GHG Emissions in King County:

2017 Inventory Update, Contribution Analysis, and Wedge Analysis

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Prepared for King County, Washington

By ICLEI USA

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The inventory portion of this report draws extensively on *King County Greenhouse Gas Emissions Inventory: A 2015 Update,* produced by Cascadia Consulting Group and Hammerschlag & Co, LLC.

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Acronyms

BOD	Biochemical oxygen demand (a metric of the effectiveness of wastewater treatment plants)
EIA	United States Energy Information Association
EPA	United States Environmental Protection Agency
CO_2e	Carbon dioxide equivalents
GHG	Greenhouse gas (limited to CO_2, CH_4, N_2O, and fugitive gases in this inventory
HFC	Hydrofluorocarbons
$MgCO_2e$	Megagrams of carbon dioxide equivalent
MOVES	Motor Vehicle Emission Simulator model (developed by EPA to quantify emissions from mobile sources)
NONROAD	Part of MOVES model developed by EPA to quantify non-road mobile emissions
ODS	Ozone depleting substance
PSCAA	Puget Sound Clean Air Agency
PSE	Puget Sound Energy
PSRC	Puget Sound Regional Council
SCL	Seattle City Light
SPU	Seattle Public Utilities
TCR	The Climate Registry
USDA	United States Department of Agriculture
WARM	Waste Reduction Model (model developed by EPA to quantify solid waste emissions)
WSDOT	Washington Department of Transportation
VMT	Vehicle Miles Travelled

Introduction and Context

This report contains three pieces of analysis: an updated greenhouse gas (GHG) emissions inventory for King County for 2017, a contribution analysis of the drivers of emissions change between 2008 and 2017, and a wedge analysis of actions that can be applied from 2017 through 2050 to achieve emissions reductions in line with shared County and city goals adopted by the Growth Management Planning Council.

Inventory update approach

GHG emissions inventories allow communities to account for sources and quantities of GHG emissions generated by community activities. King County has developed several different types of inventories in the past including a "geographic-plus" inventory and a "consumption-based" inventory. **This report is an update to the geographic-plus inventory only.** The geographic-plus inventory estimates the annual GHG emissions released within community boundaries and due to community activities, such as energy consumption and waste disposal. The consumption-based inventory accounts for the GHG emissions associated with the goods and services consumed within the community.

Table 1. Inventory comparison.

Geographic-Plus	Consumption-based
Emissions associated with all activities that occur inside the county, "plus" all electricity GHG emissions, even if the electricity is generated outside King County.	Embodied emissions associated with production, transportation, use and disposal of goods, food, and services consumed in King County.

The **geographic-plus inventory** estimates GHG emissions produced by activities of the King County community, including emissions resulting from community energy use; wastewater and solid waste processing; and terrestrial carbon lost due to land use development. It includes both "in-boundary" emission *sources*—any physical process inside the jurisdictional boundary that releases GHG emissions—and activities resulting in GHG emissions. For example, it includes emissions associated with the in-county *production* of food and goods, regardless of where those goods are consumed, such as from a manufacturer located within King County that produces goods for export.

The **consumption-based inventory** provides an inventory of the GHG emissions associated with *consumption* of food and goods within the community, regardless of where the goods were produced. For example, the consumption-based inventory would not include GHG emissions associated with the production of goods from a local manufacturer that are consumed entirely outside the community, but would include GHG emissions associated with the production of goods manufactured in another community but consumed within King county. Thus, the consumption-based inventory accounts for different, but related sources of emissions associated with community activities.

The geographic-plus and consumption-based inventories provide insights about different GHG emission footprints of a community. For example, a community may consume electricity generated from low-emission sources, but also consume goods produced in another community with high-emission energy.

The two inventories can account for these differences to paint a comprehensive picture of community emissions.

King County previously conducted geographic-plus inventories for 2003 and 2008, a limited-scope "core" inventory in 2010, and a 2015 geographic-plus inventory. As part of the 2015 inventory, the 2003, 2008, and 2010 inventories were updated to be compliant with the U.S. Community Protocol and comparable to the 2015 inventory. This 2017 inventory update follow the methodology used in the 2015 inventory.

This report also presents a **contribution analysis** of the 2008 and 2017 geographic-based inventories, which explores drivers of King County emissions trends. The contribution analysis, conducted using a tool developed by ICLEI USA, quantifies the impacts of a select set of drivers (e.g., weather, population growth, and utility fuel mix) on GHG inventories across two years, assuming no changes to operational or organizational boundaries. The intention of the contribution analysis is to better explain what caused observed changes between inventory years.

This report also includes a **wedge analysis**. The wedge analysis forecasts emissions from 2017 through 2050 under a business as usual scenario and then models the impact of nine reduction actions over that time period. The actions were developed to cumulatively achieve County and shared Growth Management Planning Council's countywide emission reduction goals.

This report is focused on assessing total countywide emissions and documenting and explaining what caused recent trends in countywide emissions. To learn more about what King County is doing to confront climate change and reduce emissions, please refer to King County's 2015 Strategic Climate Action Plan available at www.kingcounty.gov/climate.

2017 Inventory Update

The geographic-plus inventory quantifies the release of GHG emissions from activities within King County's geographic boundary, including from transportation, buildings, industrial processes, waste, water use, and agriculture. The "plus" portion expands this scope to include emissions produced by electricity generation outside of the community but consumed by in-county activities.

Results

OVERVIEW

- King County's geographic-plus greenhouse gas (GHG) emissions (Figure 1) totaled 20.1 million metric tons of carbon dioxide equivalent ($MgCO_2e$) in 2017. The geographic-plus inventory quantifies all emissions that physically occur in King County, plus emissions associated with electricity used in King County regardless of where it was produced.
- The largest sources of geographic-plus based GHG emissions were the built environment (62%), dominated by GHG emissions from residential and commercial energy usage (Figure 2), and transportation (36%), dominated by GHG emissions from passenger vehicles.
- 2017 geographic plus emissions decreased by an estimated 1.2% compared to 2007[1]. This trend is not on track towards King County and Growth Management Planning Council (GMPC) adopted greenhouse gas (GHG) reduction targets that include a near term goal of a 25% reduction in countywide GHG emissions by 2020 compared to 2007.
- Per-person GHG emissions declined to 9.5 $MgCO_2e$ per person in 2017, an estimated 11% decrease compared to 2007. King County and GMPC targets include a per capita target of an 8.5 $MgCO_2e$ per person by 2020.

[1] King County's comprehensive GHG inventories are for 2003, 2008 and 2015 calendar years. The baseline year for adopted local GHG emissions reduction targets is 2007, and this report interpolates 2007 totals based on 2003 and 2008 inventory data. Results in this report are compared to both 2007 and 2008 years.

Figure 1. Sources of geographic-plus based GHG emissions for King County in 2017, excluding supplemental sources which are less than 1% of total emissions (total = 20.1 million $MgCO_2e$). The geographic-plus inventory includes emissions that occur in King County, plus electricity related emissions no matter where they occur.

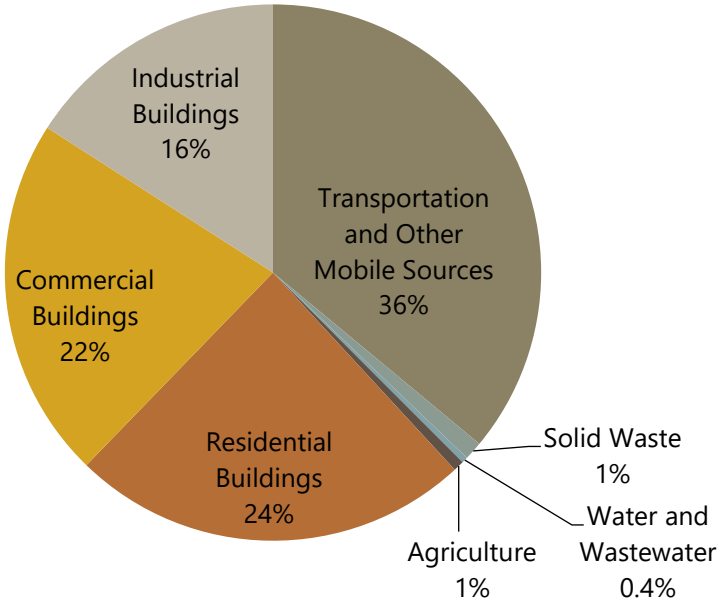


Figure 2. Sources of residential and commercial built environment GHG emissions for King County in 2017 (total = 9.1 million $MgCO_2e$).

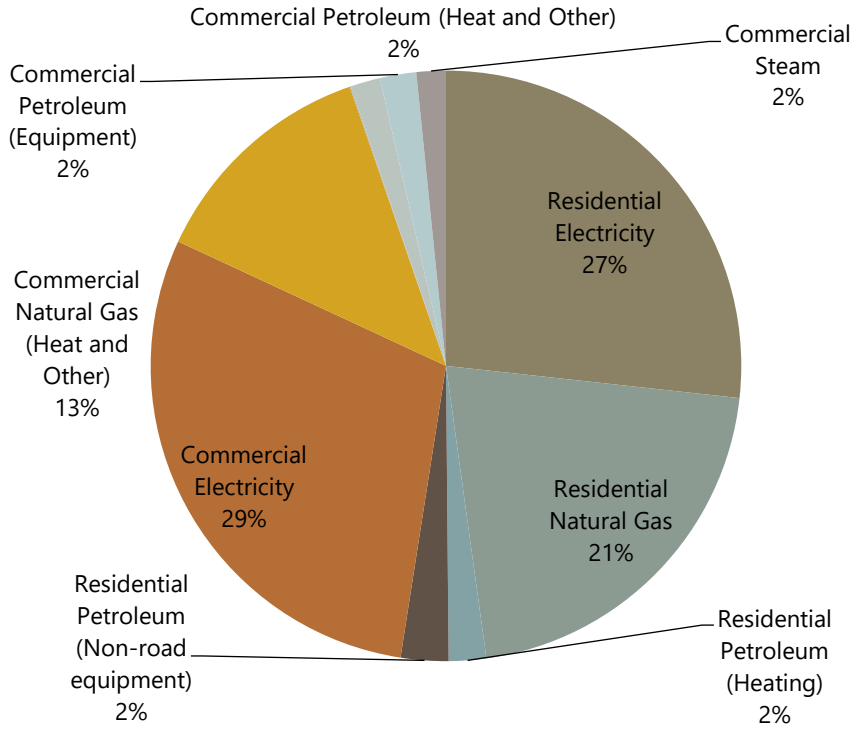


Figure 4. Geographic-plus GHG emissions by sector for King County. This chart shows trends in total GHG emissions in King County since 2003. The Contribution Analysis section of the report builds on this figure to document in a quantitative way which factors influenced trends in total emissions between 2008 and 2017.

