, King County Solid Waste Division estimates at least 90% collection efficiency; if actual collection efficiency was higher, then this inventory would overstate the amount of fugitive landfill emissions from the Cedar Hills landfill. The actual collection efficiency is a key uncertainty in estimating landfill emissions at the Cedar Hills landfill. An additional uncertainty is the rate at which methane that is not captured is oxidized to CO_2: we assumed 10% based on the *Local Government Operations Protocol* **(KC-08-50-2_LGOP**).

Key drivers of wastewater treatment emissions are King County population and the effectiveness of the methane capture and destruction systems at each treatment plant. The rate of methane capture, which is assumed to be 99% in calculations provided by King County **(KC-08-50-1)**, is likely uncertain, as is to what extent methane may escape through other means (e.g., in other parts of the wastewater treatment infrastructure before the digester).

Emissions from on-site combustion of wastes (e.g., burning of wastes in fireplaces or in backyards in rural areas) are not estimated.

Altogether, uncertainty in waste sector emissions is likely higher than for most other sectors. However, waste emissions represent less than 1% of King County's inventory, a conclusion that would not likely change significantly with further analysis of uncertainties or methods.

[18] For an estimate of the future GHG emissions associated with waste generated in years 2003 and 2008 in King County, see the companion *Supplemental Emissions Calculations* report.

[19] Landfill Gas Collection System Efficiencies. 2007. SWANA Applied Research Foundation- Landfill Gas Project Group. Available: http://www.mswmanagement.com/web-articles/landfill-gas-collection.aspx

Agriculture Sector

The agriculture sector accounts for 1% of total King County greenhouse gas emissions, and the majority of these emissions can be attributed to dairy cows and beef cattle. This sector includes emissions from enteric fermentation, manure management, and soil management. Emissions in King County have grown slightly in this category since 2003, a trend that is largely attributable to an increase in animal population. Within the agriculture sector, manure management is the largest source of greenhouse gases, accounting for over half of emissions from this sector.

Enteric fermentation refers to the production of methane (CH_4) as part of normal digestive process in livestock, especially cows and other ruminants, and varies by type of animal and amount and type of feed consumed (**KC08-103-4_US-GHG-1990to2007**).

Both CH_4 and nitrous oxide (N_2O) are released in the process of managing animal manures. Methane is released when manure decomposes anaerobically (as in lagoons), and much less so when it decomposes aerobically (as in drylots or on pasture). N_2O is released directly as part of the natural nitrification and denitrification of the organic nitrogen in livestock manure and urine. N_2O is also produced as a result of the volatilization of nitrogen as ammonia (NH_3) and oxides of nitrogen (NO_X) and runoff and leaching of nitrogen during treatment, storage, and transportation (**KC08-103-4_US-GHG-1990to2007**).

In the Puget Sound area, typically, manure is initially stored in lagoons and later sprayed onto fields in the spring and summer (**KC08-102-0_PSCAA05Inventory**), though some efforts have been underway to promote and install manure digesters to capture the methane.

Nitrous oxide is also released from soils, depending on agricultural soil management practices. Nitrous oxide is produced naturally in soils through the microbial processes of nitrification and denitrification. When nitrogen availability in soils is increased (through application of fertilizer, for example), N_2O emissions can also increase. (**KC08-103-4_US-GHG-1990to2007**).

Agriculture emissions from these categories are presented in Table 12, below.

Table 12. Agriculture Emissions (Metric Tons CO_2e)

	2003	2008
Enteric Emissions from Livestock	52,000	57,000
Manure Management	85,000	94,000
Soil Management	7,000	6,000
Total	**145,000**	**158,000**