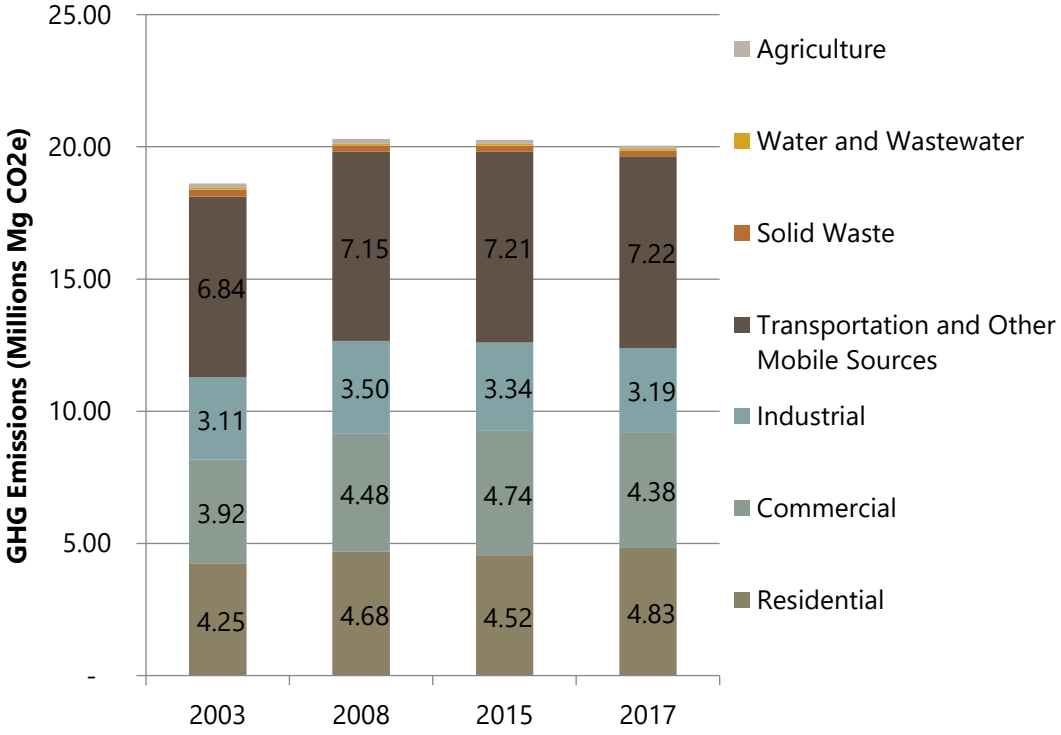


Figure 5. Per-capita emissions for King County from 2003-2017. The line represents King County's population.

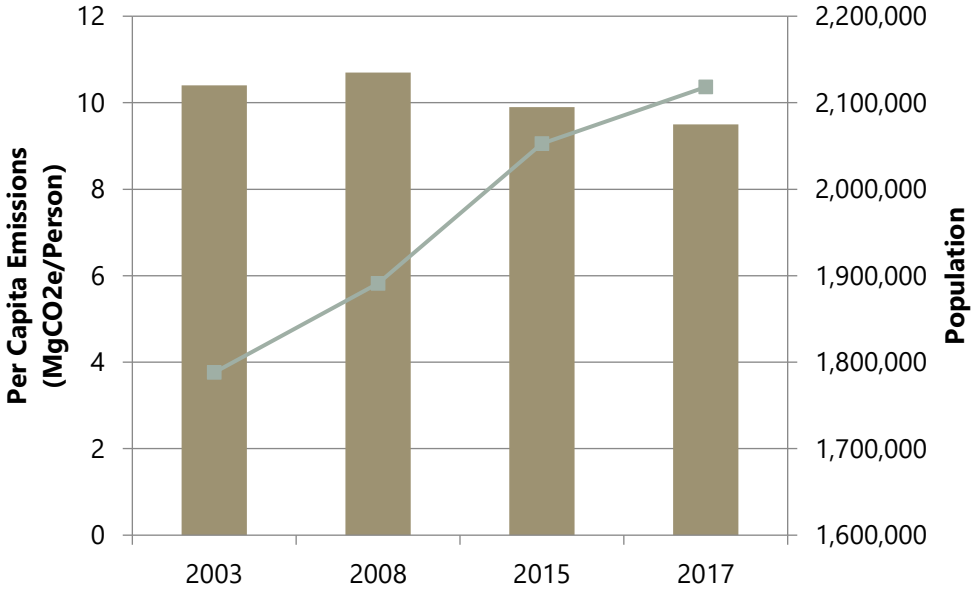


Table 2. King County GHG emissions by sector ($MgCO_2e$).

GHG Emissions by Sector (MgCO2e)		2003	2008	2015	2017
Built Environment		**11,277,100**	**12,654,300**	**12,602,600**	**12,398,000**
Residential		**4,246,500**	**4,677,800**	**4,524,400**	**4,830,200**
	Electricity	2,193,300	2,433,600	2,597,100	2,462,000
	Natural Gas	1,574,600	1,825,700	1,567,600	1,940,000
	Petroleum (Heating)	286,300	216,500	132,100	188,300
	Petroleum (Non-road equipment)	192,300	202,000	227,600	239,900
Commercial		**3,919,600**	**4,476,000**	**4,737,100**	**4,376,700**
	Electricity	2,335,300	2,682,700	2,955,800	2,712,100
	Natural Gas (Heat and Other)	1,034,300	1,174,800	1,147,400	1,177,800
	Natural Gas (Equipment)	19,100	16,100	18,700	5,600
	Petroleum (Heat and Other)	210,200	245,900	254,600	149,800
	Petroleum (Equipment)	159,700	179,200	212,500	183,300
	Steam	161,000	177,300	148,100	148,100
Industrial		**3,111,000**	**3,500,500**	**3,341,100**	**3,191,100**
	Electricity	620,600	593,400	611,600	536,500
	Process emissions	451,500	435,000	351,100	351,100
	Stationary combustion	1,429,600	1,575,100	1,323,900	1,265,700
	Fugitive gas	609,300	897,000	1,054,500	1,037,800
Transportation and Other Mobile Sources		**6,844,300**	**7,152,300**	**7,212,500**	**7,221,300**
On-road vehicles		**6,167,600**	**6,390,600**	**6,349,800**	**6,335,100**
	Passenger vehicles	5,017,700	5,251,600	5,142,700	5,130,300
	Freight and service vehicles	1,021,400	1,019,700	1,048,600	1,036,200
	Transit vehicles	128,500	119,300	158,500	168,600
Freight and passenger rail		**48,800**	**84,600**	**88,100**	97,900
Marine vessels		**94,200**	**89,500**	**107,700**	63,700
Off-road vehicles and other mobile equipment		**8,100**	**10,200**	**12,300**	7,800
Commercial airport		**525,600**	**577,400**	**654,600**	716,800
Solid Waste		**260,100**	**245,200**	**225,600**	**222,700**
Generation and disposal of solid waste		260,100	245,200	225,600	222,700

Water and Wastewater		**63,200**	**67,200**	**73,300**	**73,100**
	Potable water process emissions	800	500	900	900
	Wastewater process emissions	62,400	66,700	72,400	72,200
Agriculture		**165,100**	**171,700**	**145,500**	**129,200**
	Domesticated animal production	69,900	75,500	78,700	68,700
	Manure decomposition and treatment	95,200	96,200	66,800	60,500
Expanded: Supplementary		**109,900**	**65,800**	**58,800**	**64,100**
	Residential development	100,200	57,500	49,400	54,700
	Soil management	9,700	8,300	9,400	9,400
Total Emissions (all sectors)		**18,719,700**	**20,356,500**	**20,318,300**	**20,108,400**
	Core & Expanded Production	**18,609,000**	**20,290,200**	**20,258,600**	**20,043,400**
	Core	**13,584,300**	**14,768,700**	**14,862,000**	**14,855,300**
	Expanded: Production	**5,024,700**	**5,521,500**	**5,396,600**	**5,188,100**
	Expanded: Supplementary	**109,900**	**65,800**	**58,800**	**64,100**
Sequestration					
	Solid waste disposal	(494,687)	(473,155)	(447,313)	(539,242)
Other Emissions					
	Operation of solid waste disposal facilities	177,400	142,600	100,400	89,069
	Residential and business air travel	1,369,400	1,599,600	-	-

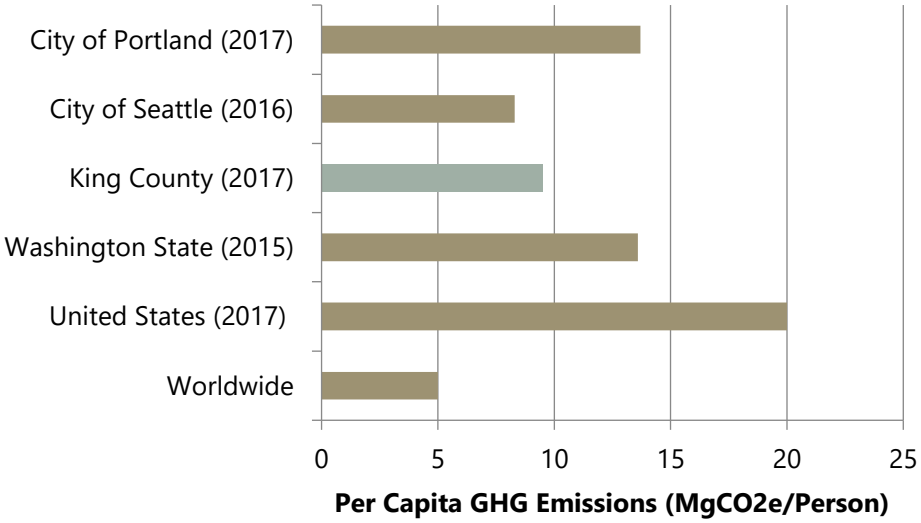
Table 3. King County GHG emissions by sector (percentage of core and expanded production $MgCO_2e$).

GHG Emissions by Sector (MgCO2e)		2003	2008	2015	2017
Built Environment		**60.2%**	**62.2%**	**62.0%**	**61.7%**
Residential		**22.7%**	**23.0%**	**22.3%**	**24.0%**
	Electricity	**11.7%**	**12.0%**	**12.8%**	**12.2%**
	Natural Gas	**8.4%**	**9.0%**	**7.7%**	**9.6%**
	Petroleum (Heating)	**1.5%**	**1.1%**	**0.7%**	**0.9%**
	Petroleum (Non-road equipment)	**1.0%**	**1.0%**	**1.1%**	**1.2%**
Commercial		**20.9%**	**22.0%**	**23.3%**	**21.8%**
	Electricity	**12.5%**	**13.2%**	**14.5%**	**13.5%**
	Natural Gas (Heat and Other)	**5.5%**	**5.8%**	**5.6%**	**5.9%**
	Natural Gas (Equipment)	**0.1%**	**0.1%**	**0.1%**	**0.0%**
	Petroleum (Heat and Other)	**1.1%**	**1.2%**	**1.3%**	**0.7%**
	Petroleum (Equipment)	**0.9%**	**0.9%**	**1.0%**	**0.9%**
	Steam	**0.9%**	**0.9%**	**0.7%**	**0.7%**
Industrial		**16.6%**	**17.2%**	**16.4%**	**15.9%**
	Electricity	**3.3%**	**2.9%**	**3.0%**	**2.7%**
	Process emissions	**2.4%**	**2.1%**	**1.7%**	**1.7%**
	Stationary combustion	**7.6%**	**7.7%**	**6.5%**	**6.3%**
	Fugitive gas	**3.3%**	**4.4%**	**5.2%**	**5.2%**
Transportation and Other Mobile Sources		**36.6%**	**35.1%**	**35.5%**	**35.9%**
On-road vehicles		**32.9%**	**31.4%**	**31.3%**	**31.5%**
	Passenger vehicles	**26.8%**	**25.8%**	**25.3%**	**25.5%**
	Freight and service vehicles	**5.5%**	**5.0%**	**5.2%**	**5.2%**
	Transit vehicles	**0.7%**	**0.6%**	**0.8%**	**0.8%**
Freight and passenger rail		**0.3%**	**0.4%**	**0.4%**	**0.5%**
Marine vessels		**0.5%**	**0.4%**	**0.5%**	**0.3%**
Off-road vehicles and other mobile equipment		**0.0%**	**0.1%**	**0.1%**	**0.0%**
Commercial airport		**2.8%**	**2.8%**	**3.2%**	**3.6%**
Solid Waste		**1.4%**	**1.2%**	**1.1%**	**1.1%**
Generation and disposal of solid waste		**1.4%**	**1.2%**	**1.1%**	**1.1%**
Water and Wastewater		**0.3%**	**0.3%**	**0.4%**	**0.4%**
Potable water process emissions		**0.0%**	**0.0%**	**0.0%**	**0.0%**
Wastewater process emissions		**0.3%**	**0.3%**	**0.4%**	**0.4%**
Agriculture		**0.9%**	**0.8%**	**0.7%**	**0.6%**
Domesticated animal production		**0.4%**	**0.4%**	**0.4%**	**0.3%**
Manure decomposition and treatment		**0.5%**	**0.5%**	**0.3%**	**0.3%**
Other Emission Sectors (Supplementary)		**0.6%**	**0.3%**	**0.3%**	**0.3%**
Operation of solid waste disposal facilities		**0.9%**	**0.7%**	**0.5%**	**0.0%**
Soil management		**0.1%**	**0.0%**	**0.0%**	**0.0%**
Residential development		**0.5%**	**0.3%**	**0.2%**	**0.3%**
Residential and business air travel		**7.3%**	**7.9%**		**0.0%**
Total Emissions (all sectors)					
Core & Expanded Production		**100.0%**	**100.0%**	**100.0%**	**100.0%**
	Core	**73.0%**	**72.8%**	**73.4%**	**74.1%**
	Expanded: Production	**27.0%**	**27.2%**	**26.6%**	**25.9%**
	Expanded: Supplementary	**0.6%**	**0.3%**	**0.3%**	**0.3%**

Table 4. Per-capita GHG emissions for King County between inventory years.

Per-capita GHG Emissions by Sector ($MgCO_2e$/capita)	2003	2008	2015	2017
Built Environment	**6.3**	**6.7**	**6.1**	5.9
Residential	2.4	2.5	2.2	2.3
Commercial	2.2	2.4	2.3	2.1
Industrial	1.7	1.9	1.6	1.5
Transportation and Other Mobile Sources	**3.8**	**3.8**	**3.5**	3.4
On-road vehicles	3.4	3.4	3.1	3.0
Freight rail	<0.1	<0.1	<0.1	0.0
Marine vessels	0.1	<0.1	0.1	0.0
Off-road vehicles and other mobile equipment	<0.1	<0.1	<0.1	
Commercial airport	0.3	0.3	0.3	0.3
Solid Waste	**0.1**	**0.1**	**0.1**	0.1
Generation and disposal of solid waste	0.1	0.1	0.1	0.1
Water and Wastewater	**<0.1**	**<0.1**	**<0.1**	0.0
Potable water process emissions	<0.1	<0.1	<0.1	0.0
Wastewater process emissions	<0.1	<0.1	<0.1	0.0
Agriculture	**0.1**	**0.1**	**0.1**	0.1
Domesticated animal production	<0.1	<0.1	<0.1	0.0
Manure decomposition and treatment	0.1	0.1	<0.1	0.0
Supplementary Emission Sectors	**0.1**	**<0.1**	**<0.1**	0.0
Soil management	<0.1	<0.1	<0.1	3.0
Residential development	0.1	<0.1	<0.1	2.4
Total Emissions				
Core & Expanded Production	**10.4**	**10.7**	**9.9**	**9.5**
Core	**7.6**	**7.8**	**7.2**	**7.0**
Expanded: Production	**2.8**	**2.9**	**2.6**	**2.4**
Expanded: Supplementary	**0.1**	**<0.1**	**<0.1**	**<0.1**

Figure 3. King County 2017 per-capita GHG emissions compared to other jurisdictions.[2]



RESIDENTIAL AND COMMERCIAL BUILDINGS

Emissions from the residential and commercial built environment resulted in the following key trends and findings:

- In 2017, the built environment accounted for 62% of communitywide emissions. Emissions from commercial and residential buildings accounted for most of those emissions and 46% of all emissions.
- Changes in energy demand and fuel mix in the commercial and residential sectors led to a 2% decrease in commercial and 3% increase in residential energy emissions compared to 2008. Residential increases can be attributed largely to increases in natural gas consumption.

King County's electricity and natural gas are delivered through two energy providers: Seattle City Light (SCL) and Puget Sound Energy (PSE). Both providers generate electricity primarily through hydroelectricity, however other sources such as coal and natural gas are also used—especially when hydroelectric capacity is low.

King County's electricity is also connected to the regional grid, which has its own emissions profile. To put King County's emissions in context, a sensitivity analysis was run per the recommendations of the U.S.

[2] Methodologies may vary among jurisdictions. Only comparable sectors are included in per-capita totals. Comparison is for illustrative purposes only. Data sources: (Washington State Department of Ecology, 2018), (Seattle Department of Sustainability and Environment, 2019), (Global Carbon Project, 2017), (U.S. Environmental Protection Agency, 2019).

Community Protocol to compare the utility-specific emissions profile with that of the regional grid. In general, the utility-specific emissions profiles out-performed (generated fewer GHG emissions) the regional emission factor. As a policy preference, and consistent with U.S. Community Protocol, King County has requested that we use utility-specific emissions coefficients in this overall inventory to best reflect local conditions and partnerships with Seattle City Light and Puget Sound Energy to phase in renewable electricity sources and phase out fossil fuels.

Figure 4. Sources of residential (left) and commercial (right) GHG emissions in 2017.

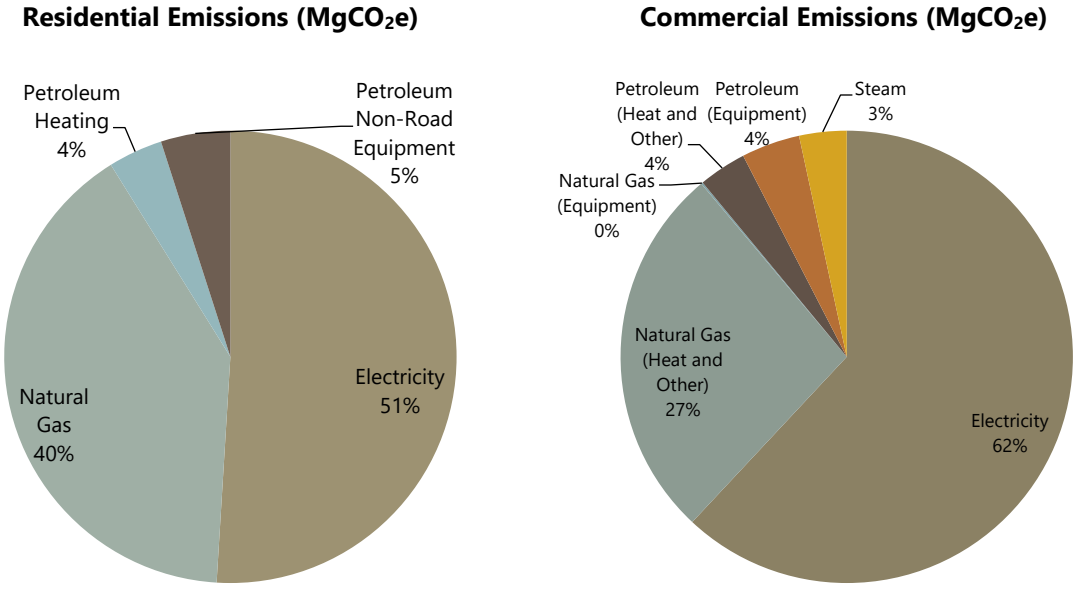
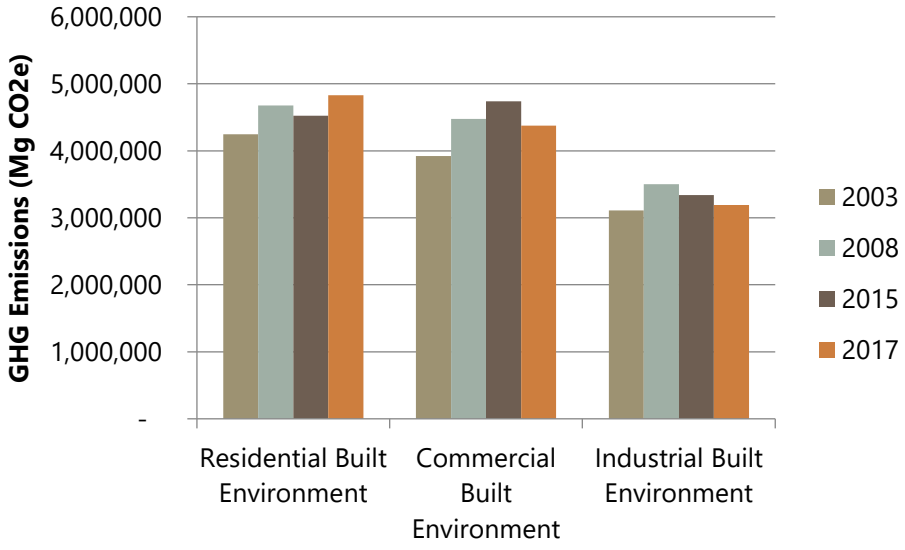


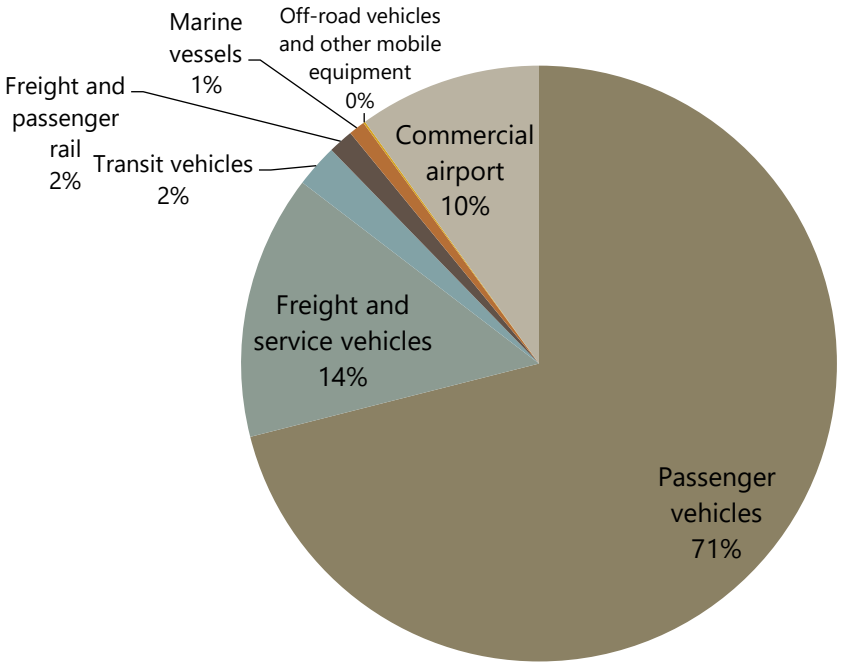
Figure 5. Emission sources from the built environment from 2003 to 2017.



TRANSPORTATION

Transportation accounted for 36% of GHG emissions in 2017, and was the largest source of emissions after the built environment. Total transportation emissions have remained relatively steady since 2008 (Figure 6), and have declined by 10% per capita within that time period. Most transportation emissions in 2017 stemmed from passenger vehicles (71%).

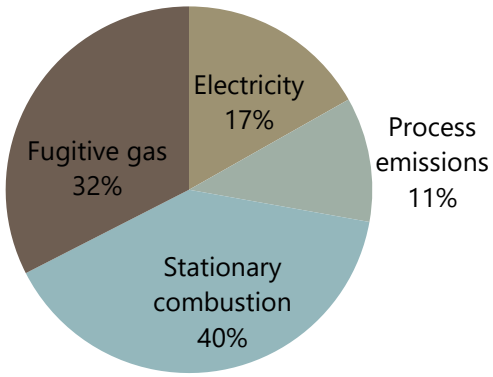
Figure 6. GHG emission sources for transportation in 2017. *Note: commercial airport emissions include only airplane takeoff and landing emissions only from SeaTac International Airport and the King County International Airport.*



INDUSTRY

Industrial GHG emissions decreased 8% from 2008 to 2017. Emissions from electricity in the industrial sector have decreased 9% to about 536,000 $MgCO_2e$ in 2017. Process emissions, a significant portion of overall industrial emissions, have decreased 19% since 2008. Emissions from stationary combustion decreased 19% since 2008, even as electricity demand increased within the industrial sector. Fugitive gas emissions increased 15% between 2008 and 2017. The fugitive gas source includes hydrofluorocarbons (HFCs), refrigerants, and other ozone depleting substance (ODS) substitutes.