Source Notes

Agriculture emissions were calculated using data from USDA National Agricultural Statistics Service (NASS) census data **(KC08-101-1_07CensusAg-WAStateCounty** and **KC08-101-0_02CensusAg)** and the EPA's inventory of U.S. greenhouse emissions. The estimation methodology draws upon previous PSCAA inventory work, as well as EPA's Climate Leaders **(KC08-105-1_ClimateLeadersGHGProtocol)** and IPCC guidelines **(KC08-105-2_IPCCGuide-LivestockManure)**. Enteric fermentation emissions were calculated by multiplying King County livestock populations by animal-specific emission factors **(KC08-103-1_US-GHG-1990to2000** and **KC08-103-3_US-GHG-1990to2004Annex)**. Manure management emissions were derived from data on animal population, typical animal mass, volatile solid emissions factors, maximum methane generation potential, a composite methane conversion factor, excreted nitrogen, and nitrous oxide emissions factors **(KC08-103-3_US-GHG-1990to2004Annex** and **KC08-102-0_PSCAA05Inventory)**. Soil management emissions were calculated by scaling direct and indirect emissions from national totals based on relative cropland area **(KC08-103-4_US-GHG-1990to2007)**.

Calculation steps and data sources are listed in **KC08-00-1_MasterSpreadsheet_053111 'Agr'**.

For reference, livestock populations from the USDA's 2002 and 2007 censuses (used here to approximate populations in 2003 and 2008, respectively) are documented below.

Count of animals		2002	2007
	Beef Cattle	8,730	11,490
	Beef Cow	2,376	3,009
	Milk Cow	11,423	10,025
	Horse	5,227	6,941
	Sheep	1,780	1,751
	Swine	559	798
	Goat	165	289
	Mink	2,972	3,899
	Poultry	8,983	12,849

Key Drivers and Uncertainties

The parameters which have the largest impact on emissions in this sector are the number and type of farm animals (manure management and enteric fermentation), farm area (soil management), and manure treatment methods (manure management).

Under this inventory methodology, which relies strongly on national averages, local policies and measures that affect agricultural emissions – such as those that influence feed or fertilizer practices – would not necessarily be reflected in a regular GHG inventory. Other efforts that reduce the greenhouse gas emissions impact of manure treatment, such as through use of anaerobic digesters or field spreading, could also be estimated, although tracking changes in such practices over time could be challenging.

A key assumption in making calculations based on animal populations is that the available, bi-decadal census data is representative of the years of interest. In this inventory, it is assumed that 2007 and 2002 census data is representative of 2008 and 2003 populations, respectively.

The calculations for manure management are subject to uncertainty due to coarse estimates of manure treatment systems and associated conversion and emissions factors. For example, the methane conversion factor (MCF, which represents the potential for methane production for a type of manure management system) in this inventory is assumed to be the average of a factor for liquid/slurry and uncovered anaerobic lagoon, for the average annual temperature in the region. This assumption is made to accommodate the dominant practices in King County, but is therefore not sensitive to other practices (including use of digesters or dry spreading) used in the county. These assumptions are consistent with those in the PSCAA inventory report (**KC08-102-0_PSCAA05Inventory**), though future inventories could refine this method.

Agricultural soil emissions are calculated through a top-down method, scaling down from total land area and farm acreage in the United States to King County. This approach does not consider differing crop types and farm practices, such as fertilizer application rates, in King County.

Overall, uncertainty in agricultural GHG emissions is higher than for most other sectors. However, due to the small emissions in this sector relative to other sectors, further effort to reduce this uncertainty may not be warranted at this time.

Land Use Change Sector

King County contains significant stocks of carbon in forests. When trees and other biomass are removed from a site to prepare for development or other uses, these carbon stocks are lost and CO_2 emissions result when, for example, the land-clearing debris is burned or left to decay.[20]

Residential development is a significant driver for land-clearing in King County. This inventory includes an estimate of the land-clearing emissions due to residential development in both 2003 and 2008. Estimates are based on records of residential building permits issued by King County and an assessment of the average carbon lost per acre due to land-clearing.

Table 13 presents estimates of CO_2 released as a result of land-clearing for residential development.