Figure 7. Sources of industrial emissions for King County in 2017 (total = 3.1 million $MgCO_2e$).



SOLID WASTE

Emissions from solid waste disposal have declined in King County since 2003 despite increasing population (

). Since 2008, emissions have declined 9%, totaling 222,679 $MgCO_2e$ in 2017. Per-capita emissions have decreased 11% over that same timeframe. Solid waste emissions are estimated for all waste generated in King County using factors drawn from the EPA's WARM model. Emissions are estimated for methane produced in landfills and for transportation of solid waste to the landfill. This methodology is consistent with the US Community Protocol. Separate calculations that estimate emissions from active landfills in King County are provided in the Supplemental Calculations section of this report. Neither estimate include the carbon sequestration benefits of solid waste disposal—only the GHG emissions.

WASTEWATER

Within a community, emissions from wastewater treatment are estimated based on the number of people served and the fuel mix of the energy source. We estimate that wastewater emissions have increased by 9% from 2008 to 2017, and have been relatively stable on a per-capita basis over that period. King County supplies biosolids as soil amendments for several Washington operations, which likely reduces the need for artificial fertilizer. The GHG benefits associated with biosolids applications are outside the scope of this inventory.

Supplemental Calculations

The inventory includes calculation of two supplementary emissions sources: 1) soil management and 2) residential development, detailed in the "Agriculture and Land Use Change" section below. We also calculated emissions from two sources for informational purposes only: 1) active landfills and 2) potable water treatment and conveyance. These calculations are purely informational because they overlap with communitywide energy and solid waste emissions, respectively.

AGRICULTURE AND LAND USE CHANGE

Agriculture accounts for only about 0.6% of GHG emissions in King County, and this relative contribution has remained steady over time. Emissions are primarily derived from enteric digestion of ruminants and manure. Enteric emissions are increasing despite declining per-cattle emissions, indicating an increase in the county's animal population. During the same time, manure emissions declined 37%.

Emissions from soil management increased 13%, but remain very small compared to other sources. In 2017, soil management released 9,400 $MgCO_2e$.

We estimate that emissions from land use change (i.e., residential development) has declined by 5% due to a decline in the number of building permits issued and, consequently, acres of land cleared for new residential construction over that time period.

LANDFILLS

For informational purposes, we also provide calculated emissions from landfills (both open and closed) currently managed by King County. These values are not included in the final inventory tally, as the values overlap with those associated with the generation and disposal of waste by King County businesses and residents.

Table 5. Landfill GHG estimates for King County owned Landfills

Greenhouse Gas Emissions ($MgCO_2e$)	2007	2015	2017
Open and Closed Landfills in King County	74,493	87.282	84,496

POTABLE WATER

Potable water in King County is sourced from the Cedar River and Tolt watersheds. Like for wastewater, emissions from potable water treatment and conveyance are dependent on the number of people served and the fuel mix of the energy source. Total emissions from potable water used in King County were under 1,000 $MgCO_2e$ in 2017. Overall, potable water is an extremely small source of GHG emissions in King County.

WASTEWATER TREATMENT

For informational purposes, we also provide calculated emissions associated with wastewater treatment by King County. These values are not included in the final inventory tally, as the values overlap with those associated with the wastewater emissions estimated based on national scaling factors.

Table 6. Wastewater GHG estimates for King County wastewater treatment processes

Greenhouse Gas Emissions ($MgCO_2e$)	2007	2015	2017
Wastewater	6,350	5,673	6,344

Data Sources

Conducting the inventory involved acquiring the following data, summarized in Table 7 and detailed in the following sections:

- **Activity data** that quantifies levels of activity that generate GHG emissions, such as miles traveled and kWh of electricity consumed.
- **Emission factors** that translate activity levels into emissions (e.g., $MgCO_2e$ per kWh).

Table 7. Key data sources for King County's 2017 geographic-plus inventory.

Sector	Activity	Emission Factors
Transportation (Road)	• Daily vehicle miles traveled (Puget Sound Regional Council)	• EPA MOVES2014a model
Transportation (Transit)	• King County Metro and Sound Transit fuel use (National Transit Database 2017)	• US EPA (U.S. Environmental Protection Agency, 2015)
Transportation (Air)	• Jet fuel and aviation gas consumed at SeaTac airport and Boeing Field	• US EPA (U.S. Environmental Protection Agency, 2015)
Transportation (Marine)	• Puget Sound Maritime Air Emissions Inventory (Puget Sound Clean Air Agency, 2012) • Washington State Ferries route statements (Washington State Department of Transportation, 2015)	• EPA NONROAD • US EPA (U.S. Environmental Protection Agency, 2015)
Buildings and Industry (Electricity)	• kWh consumption (SCL and PSE)	• Utility fuel mix (Washington State Department of Commerce, 2015) • SCL reported emission factors (The Climate Registry, 2015)
Buildings and Industry (Natural Gas and Oil)	• Gas use (PSE provided by King County) • Oil use (U.S. Energy Information Administration, 2015)	• Carbon content of natural gas and oil (U.S. Environmental Protection Agency, 2015)
Fugitive Gases	• Substitution of ozone-depleting substances • SF_6 emissions from electric utility switchgear insulation	• US EPA (U.S. Environmental Protection Agency, 2015) • IPCC
Solid Waste	• Landfill gas generation • Tons disposed and composted (King County, 2017)	• US EPA WARM v14 model • Customized landfill methane capture rates (Coven, et al., 2014)
Wastewater	• Wastewater treatment rates from King County and Seattle Public Utilities	• National wastewater factors (Local Governments for Sustainability USA, 2013)
Water	• Quantity and use provided by Seattle Public Utilities	• Energy provider emission factor

Sector	Activity	Emission Factors
Agriculture	• Acres of cropland and number of livestock (U.S. Department of Agriculture, 2014)	• Emissions per animal or per acre (U.S. Environmental Protection Agency, 2015)
Land Use Change	• Acres of land cleared for development (King County Assessor's database 2017)	• Average carbon stocks in King County as assessed by the University of Washington

TRANSPORTATION

- **Vehicle miles traveled (VMT)** were derived from Puget Sound Regional Council and accounted for all mileage within the county boundary regardless of trip origin or destination. The PSRC then used emission factors derived originally from the EPA MOVES model and modified those factors to reflect regional vehicle fleet age and fuel composition. The PSRC data reported overall emissions for passenger vehicles (cars, motorcycles, light trucks), medium trucks, and heavy trucks. Past runs of the PSRC model had produced VMT and emissions results for 2016. Due to the time and cost of performing specific model runs for the purpose of the inventory, VMT and resulting emissions for 2017 built upon previous analysis and assumed a constant rate of growth from 2016-2017 as occurred 2015-2016.
- We acquired **fuel consumption** data for Metro (King County's bus transit service) and Sound Transit (a regional transit service that serves King County) from the National Transit Database from the Federal Transit Administration.
- Updated **jet and aviation fuel data** for Boeing Field from King County were unavailable and these values were scaled from 2015 values using the number of flight operations in each year.
- **Ferry** fuel data is reported annually by WSDOT for each ferry route. We used the fiscal year that most closely associated with our year of interest.
- The Puget Sound Clean Air Agency published a 2016 report on maritime air emissions, which we used to enumerate 2017 **freight rail and port** emissions, following recommendations from the 2015 version of this report.
- Emissions from **pleasure boats** and other small-engine recreational vessels were obtained EPA MOVES v14, which now incorporates the previously used NONROAD model.

BUILDINGS AND ENERGY

- Data on **electricity** and **natural gas** use were provided by the two King County utilities: SCL and PSE.
- **Residential heating fuel** consisted of natural gas, of which the data were provided by PSE, and heating oil, provided by EIA.
- Other residential emissions were calculated using EPA MOVES v14, which now incorporates the previously used NONROAD model. . Emissions include common non-road equipment, often for gardening and landscaping purposes, such as lawnmowers.
- **Commercial heating** is provided through natural gas, and steam from Enwave, a Seattle steam company that heats approximately 200 commercial downtown buildings. Enwave provides emissions data to the PSCAA.

- Additional commercial non-road sources were calculated EPA MOVES v14, which now incorporates the previously used NONROAD model. These nonroad sources include fuel used for commercial landscaping and non-flight equipment at airports.
- **Industrial process** emissions are recorded by the PSCAA, which provided data on large sources of emissions from industry.
- Data on **fugitive refrigerant** emissions at regional scales is scarce. A nationally reported number by the EPA was used to scale to King County.
- PSE provided data on **natural gas consumption**, and the EIA provided data on **industrial oil**. We obtained emission factors for fuels from the EPA (U.S. Environmental Protection Agency, 2015).
- We calculated an emissions factor for PSE using the fuel mix reported in the annual Fuel Mix Disclosure reporting conducted by the Washington State Department of Commerce. SCL reports an emissions factor through The Climate Registry (TCR), which we used for all years except 2003, which predated TCR. For a 2003 SCL emissions factor, we used the fuel mix report (Washington State Department of Commerce, 2015).

SOLID WASTE

- We used King County waste composition data, along with emissions factors from the EPA WARM v14 model, to calculate emissions from **waste disposal and composting**. Landfill emissions assumed 90% and 75% landfill gas capture rates for King County and Seattle waste, respectively. The waste composition was updated for 2017, using data from the 2015 King County Waste Characterization and Customer Survey Report.

WASTEWATER

- Wastewater emission calculations required data from King County **wastewater treatment plants**, provided by facility engineers and publicly available documents.

POTABLE WATER

- **Potable water emissions** required data on water use, publicly available from Seattle Public Utilities, and energy use estimates provided by the U.S. Community Protocol.

AGRICULTURE

- The USDA provides publicly available data on the number of animals by county, these were recently updated with the publication of the 2017 Agriculture Census. The EPA provides national-level **animal enteric and manure** emission factors, and state-level emissions factors for cattle.

LAND USE

- The King County Assessor's office publicly provides land use data for King County, which we used to calculate the emissions associated with **new development** in 2017.

Key Differences between Past and Current Methodologies

This 2017 inventory update was conducted in adherence with the U.S. Community Protocol. See the text box on the following page for more information on this protocol and how it compares to other available protocols. To the extent possible this inventory attempted to replicate the methodologies used in the 2015 inventory to ensure consistency of results over time. Due to some inherent limitations in some estimation techniques that rely on studies or modeling efforts by other agencies, some degree of methodology shift is impossible to avoid. In the future shifting methodologies could be minimized by sourcing as much data as possible from local measurement.

Each inventory update often requires some level of change from past practices in order to make improvements on calculations that were data-limited in the past or work within data limitations of the current inventory. Table 7 contains a summary of the major methodological shifts in the two most-recent inventories.

The U.S. Community Protocol

The Community Protocol was built to provide easily applicable and accurate community-level estimates of GHG emissions. This protocol provides a consistent framework in which to compare protocols from a geographic boundary across time. The U.S. Community Protocol was designed for community-scale GHG accounting, making it a valuable tool for counties and cities, and an appropriate choice for King County. The Community Protocol is widely used, understood, and respected.

This inventory follows the Community Protocol methodology, and deviates from its stated methods only when more precise, local data is available, per the Community Protocol recommendations. The Local Governments for Sustainability (ICLEI) created the U.S. Community protocol in 2013. The U.S. Community Protocol requires, at a minimum, reporting of the following five activities: 1) Use of electricity by the community 2) Use of fuel in residential and commercial stationary combustion equipment 3) On-road passenger and freight motor vehicle travel 4) Use of energy in potable water and wastewater treatment and distribution 5) Generation of solid waste by the community. Other protocols, such as the Global Protocol for Community-scale GHG Emissions (GPC) are also commonly used. Whereas the GPC focuses primarily on the reporting and categorical requirements of an inventory, the U.S. Community Protocol provides specific methodologies, and often emission factors, to calculate different emissions sources.

This inventory calculates emissions associated with the five activities required of the U.S. Community Protocol, as well as other activities calculated in prior inventory years. The first two activities (community electricity use and stationary fuel combustion) are presented together within the "Residential and Commercial Buildings" and "Industry" sections of this report.

Additionally, the GPC includes consumption-based emissions, and some sinks, whereas the U.S. Community Protocol does not include sinks. Carbon sinks refer to processes that take greenhouse gases out of the atmosphere. By not accounting for sinks, the U.S. Community Protocol can over-represent the net GHG emissions, and allows for some societal goods, such as waste composting, to be perceived negatively. However, other sinks, such as a landfilling, could be perceived positively as a GHG sink, even though increased landfilling of waste is generally not considered a societal good.

Table 8. Brief methodological outline of previous inventories and this report.

Sector	Methodology for previous inventories	Methodology update for 2015 compared to all past inventory years	Methodology Update for 2017 relative to 2015
Transportation (Road Vehicles)	• VMT from Puget Sound Regional Council (PSRC) data • National emission factors (U.S. Environmental Protection Agency, 2008)	• Emissions calculated by PSRC as a function of VMT, fuel mix, fleet age, and EPA MOVES2014a emission factors • Inclusion of CH_4 and N_2O	• Emissions scaled from 2015
Transportation (Transit)	• Transit fuel data used to determine emissions	• No change to transit	• No Change
Transportation (Air)	• Landing-takeoff (LTO) emissions for King County airport • King County leisure/business travel emissions for SeaTac	• Only included LTO emissions for both King County International Airport and SeaTac • King County resident/business air travel emissions moved to consumption-based inventory	• Emissions from King County International and SeaTac scaled from 2015 on the number of flights. • No consumption-based values in this geographic-plus inventory
Transportation (Marine)	• Per-route, per-vessel ferry use (no source) • Freight emissions scaled with freight tonnage (Puget Sound Clean Air Agency, 2012)	• Ferry fuel use (Washington State Department of Transportation, 2015) multiplied by diesel emission factors (U.S. Environmental Protection Agency, 2015) • NONROAD model outputs of harbor craft	• No Change in Ferry Fuel Use • Harbor craft based on outputs from NONROAD module of EPA MOVES 2014a with identical inputs as 2015.
Transportation (Freight)	• Freight emissions (Puget Sound Clean Air Agency, 2012) scaled to year's tonnage	• No change	• No change in methodlogy though updated the original source data to the PSCAA 2016 Inventory
Buildings and Industry (Electricity)	• Puget Sound Energy (PSE) and Seattle City Light (SCL) emission factors calculated using fuel mix	• Inclusion of CH_4 and N_2O emission factors to fuel mix	• No Change

Sector	Methodology for previous inventories	Methodology update for 2015 compared to all past inventory years	Methodology Update for 2017 relative to 2015
	reports to derive emissions from fuel combustion (Washington State Department of Commerce, 2015)	• TCR-based emission factor for SCL (The Climate Registry, 2015) • TCR-based methodology for PSE emission factor • Accounted for transmission losses	
Buildings and Industry (Natural Gas and Oil)	• Quantity of natural gas and oil with emission factor (U.S. Environmental Protection Agency, 2015) • Mobile road emission factors (U.S. Environmental Protection Agency, 2008) applied to NONROAD fuel use data	• Inclusion of CH_4 and N_2O, quantity of natural gas and oil with EPA emission factors (U.S. Environmental Protection Agency, 2015) • NONROAD emission factors applied to NONROAD fuel use data (U.S. Environmental Protection Agency, 2015)	• No Change
Fugitive gases (ODS substitutes and switchgear insulation SF_6)	• EPA ODS tool • Scaled countywide SF_6 values	• National ODS substitutes value scaled to region by population (U.S. Environmental Protection Agency, 2015) • Utility-specific SF_6 emissions values	• No Change
Waste	• Waste characterization (King County, 2017) and EPA WARM v8 emission factors	• Waste characterization (King County, 2017) and updated EPA WARM v14 emission factors • Included composting emissions	• New waste characterization.
Wastewater	• Included biogas emissions	• Included biogas emissions, BOD_5 emissions, and septic systems	• Included minor process emissions not previously identified in the biogas scrubbing process and incomplete combustion from flaring

Sector	Methodology for previous inventories	Methodology update for 2015 compared to all past inventory years	Methodology Update for 2017 relative to 2015
Potable Water	• Included within community energy (electricity)	• Included within community energy, but also called out as a separate line item	• No Change
Agriculture	• Enteric and manure emission factors (U.S. Environmental Protection Agency, 2015) and number of animals (U.S. Department of Agriculture, 2014)	• Updated enteric emission factors (U.S. Environmental Protection Agency, 2015)	• Updated number of animals based on the 2017 USDA Agricultural Census
Land Use Change	• Permit data (King County, 2017) • Carbon storage assumptions	• No change	• No Change

TRANSPORTATION (ROAD)

On-road passenger vehicle and freight emissions were calculated by the Puget Sound Regional Council (PSRC). PSRC applied its activity-based travel model data to the EPA's Motor Vehicle Emission Simulator (MOVES) model to arrive at emissions estimations by vehicle type.

PSRC's activity-based travel model produces vehicle miles traveled (VMT), facility type, and speed estimates for time periods within a typical workday in King County. VMT outputs were provided by vehicle type for passenger vehicles (further allocated to single occupancy vehicle, HOV2, and HOV3), buses, medium trucks, and heavy trucks. At the time of this inventory, PSRC had developed and calibrated this model for analysis years 2006, 2014, and 2016.

MOVES estimates from cars, trucks, and non-highway mobile sources under user-defined vehicle types, time periods, geographic areas, vehicle operating characteristics, and road types. The model simulates emissions for various vehicle operating processes, such as running, starts, or hoteling. PSRC's use of the model was run using California LEV II standards, which were adopted by the State of Washington beginning with 2009 model year vehicles. PSRC also used County-specific input files provided by the Washington Department of Ecology that reflect the climate, vehicle mix, and inspection and maintenance requirements specific to each county.

Because the PSRC model was only run for 2006, 2014, and 2016, PSRC linearly interpolated results from modeled years to estimate 2008 and 2015 emissions in past inventories and 2016 to 2017 for this inventory. Both activity data in VMT and the running, start, and hoteling emissions were scaled linearly in this way. To arrive at 2003 emissions estimates, we used regression analysis to estimate 2003 VMT by vehicle type, and then scaled 2008 running and start emissions by the of ratio of 2003 to 2008 VMT.

Transit fuel use for Metro and Sound Transit were multiplied by standard fuel emissions factors from the EPA to derive transit emissions.

TRANSPORTATION (AIR)

Emissions associated with air travel were calculated for jet fuel use and, if available, for ground support equipment. Because ground support equipment is classified as "commercial equipment," its emissions are included in the non-road equipment section of the inventory.

For Boeing Field (King County International Airport) and SeaTac Airport, for the 2015 inventory was based on aviation and jet fuel dispensed on site in 2015, and used a standard fraction of that fuel towards King County's share of emissions. This fraction—the proportion of fuel consumed in landing and takeoff (LTO)—is estimated at 10% (Rypdal, 2001). We applied emissions factors from the U.S. EPA Inventory of Greenhouse Gas Emissions and Sinks report (U.S. Environmental Protection Agency, 2017).

For SeaTac airport, greenhouse gas emissions estimates are also available directly from the airport's 2015 air quality criteria pollutant emissions inventory, which uses the Federal Aviation Administration's EDMS model version 5.1.4.1.

In 2017, direct data was not available from either airport. In order to estimate these emissions, fuel use was scaled using the ratio of the number of flight operations that occurred at each airport from 2015 to 2017, obtained from the Federal Aviation Administration' Air Traffic Activity Data System (ATADS).

TRANSPORTATION (RAIL)

We used the PSCAA 2016 Maritime Air Emissions report (Starcrest Consulting, 2018) and scaled by 2017 tonnage to determine emissions from freight. The Port of Seattle reports rail emissions to the PSCAA, which then breaks down emissions by county in this report. This methodology reflects that used in 2003,2008, and 2015. The 2016 Maritime Air Emissions Report demonstrated significant emissions reductions compared to 2012 which is reflected in this report. It is likely that a significant portion of these reductions had occurred by 2015 but were not reflected in those previous analyses.

BUILDINGS AND INDUSTRY (ELECTRICITY)

Previously, electric utility emissions factors used the fuel mix report for the appropriate year. Washington State Department of Commerce requires an annual fuel-mix report from all public electrical utilities. The new inventory used the 2015 fuel mix report (Washington State Department of Commerce, 2015) to determine PSE's emission factor, but also included CH_4 and N_2O, which had not previously been included. The new inventory retroactively updated previous emission factors to include these gases.

SCL reports to The Climate Registry (TCR) following a rigorous and third-party audited methodology. Per the recommendations of the U.S. Community Protocol, the new inventory uses TCR's reported SCL emissions factor (The Climate Registry, 2015), except for 2003, which predated TCR. We used the fuel mix reported in the Washington Department of Commerce annual 2003 report to determine SCL's 2003 emission factor. We also applied the TCR methodology for calculating utility emissions factors to PSE—the other electricity utility in King County—to arrive at their utility-specific emissions factor.

The US Community Protocol calls for quantification of emissions from electric power transmission and distribution losses. We updated past inventories to account for these losses, which make up about 8% of total electricity generation. Proportional losses were derived from estimated regional grid loss data published by the Emissions and Generation Resource Integrated Database (eGRID).

BUILDINGS AND INDUSTRY (NATURAL GAS AND OIL)

The 2017 inventory uses the same industrial small equipment emission factors from the EPA NONROAD model rather than mobile emissions factors previously used. PSCAA provided data on combustion and process emissions for large industry. Process emissions occur from the manufacturing of certain goods including steel, cement, and glass, and can be measured by applying an equation to the quantity of material produced.

FUGITIVE EMISSIONS

Previous inventories used a State Inventory tool developed by the EPA to derive regional emissions from ODS substitutes gases. However, this tool is no longer available. In the 2015 and 2017 inventory updates

we scaled the national EPA-reported emissions from substitution of ozone-depleting substances (U.S. Environmental Protection Agency, 2015), (U.S. Environmental Protection Agency, 2019) to a regional scale by population.

We also quantified SF_6 emissions from switchgear insulation used by electric utilities. These values were derived from values reported by the utilities.

WASTE

Previous King County geographic-plus inventories included solid waste emissions through quantification of emissions from landfills within the county. Previous inventories also calculated solid waste emissions from all King County residents and businesses; however, these values were not included in the final geographic plus inventory tally. Because the U.S. Community Protocol prioritizes emissions calculations based on activity boundaries (as opposed to just geographic boundaries), we decided to emphasize emissions associated with all generation and disposal of waste, regardless of where the waste is transferred. This means that the solid waste emissions depicted in King County's inventory include those from Seattle residents and businesses, which are transported to a landfill in Oregon for disposal.

For calculating emissions from generation and disposal of solid waste, we used the same methodology to measure resident and business waste emissions as used in the past, but extracted new emission factors from the EPA WARM v14 model, and reapplied these emission factors to previous years. We translated waste composition data for Seattle and King County (King County, 2017) into the EPA WARM categories and applied travel distance and landfill gas capture data to obtain accurate measures. We also included emissions from composting, which were not incorporated in previous inventories.