Table 13. Land Use Change Emissions (Metric Tons CO_2e)

	2003	2008
Residential Development	123,000	53,000
Totals	**123,000**	**53,000**

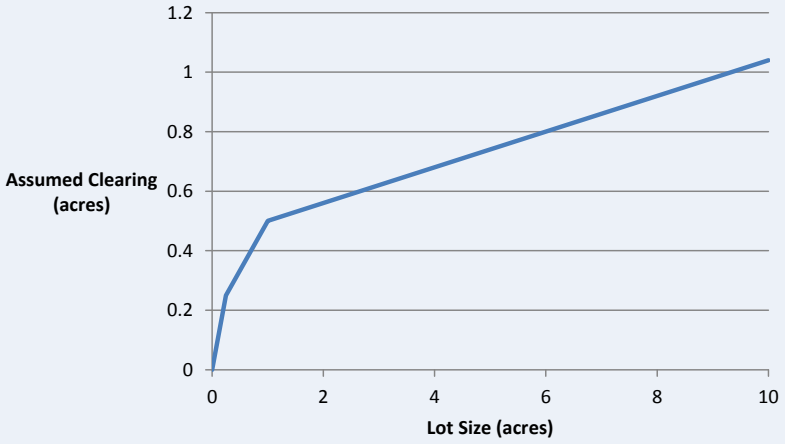
Forest land (including urban forests) can also remove, or sequester, CO_2 from the atmosphere. Estimates of carbon sequestration on forest land in King County are included in the companion *Supplemental Emissions Calculations* document, which also addresses other sources of emissions avoided, sequestered, or stored (e.g., storage in landfills or emissions avoided due to recycling programs).

[20] For an assessment of the relative GHG emissions from other possible end-uses of woody biomass other than combustion or on-site decomposition, see Lee, Carrie, Peter Erickson, Michael Lazarus, and Gordon Smith. 2010. *Greenhouse gas and air pollutant emissions of alternatives for woody biomass residues: Final Draft Version 2.0*. Stockholm Environment Institute - U.S. Center for the Olympic Region Clean Air Agency, November.

Source Notes

The area of parcels issued building permits in 2003 and 2008 were obtained from the King County Department of Assessments database (**KC08-80-1_Assessor_Database**). We queried the database for the first issuance of permits of type "building, new" for each residential parcel in years 2003 through 2008. Calculations are documented in **KC08-80-5_Assessor_Data_Analysis.**

Parcels were assumed to start at 41% canopy cover **(KC-08-80-2_Carbon Stocks)**. Parcels up to 0.25 acres were assumed to be 100% cleared. Parcels between 0.25 and 1 acres were assumed to be 50% cleared (at 41% canopy cover). Parcels over 1 acre were assumed to have 0.5 acres plus 0.06 acres cleared of forest for each additional acre of parcel size. The following chart describes this assumed relationship graphically. The clearing rate equation for parcels above 1 acre was based on a regression analysis of prior data collected by Gordon Smith based on aerial photos of development parcels in King County **(KC08-80-3_GHG_Snoqualmie)**. The clearing rates for parcels less than one acre were based on judgment of Gordon Smith as to a development threshold (0.25 acres) below which all of the lot would likely be cleared.



The above-ground carbon content of trees on land cleared was assumed to be 56 tons of carbon per hectare, or 83 tons CO_2e per acre, per research by the University of Washington researchers **(KC-08-80-2_Carbon Stocks)** and assumes that any land cleared started at a 41% canopy cover, the average canopy coverage of three transects extending across King County in that study. We increase this figure by 21% to include the below-ground carbon content of trees (e.g., coarse roots) per information provided by the U.S. Forest Service **(KC08-80-4_USFS_CCT)** and to be consistent with the assessments of forest carbon presented in the companion *Supplementary Emissions*

Key Drivers and Uncertainties

The key driver for emissions from land clearing is assumed here to be residential development. Land clearing for other types of uses (e.g., commercial development, agriculture) is assumed to be small relative to residential development and is not quantified here.

Uncertainty exists in each of the key variables, including the actual year that clearing was conducted (we assign it here to the year in which the first building permit was issued), the number of acres of forest cover actually cleared in each parcel, and the starting carbon stocks

of the forest cleared. Further work to analyze aerial photos of the particular parcels permitted in each year, though time-consuming, could help refine these estimates.

Attachments

Attachment A: Source documentation

The formal inventory is a dataset consisting of electronic files. These data files are divided into the following categories:

Index file – A single index file, <KingCounty2008GHGInventory-DatasetIndex.xlsx>, lists names, descriptions, and sources of all other files in the inventory.