LANDFILL EMISSIONS

For informational purposes, we also calculated emissions from King County's currently managed landfills. These values are not included in the final inventory tally, as the values overlap with those associated with the generation and disposal of waste by King County businesses and residents described above.

WASTEWATER

King County previously estimated wastewater-related GHG emissions through quantification of emissions associated with the treatment processes and combustion of waste gas. Previous calculations used population-based methodologies and were simply updated with new population figures. . The 2015 inventory included 85,000 residents in King County use septic systems (King County, 2017), which release methane. This value was held constant as new septic systems are not being installed at a rate that is equal to population growth.

AGRICULTURE

Methods and emissions factors used in the 2015 inventory were unchanged, however the source of activity data as measured in number of animals was updated with newly published figures from the 2017 Agriculture Census (USDA, 2019).

LAND USE

The King County Assessor's office supplied data on new residential construction. We used previous equations and carbon storage assumptions to model emissions.

POTABLE WATER

Previous inventories did not quantify emissions from potable water as a separate category, but rather as part of the overall community energy use. Potable water emissions are already included elsewhere because emissions are due to electricity use, and thus cannot be summed or these emissions would be double-counted with emissions derived from electrical use. However, by attributing GHG emissions to such processes, this report seeks to provide additional granularity on what processes are responsible for GHG emissions. Groundwater pumping, a source of energy use, was not applicable because King County derives potable water from surface water. Emissions from residential wells are included in the built environment category. The quantity of water conveyed was multiplied by a national kWh/gallon factor within the U.S. Community Protocol to determine energy use. The quantity of surface water (all water for public water for King County) was multiplied by a national kWh/gallon factor within the U.S. Community Protocol to determine energy use. Energy use was then summed and multiplied by the SCL emissions factor to derive emissions related to potable water. Seattle Public Utilities reported water use (Seattle Public Utilities, 2012).

Data Sensitivity to Local Conditions

In the King County 2017 greenhouse gas inventory, some values are associated with locally-derived data, and thus are sensitive to changes in policy within King County and between King County and larger-scale jurisdictions (i.e. Washington state or national). Other values are based on national or regional data, and thus may not accurately reflect King County progress or programmatic influence. In this section, we briefly discuss data sources within the King County greenhouse gas inventory and their associated sensitivity to local influence.

Table 9. Summary of data sensitivity to local conditions for the King County 2017 communitywide inventory

Inventory sector or source	Percent of total 2017 emissions	Values are sensitive to local conditions	Values are sensitive to local conditions, with some exceptions	Values are based on scaled regional/state data	Values are based on scaled national data
Electricity	30%		✓		
Natural Gas	23%	✓			
Petroleum heating	2%			✓	
Non-road equipment/vehicles	6%				✓
Steam	1%	✓			
Industrial processes	2%		✓		
Fugitive gas	N/A*				✓
On-road vehicles (incl. transit)	33%		✓		
Rail	0.15%		✓		
Marine vessels	.33%		✓		
Solid waste	1%	✓			
Potable water	0.005%		✓		
Wastewater	0.4%	✓			
Agriculture	1%	✓			
Soil management	N/A*		✓		
Residential development	N/A*	✓			

**Supplementary emissions are not included in the "Core + Production" inventory total.*

Overall, the major emissions categories for King County—electricity, natural gas, and on-road vehicles—are sensitive to local conditions. Once exception is line loss estimations for electricity, which adds 8% to total electricity emissions and is based on regional grid estimates. Collectively, these categories account for 75% of King County's 2017 emissions.

The largest emissions source that may not be sensitive to local conditions is from non-road equipment and vehicles, which makes up 6% of King County's total 2017 emissions.

Sensitivity, by Sector

RESIDENTIAL

Electricity emissions data is derived from emission factors and consumption data for two local providers, Seattle City Light and Puget Sound Energy, and are thus sensitive to local changes in fuel mix and electricity use. Line loss estimations, however, are based on regional values, and thus overall electricity emissions are mixed in their sensitivity to local conditions.

Emissions associated with **natural gas** are calculated with a nationally derived emissions factor and local usage data provided by PSE. These numbers are **sensitive** to local activity.

Petroleum heating emissions are derived from a statewide value of oil-heated homes that is scaled to King County by population and a national emissions factor. These numbers are **not sensitive** to local activity.

Petroleum (non-road) emissions estimates are produced by the NONROAD module of the EPA MOVES model, which calculates emissions based on a nationally built model that provides county-specific outputs. These numbers are **not sensitive** to local activity.

COMMERCIAL

Electricity emissions data is derived from emission factors and consumption data for two local providers, Seattle City Light and Puget Sound Energy, and are thus sensitive to local changes in fuel mix and electricity use. Line loss estimations, however, are based on regional values, and thus overall electricity emissions are mixed in their sensitivity to local conditions.

Emissions associated with **natural gas heating** are calculated with a nationally derived emissions factor and local usage data provided by PSE. These numbers are **sensitive** to local activity.

Natural gas equipment emissions estimates are produced by the NONROAD module of the EPA MOVES model, which calculates emissions based on a nationally built model that provides county-specific outputs. These numbers are **not sensitive** to local activity.

Petroleum heating emissions are derived from a statewide value of oil-heated homes that is scaled to King County by population and a national emissions factor. These numbers are **not sensitive** to local activity, but do reflect regional trends

Petroleum equipment emissions estimates are produced by the NONROAD module of the EPA MOVES model, which calculates emissions based on a nationally built model that provides county-specific outputs. These numbers are **not sensitive** to local activity.

Steam emissions from Enwave are reported to the Puget Sound Clean Air Agency. Emissions are from local data and thus are **sensitive** to local activity and fuel mix.

INDUSTRIAL

Electricity emissions data is derived from emission factors and consumption data for two local providers, Seattle City Light and Puget Sound Energy, and are thus sensitive to local changes in fuel mix and electricity use. Line loss estimations, however, are based on regional values, and thus overall electricity emissions are mixed in their sensitivity to local conditions.

Process Emissions are associated with local manufacturing of certain products (e.g., cement, glass, steel) and are based on national emission factors and local manufacturing data. Emissions data are **sensitive** to local activity.

Stationary Combustion is based on local use of natural gas, petroleum scaled from statewide data by the proportion of industrial employees, and outputs from the NONROAD module of the EPA MOVES model. Although the natural gas consumption is locally-specific, the petroleum and MOVES data are not, and thus the overall reported value is **not sensitive** to local conditions.

Fugitive gas emissions are mixed. The majority of fugitive emissions—**refrigerant** emissions—are scaled from a national value reported by the EPA, are thus not sensitive to local activity. **Switchgear insulation** SF_6 emissions data, however, are based on utility-specific reporting and are thus sensitive to local conditions. Because SF_6-dervied GHG emissions are relatively small, however, this sector is largely not sensitive to local conditions.

TRANSPORTATION

On-road vehicle activity and fuel mix are county-specific and modeled by the Puget Sound Regional Council using local data. These emissions are **sensitive** to local change, though the use of scaling and interpolation between years makes these values less certain

Truck freight and service vehicle activity and fuel mix are modeled by the Puget Sound Regional Council using local data. These emissions are **sensitive** to local trends.

Transit vehicle activity and fuel mix are derived from local fuel data and fuel mix. These emissions are **sensitive** to local change.

Freight Passenger and Rail data was taken from the Puget Sound Clean Air Agency (PSCAA) 2016 Maritime Air Emissions Inventory report (Starcrest Consulting, 2018) and scaled to 2017 by tonnage. This data is based on activity data from local providers. While not year-specific, this data source has captured significant efficiency gains in the sector from 2011 to 2016.

Marine data were obtained from three sources: The NONROAD module of EPA MOVES, Washington State Department of Transportation (WSDOT), and the 2016 Puget Sound Maritime Air Emissions Inventory. The extent to which MOVES modeled **pleasure craft emissions** are sensitive to local conditions is low.

WSDOT ferry fuel expenditures were used to determine ferry emissions, and thus are sensitive to local conditions. Emissions from ocean-going vessels were based on local port data, but were then scaled one year from the 2016 to 2017, and thus are not entirely reflecting of local conditions. Overall, marine emissions are mixed in their sensitivity to local conditions in the target year.

Off-road vehicles and other mobile equipment emissions estimates are produced by the NONROAD module of the EPA MOVES model, which calculates emissions based on a nationally built model that provides county-specific outputs. These numbers are **not sensitive** to local activity.

SOLID WASTE

Generation and disposal of solid waste were calculated by applying local waste composition and tonnage values to the EPA WARM v14 model. Emissions factors in the WARM model were modified to reflect local waste transport-related emissions and landfill methane recovery rates. These emissions are thus **sensitive** to local conditions.

Emissions from **operation of solid waste disposal facilities** are based on locally measured or modeled landfill emissions, and are thus **sensitive** to local conditions.

WATER AND WASTEWATER

Potable water emissions are based on US Community Protocol assumptions of energy use per unit water consumed. Electricity emission factors and water use statistics are from local sources. Although energy use per unit water may change with time, this analysis is generally **sensitive** to local activity as a function of the quantity of water consumed.

Wastewater process emissions are based on local wastewater treatment facility treatment processes and population served, and are thus **sensitive** to local activity.

AGRICULTURE

Domesticated animal production emissions are based on county animal populations measured by the US Census Bureau and nationally accepted emission factors, and is thus **sensitive** to local activity.

Manure decomposition emissions are based on local animal populations measured by the US Census Bureau and nationally accepted emission factors, and is thus **sensitive** to local activity.

SUPPLEMENTARY EMISSION SECTORS

Soil management emissions are based on EPA emission factors and county-specific cropland statistics from the US Census Bureau. Although the emission factors are not sensitive to local conditions, the basis on county-specific activity data makes these emission values fairly **sensitive** to local conditions.

Residential development emissions were derived from local King County data and are thus **sensitive** to local activity.

Contribution Analysis

Introduction

Contribution analysis is a way to discover the reasons for change between two inventories separated in time. King County participated in the project *Analyzing Drivers of Change in Greenhouse Gas Emissions Inventories*, Co-led by the City of Bellevue and ICLEI USA – Local Governments for Sustainability, which developed a methodology and tool for contribution analysis. This project resulted in a contribution analysis for 2008-2015 emissions using a beta version of the tool.

This updated contribution analysis for 2008-2017 emissions was conducted using the tool available at http://icleiusa.org/ghg-contribution-analysis/ .

Results

In 2008, total emissions (including supplementary sectors) were 20.36 million $MgCO_2e$. In 2017, total emission were 20.07 million $MgCO_2e$, resulting in a 1.4% decrease (289,800 $MgCO_2e$) from the 2008 value. The decomposition analysis (Figure 8 and 13) shows that multiple, significant pressures on the GHG inventory worked in opposition to each other to yield this relatively modest net change.

Figure 12 provides a summary with the three largest factors increasing emissions, and the three largest factors decreasing emissions. The remaining increases and the remaining decreases are combined together. Emissions increases are primarily driven by growth in population and commercial buildings. Increased efficiency of passenger vehicles (decreased emissions per mile) was the largest contributor to decreasing emissions. Decreased industrial energy use and more efficient electricity use by households also contributed significantly to decreasing emissions.

Figure 8: Top contributions to change between the 2008 and 2017 total GHG inventories for King County.

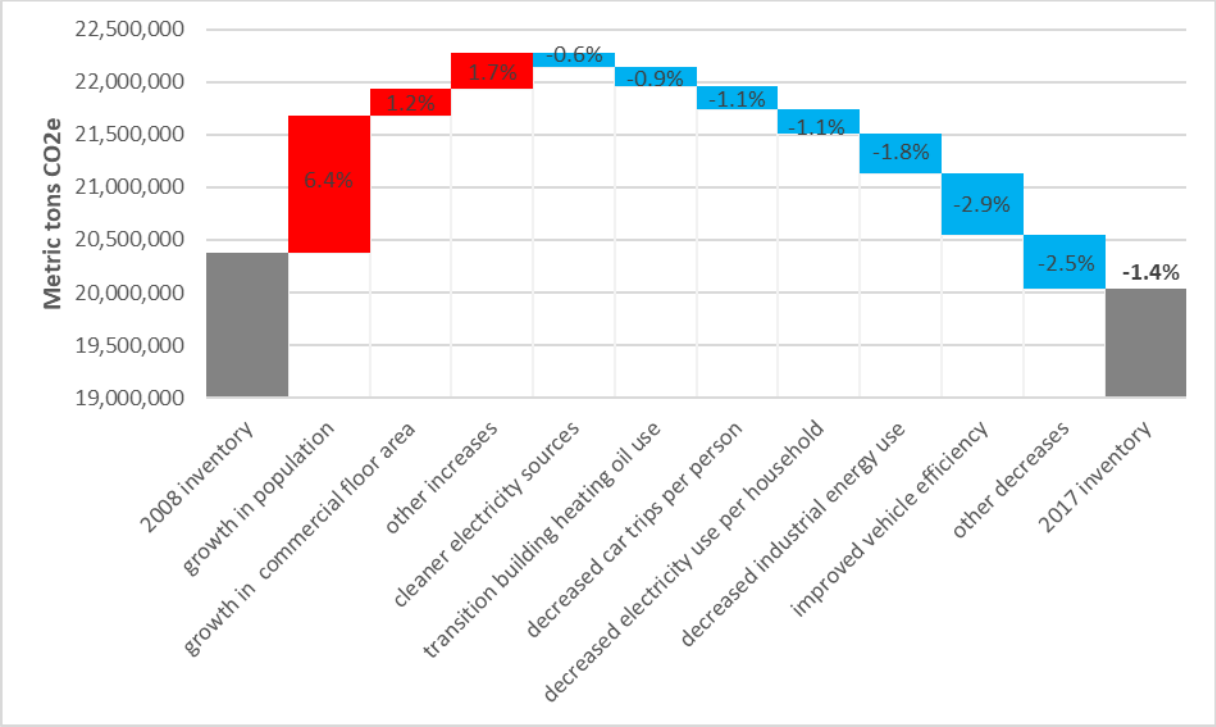


Figure 13: Detailed contributions to change between the 2008 and 2017 total GHG inventories for King County.

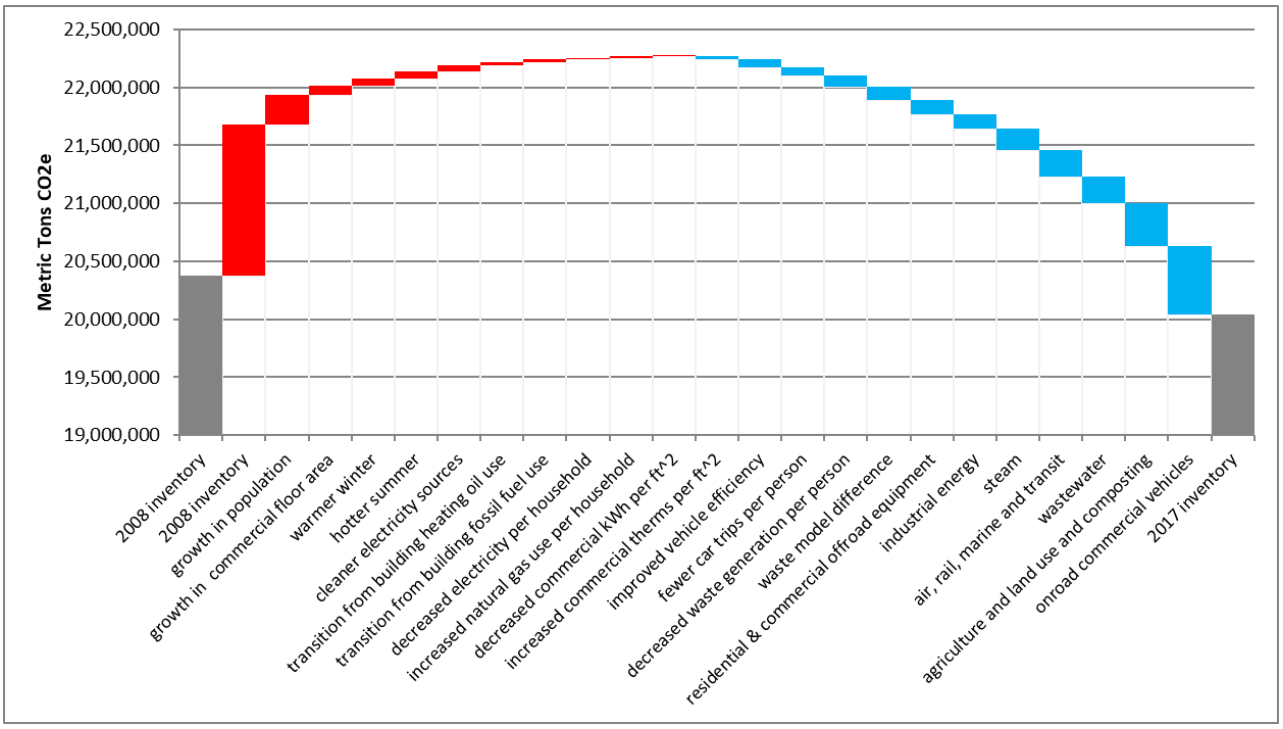


Figure 13 shows a detailed breakdown of the factors contributing to increases and decreases, as listed below.

INCREASES:

Population (+1,302,000 $MgCO_2e$ / +6.4%) includes the impacts of increased housing, increased driving, and increased solid waste generation driven by King County's growing population. King County's population increased 14% from 1.89 million in 2008 to 2.12 million in 2017.

Commercial floorspace (+252,000 $MgCO_2e$ / +1.2%) increases with growth in business activity in King County and drives increased consumption of energy for heating, cooling, lighting, and other building energy.

Industrial process and fugitive (+81,000 $MgCO_2e$ / +0.4%) this increase was driven primarily by increased use of HFCs in refrigeration/air conditioning systems, fire suppressants, and foam manufacture. This data is based on national averages and King County's population and may not reflect local changes.

Onroad commercial vehicles (+66,000 $MgCO_2e$ / +0.3%) is the total change in emissions from this source, which was not subject to further decomposition.

Increased natural gas use per household (+58,000 $MgCO_2e$ / +0.3%) is the net remaining change after accounting for weather, and for the percent of households shifting from fuels to electricity for heating. This change is likely influenced by multiple positive and negative factors, including consumer behavior, changes in average home size, and changes to building and equipment efficiency.

Air, transit, marine, and rail (+54,000 $MgCO_2e$ / +0.3%) is the total change in emissions from these forms of transportation. They are not subject to decomposition, so the bar shows the total change in their emissions, driven in part by population, economic growth, and additional, minor factors.

Residential and commercial offroad equipment (+27,000 $MgCO_2e$ / +0.1%) is the total change in emissions from this equipment. This data comes from the EPA MOVES model which downscales national data and may not reflect local changes.

Increased commercial therms per square foot (+24,000 $MgCO_2e$ / +0.1%) is the net remaining change after accounting for weather. This change is likely influenced by multiple positive and negative factors, including occupant behavior and building equipment and controls.

Hotter summer (+14,000 $MgCO_2e$ / <0.1%) is the effect of hotter weather increasing electricity demand for cooling in residential and commercial buildings.

Wastewater treatment (+10,000 $MgCO_2e$ / <0.1%) is the total change in emissions from this source.

Waste model difference (+6,000 $MgCO_2e$ / <0.1%) is the difference between the change in solid waste disposal emissions as modeled in the inventories, and the change as modeled within the contribution analysis tool.

DECREASES:

Steam (-29,000 $MgCO_2e$ / -0.1%) is decreased fuel use in district heating systems. This is the total change in emissions from this source, which was not subject to further decomposition.

Agriculture and land use and composting (-67,000 $MgCO_2e$ / -0.3%) is the net change for these sources.

Transition buildings from fossil fuel use (-70,000 $MgCO_2e$ / -0.3%) as a higher percentage of households use electric heating, emissions decrease because of the efficiency of heat pumps and the relatively clean electricity supply in the region.

Warmer winter (-103,000 $MgCO_2e$ / -0.5%) is the decreased demand for heating fuels and electricity because of warmer winter weather.

Decreased commercial kWh/square foot (-112,000 $MgCO_2e$ / -0.5%) is the net remaining change after accounting for weather. This change is likely influenced by multiple positive and negative factors, including occupant behavior and building equipment and controls.

Decreased waste generation per person (-122,000 $MgCO_2e$ / -0.6%) is the impact of less waste per person sent to landfill.

Cleaner electricity sources (-124,000 $MgCO_2e$ / -0.5%) is the impact of shifting to cleaner electricity generation sources.

Transition buildings from heating oil use (-185,000 $MgCO_2e$ / -0.9%) is a shift of residential and commercial uses from fuel oil to relatively cleaner natural gas.

Decreased car trips per person (-225,000 $MgCO_2e$ / -1.1%) represents the change in driver behavior leading to less gasoline use per person.

Decreased electricity use per household (-233,000 $MgCO_2e$ / -1.1%) represents the changes in behavior and building stock resulting in reduced residential electricity usage. This is the net remaining change after accounting for weather and transition of building heating from fossil fuels to electricity.

Decreased industrial energy use (-366,000 $MgCO_2e$ / -1.8%) represents the emissions reduction from combined industrial electricity, natural gas, and other fuel usage.

Improved vehicle efficiency (-595,000 $MgCO_2e$ / -2.9%) is the reduction in emissions associated with reduced gasoline consumption in newer vehicles meeting more stringent federal standards.

Discussion

King County's GHG inventory is swayed by population growth, economic growth, weather, utility fuel mix, and federal fuel economy standards, all of which fall outside the direct control of local government.

From 2008 to 2017, King County saw a net 1.4% decrease in emissions as a result of significant positive and negative drivers working against each other. In fact, all of the positive forces when combined are over 9% of the inventory in size, counterbalanced with similarly sized negative forces. Population and commercial sector growth were the primary drivers increasing emissions, on their own creating a 7.6% increase. Several of the other increasing factors are also associated with population and economic growth, although the impact of population on them was not specifically analyzed. These include: industrial process and fugitive, onroad commercial vehicles, air, transit, marine and rail, residential and commercial offroad equipment, and wastewater treatment.

On the reduction side, a variety of factors working together were needed to overcome the impact of growth. Greater efficiency, both for vehicles and for electricity use in residential and commercial buildings is a particularly important contributor. Decreased emissions from industrial energy use may reflect increased efficiency, or may be more driven by economic changes in production and types of industries—there is not sufficient data to determine this. Decreases in vehicle miles per person and waste sent to landfill per person were also important. Finally, a shift to cleaner fuels both in electricity generation and in buildings, made a modest contribution to reductions.

If we compare historical changes from 2008 to 2017 with the wedge model scenario described in the next section, most indicators, such as kWh per household, VMT per person, electricity fuels mix, and vehicle emissions per mile are moving in the right direction, but the rate of change for each indicator will need to be significantly accelerated to meet emissions reduction goals.