Source files – These files are numbered KC08-00-00 to KC08-100-00. The files are organized by category in the following format:

KC08-00 Inventory
KC08-10 Transportation
KC08-20 Buildings
KC08-40 Industry
KC08-50 Waste
KC08-70 Population and Employment
KC08-80 Land Use
KC08-60 Electricity
KC08-100 Agriculture

Calculation files – File KC08-00-1 is the master calculation file for the inventory, and includes at least the highest-level calculations for every datum reported in this document. Every table describing the inventory in this document is duplicated from <KC08-00-1.xlsx>.

Every datum in the calculation files is traceable to one of the source files through the KC08-XX-XX number provided in the "call no." column of most of the calculation files. These sources files are listed below in Table 15. In addition, some source files from prior inventory work in Seattle are referenced. These source files are in the format 08-XX-XX (*2008 Seattle Community Greenhouse Gas Inventory*) or 05-XX-XX (*2005 Inventory of Seattle Greenhouse Gas Emissions: Community & Corporate*), and are maintained by the City of Seattle Office of Sustainability & Environment (OSE).

Table 14. Catalog of Source Documents

KC08-00-0	**Inventory**		
KC08-00-1	Master Spreadsheet	.xlsx	MasterSpreadsheet_MMDDYY
KC08-10-0	**Transportation**		
KC08-11-0	**Road**	folder	
KC08-11-2	Trips and VMT for King County, by vehicle type	.xls	TripsVMT-KC
KC08-11-3	2009 Transit GHG Emissions Reporting for CCX	.xls	KCM-Motorbus
KC08-11-4	National Transit Database (NTD) 2008 files - Data Tables: T17 Energy Consumption	.xls	T17EnergyCons
KC08-11-5	King County Department of Transportation - Metro Transit Division (King County Metro) - 2008 Agency Profile	.pdf	NTD-KCMetro08
KC08-11-6	King County Department of Transportation - Metro Transit Division (King County Metro) - 2003 Agency Profile	.pdf	NTD-KCMetro03
KC08-11-7	Central Puget Sound Regional Transit Authority (ST) - 2008 Agency Profile	.pdf	NTD-ST08
KC08-11-8	Central Puget Sound Regional Transit Authority (ST) - 2003 Agency Profile	.pdf	NTD-ST03
KC08-11-9	Correction factor for average daily (from weekday) VMT	.docx	VMTcorr
KC08-11-10	Table 5.1: Summary Statistics for Heavy Single-Unit Trucks, 1970–2009	.xls	SingUnitTruck
KC08-11-11	Table 5.2: Summary Statistics for Combination Trucks, 1970–2009	.xls	CombTruck
KC08-11-12	Table 4-11: Passenger Car and Motorcycle Fuel Consumption and Travel	.xls	Passenger_Motorcycle
KC08-11-13	Table 4-12: Other 2-Axle 4-Tire Vehicle Fuel Consumption and Travel	.xls	Light_truck
KC08-11-14	2009 and 2010 Energy Consumption Non-Rail	.xls	KCM-Motorbus10
KC08-12-0	**Marine & Rail**	folder	
KC08-12-1	Puget Sound Maritime Air Emissions Inventory (2007)	.pdf	PS05MaritimeInv
KC08-12-2	Port of Seattle Container and Tonnage Statistics Reporting System, "Seattle Harbor 10 year history of cargo volumes handled: 2000-2009."	.xlsx	POS-Tonnage
KC08-12-3	2008 montly ferry routes	.xls	FerryRoutes
KC08-12-4	Weighting calculations for the FauntleRoy-Vashon- Southworth ferry route	.xlsx	FVS-weight
KC08-12-5	Geographic Allocation of Nonraod Engine Population Data to the State and County Level, EPA420-R-05-021, December 2005	.pdf	GeogAllocNONROAD
KC08-12-6	Port of Seattle Seaport Statistics: Cruise Passengers	.xlsx	CruisePass
KC08-14-0	**Air**	folder	
KC08-14-1	Method for allocating SeaTac air emissions to King County	.xlsx	SeaTacRatio
KC08-14-2	2008 Seattle-Tacoma International Airport Activity Report	.pdf	AnnActReport08
KC08-14-3	Sea-Tac Jet Fuel Consumption	.doc	SeaTacFuel
KC08-14-4	2005 Seattle-Tacoma International Airport Activity Report	.pdf	AnnActReport05
KC08-14-5	2003 Seattle-Tacoma International Airport Activity Report	.pdf	AnnActReport03
KC08-20-0	**Buildings**		
KC08-20-1	American Community Survey (2008) - House Heating Fuel (Occupied Housing Units)	.csv	ACS08HeatFuel
KC08-20-2	American Community Survey (2003) - House Heating Fuel (Occupied Housing Units)	.csv	ACS03HeatFuel
KC08-21-0	Sales of Distillate Fuel Oil by End Use (Washington) - from EIA's Independent Statistics and Analysis, Petroleum Navigator	.xls	EIA-DistFuel-WA
KC08-22-0	Heating Degree Days and Cooling Degree Days for Sea-Tac airport	.xlsx	HDD_CDD
KC08-23-0	American Community Survey (2010) - House Heating Fuel (Occupied Housing Units)	.xls	ACS10HeatFuel
KC08-24-0	2010 Process Data	.xlsx	08-10ProcessData
KC08-40-0	**Industry**		
KC08-40-1	2000-2008 Process Data	.xls	00-08ProcessData
KC08-40-2	2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 3: Industrial Processes and Product Use, Chp. 2: Mineral Industry Emissions	.pdf	IPCCGuide-MinIndust
KC08-40-3	Waste Monitoring Program: Market Assessment for Recyclable Materials in King County, Final Report (2006)	.pdf	RecyMatKC
KC08-40-4	Fuel usages from Lafarge Plant	.xls	LafargeFuel03-09
KC08-40-5	CO2 measurements (from the stacks) in 2006 from several facilities	.xls	CO2_AOP_Sources_2006_data
KC08-41-1	NONROAD 2008 - King County Fuel Consumption Data and Calculations	.xlsx	NONROAD-EquipCalcs
KC08-42-1	State Inventory and Projection Tool: IP Module	.xls	SIT-IP-WA-ODS
KC08-42-2	U.S. Census Bureau, American Factfinder: United States -- States, 2008 Population Estimates	website	WApop
KC08-43-1	Data on Economic Value Added by Industry from the 2007 U.S. Economic Census	.xlsx	Ind_ValueAdded
KC08-50-0	**Waste**		
KC08-50-1	Wastewater calculations	.xls	WWT
KC08-50-2	Local Government Operations Protocol for the quantification and reporting of greenhouse gas emissions inventories (2008)	.pdf	LOGP
KC08-50-3	Applicability of Greenhouse Gase Mandatory Reporting Rules to Closed Rural Landfills at Cedar Falls, Enmclaw, Hobart and Vashon Island	.pdf	Closed_Landfills
KC08-50-4	Waste emissions calculations	.xlsx	Waste_calcs
KC08-50-5	EPA WARM model	.xls	WARM_v11_exploded
KC08-50-6	King County (ex-Seattle) municipal solid waste disposal quantities	.xlsx	KingCountyDisposal
KC08-50-7	Seattle municipal solid waste disposal quantities	.xlsx	SeattleDisposal
KC08-50-8	Calculations for recycling benefits	.xlsx	Recycle_calcs
KC08-50-9	Landfill gas flow rate and methane fraction	.xlsx	Cedar_Hills_CH4
KC08-50-10	Landfill gas management definitions and collection efficiency	.doc	Collection_efficiency
KC08-50-11	Landfill flare combustion efficiency	.doc	Cedar_Hills_combustion
KC08-60-0	**Electricity**		
KC08-60-1	SCL geodata sheet - kWh consumption 1995-2008	.xls	SCLkWh95-08
KC08-61-1	King County 2008 Electricity and Natural Gas Usage	.xls	PSE08
KC08-61-2	King County 2003 Electricity and Natural Gas Usage	.xls	PSE03
KC08-63-1	Fuel mix reporting emissions factors calculated for PSE and SCL	.xls	FuelMixPSE-SCL
KC08-64-1	SCL geodata sheet - kWh consumption 1995-2010	.xls	SCLkWh10
KC08-65-1	King County 2010 Electricity and Natural Gas Usage	.xlsx	PSE10
KC08-70-0	**Population and Employment**		
KC08-70-0	Population Estimates States	.csv	Pop_States
KC08-70-1	Population Estimates Counties	.csv	Pop_Counties
KC08-70-2	Population Estimates Cities	.csv	Pop_Cities
KC08-70-3	Population Estimates Nation	.csv	Pop_Nation
KC08-70-4	Employment Estimates King County, Washington State, and the U.S.	.xlsx	Employment
KC08-70-5	Population Estimates Counties 2010	.xlsx	Pop_Counties_2010
KC08-80-0	**Land Use**		
KC08-80-1	King County Assessor Database (as assembled as a Microsoft Access database from data files downloaded from King County website)	.mdb	Assessor_Database
KC08-80-2	Terrestrial Carbon Stocks Across a Gradient of Urbanization: A Study of the Seattle, WA Region	.pdf	Carbon_Stocks
KC08-80-3	Analysis of Greenhouse Gas Emission Effects of King County's Acquisition of Development Rights to Snoqualmie Tree Farm	.doc	GHG_Snoqualmie
KC08-80-4	USFS Carbon Calculation Tool biomass carbon stocks for King County, Washington	.xls	USFS_CCT
KC08-80-5	Analysis of King County Assessor Database	.xls	Assessor_Data_Analysis
KC08-100-0	**Agriculture**		
KC08-100	**2007 Census of Agriculture**	folder	07CensusAg
KC08-100-1	2007 Census of Agriculture: Washington State and County Data, Vol. 1, Geographic Area Series, Part 47, AC-07-A-47.	.pdf	07CensusAg-WAStateCounty
KC08-100-2	2007 Census of Agriculture: Introduction	.pdf	07CensusAg-Intro
KC08-100-3	2007 Census of Agriculture: Washington: Counties	.pdf	07CensusAg-WACountiesMap
KC08-100-4	2007 Census of Agriculture: United States	.pdf	07CensusAg-US
KC08-101-0	2002 Census of Agriculture	.pdf	02CensusAg
KC08-102-0	PSCAA, "2005 Air Emission Inventory for King, Kitsap, Pierce, and Snohomish Counties" (2008)	.pdf	PSCAA05Inventory
KC08-103-0	**Inventory of U.S. Greenhouse Gas Emissions and Sinks**	folder	US-GHG-EmissSinks
KC08-103-1	Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2000 (2002); EPA 430-R-02-003	.pdf	US-GHG-1990to2000
KC08-103-2	Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004 (2006); EPA 430-R-06-002	.pdf	US-GHG-1990to2004
KC08-103-3	Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004 (2006); EPA 430-R-06-002; All Annexes	.pdf	US-GHG-1990to2004Annex
KC08-103-4	Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007 (2009)	.pdf	US-GHG-1990to2007
KC08-103-5	Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007 (2009), Annexes	.pdf	US-GHG-1990to2007Annex
KC08-105-0	**Manure Management**	folder	ManureManagement
KC08-105-1	EPA, "Climate Leaders Greenhouse Gas Inventory Protocol Offset Project Methodology for Project Type: Managing Manure with Biogas Recovery Systems," version 1.3. 2008.	.pdf	ClimateLeadersGHGProtocol
KC08-105-2	2006 IPCC Guidelines for National Greenhouse Gas Inventories; Volume 4: Agriculture, Forestry and Other Land Use; Chapter 10: Emissions from Livestock and Manure Management	.pdf	IPCCGuide-LivestockManure

Attachment B: Population Information

In several cases it was necessary to estimate emissions by scaling by population from other years, or from the state to county level. The population figures used in these estimates are listed in Table 15 below.

Table 15. Population Information by Area and Employment Type

	2003	2008
King County		
Residents	1,769,753	1,884,242
Commercial Employees	926,409	1,005,634
Industrial Employees	104,316	110,885
Washington State		
Residents	6,113,262	6,566,073
Commercial Employees	2,180,230	2,409,221
Industrial Employees	283,569	292,142

Source Notes

Population: Resident populations were all acquired from the U.S Bureau of the Census Population Estimates Program (www.census.gov/popest/). Population estimates are from **KC08-70-0, KC08-70-1, KC08-70-2,** and **KC08-70-3.**

Employees: King County and Washington State commercial and employee totals are from the Washington State Employment Security department **(KC08-70-4_Employment)**.