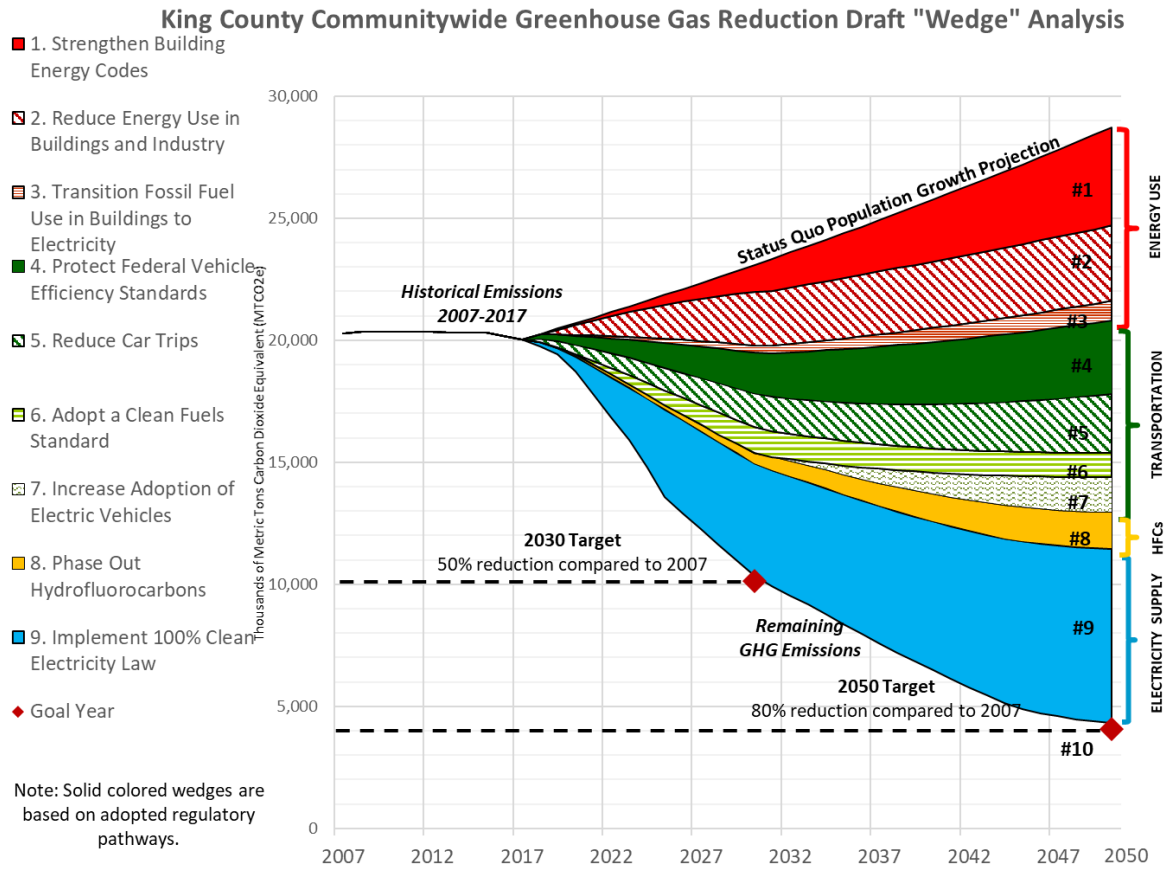
Wedge Analysis

Introduction

The wedge analysis forecasts emissions from 2017 through 2050 under a business as usual scenario and then models the impact of nine reduction actions over that time period. The actions were developed to cumulatively achieve County and shared Growth Management Planning Council's countywide emission reduction goals to reduce emissions 50% from 2007 baseline emissions in 2030, and by 80% in 2050. The estimated collective impact of the actions is a 49% reduction in 2030 and 79% in 2050. This wedge analysis covers all geographic-based King County community scale emissions sources.

For the business as usual projection, the analysis uses a 1.1% per year population growth estimate which is derived from the Puget Sound Regional Council's Vision 2050. This growth rate is applied to all countywide GHG sources.

Figure 14: Wedge analysis results



Actions

Building Energy Efficiency

1. **Strengthen Building Energy Codes (Washington State Building Energy Code for new buildings).** State Energy Code requires buildings constructed from 2013 to 2031 move incrementally toward a 70% reduction in energy use from a 2006 baseline by 2031, and zero fossil fuel usage by 2031.
    - **Note:** 2015 code is taken as business as usual case for this measure. Reduction applied is a 44% reduction from 2015 energy code usage in 2031. Remaining fossil fuel use of new buildings in 2031 is transitioned to electricity, after the 44% reduction is applied.
    - **Note:** 2018 state energy code will mark the halfway point when the code will have reduced new building energy use by about 35%

2. **Reduce Energy Use in Buildings and Industry.** Reduce energy use of existing residential and commercial buildings 25% by 2030 and 50% by 2050.
    - **Note:** This largely maintains the existing 2030 target in the 2015 SCAP and K4C Joint Climate Action Commitments. The new 2050 target is developed as part of this modeling exercise.
    - **Note:** Excludes buildings with major retrofit that would trigger energy code (these reductions are attributed to the "Strengthen Energy Code" wedge).

3. **Transition Fossil Fuel Use in Buildings to Electricity (existing buildings).** Transition residential and commercial natural gas use to electricity (e.g. heat pumps). Transition 20% of fossil fuel use by 2030, 50% by 2040 and 80% by 2050. Applied to remaining natural gas, fuel oil and propane usage after energy code and existing building efficiency actions.
    - **Note:** This is a new pathway and target. 2030 and 2050 targets are consistent with those also considered as part of Carbon Neutral Implementation Plan for County facilities.

Transportation

4. **Protect Federal Vehicle Efficiency Standards** (also known as Corporate Average Fuel Economy standards). Federally required fuel efficiency improvements to light duty, medium, and heavy duty vehicles.
    - **Note:** Does not include any assumed improvements past 2035.

5. **Less Car Trips (Vehicle Miles Traveled (VMT) Reductions).** 20% total reduction from 2017 baseline light duty vehicle VMT by 2030. Then reduction in light duty per-capita VMT to 50% below 2017 baseline by 2050. No change from base case for medium or heavy duty vehicle VMT.
    - **Note:** This largely maintains the existing 2030 target in the 2015 SCAP and K4C Joint Climate Action Commitments. The new target for 2050 is based on WA State VMT reduction requirements.
    - **Note:** Does not include reductions in medium or heavy duty vehicle VMT

6. **Adopt a Clean Fuels Standard.** 20% reduction in transportation fuels emissions intensity (CO2 per MMBtu) between 2021 and 2030. Applied to fuel use after federal fuel economy standards and VMT reduction. Applied to light, medium and heavy duty on-road vehicles and to offroad equipment.

- **Note:** 20% target and timeline originates from June 2019 discussions of likely target scenarios from Puget Sound Clean Air Agency staff
- **Note:** Half of the target is assumed to be achieve through vehicle electrification and the other half is assumed to be achieved from use of lower GHG intensity liquid fuels

7. **Electric Vehicle Adoption.** Growth in EVs as percent of new light duty vehicle (LDV) sales from 7% (actual) in 2018 to 100% in 2035 which results in 21% of LDVs being electric in 2030 and 100% electric in 2050. Additionally, in 2035 50% of new Medium Duty Vehicle (MDV) sales and 28% of new Heavy Duty Vehicles (HDVs) sales are electric, ramping up over time to achieve a fleetwide percentage of 60% electric MDVs and 40% electric HDVs in 2050.
    - **Note:** Emissions reduction from EV adoption only shows up when it exceeds that required through the low carbon fuel standard, as described in wedge #6.
    - **Note:** MDV and HDV pathways are aligned with "optimal targets for electrification outlined in *Meeting the Challenge of Our Time: Pathways to a Clean Energy Future for the Northwest*.
    - **Note:** Residential and commercial off road equipment assumed to follow the LDV pathway and industrial and construction off road equipment assumed to follow the HDV pathway.
    - **Note:** EV wedge shows emissions with 2017 electricity generation mix. Additional emissions reduction from powering EVs with clean electricity is included in "Implement the 100% Clean Electricity Law".

Hydrofluorocarbons

8. **Phase Out Hydrofluorocarbons (HFCs).** WA House Bill 1112 requires the phase out of high global warming potential HFCs as refrigerants and foaming chemicals by 2024.
    - **Note:** 20 year lifetime assumed for existing equipment using HFCs.
    - **Note:** Motor vehicle air conditioning HFC phase out (approx. 21% of US HFC emissions) are included in the estimate but is contingent on another state enacting a similar regulation.

Clean Electricity

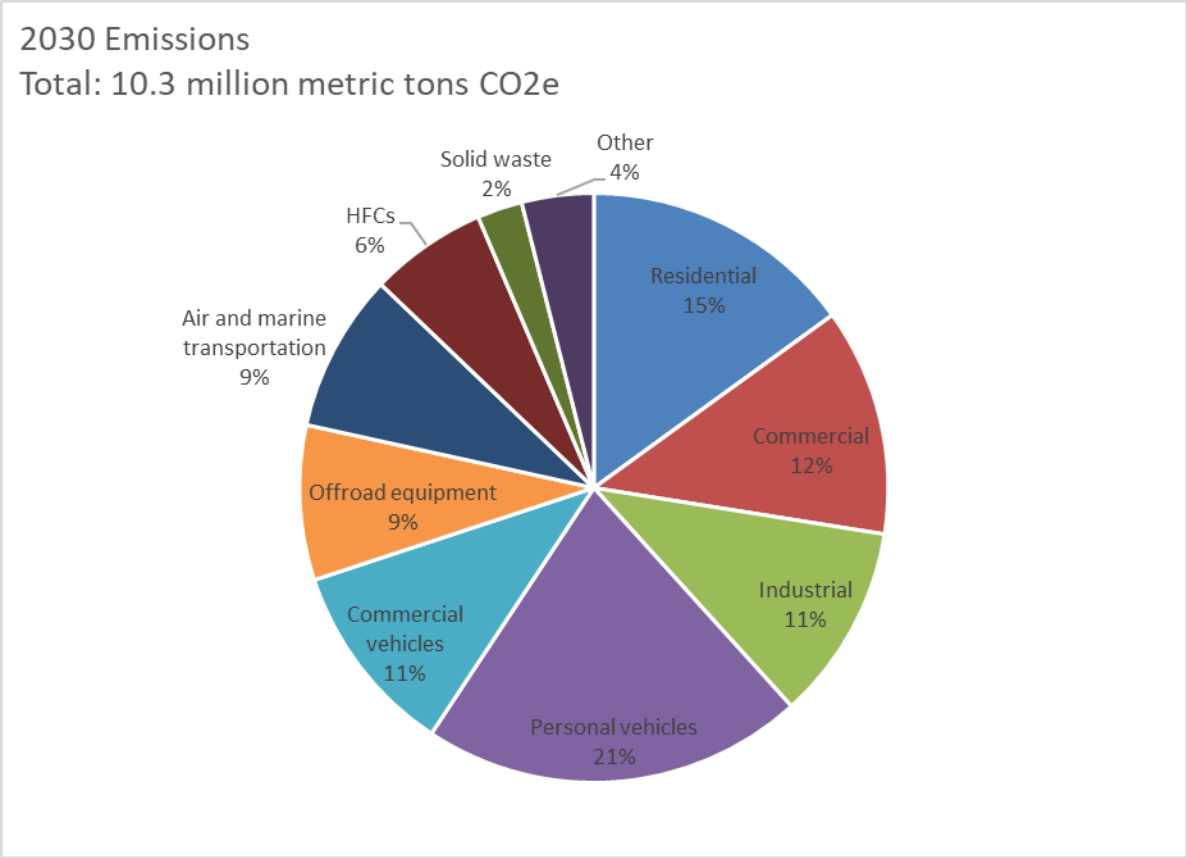
9. **Implement 100% Clean Electricity Law (WA renewable portfolio standard and 100% Clean Electricity Legislation - SB 5116).**
    - **Note:** Renewables increase to 15% by 2020 as required by existing Washington State Renewable Portfolio Standard.
    - **Note:** By 2020, Colstrip Coal Power Plant Units #1 and #2 are closed, replaced with half natural gas and half clean energy. By 2023 Colstrip Units #3 and #4 are closed. Transalta coal power plant in Centralia is closed by 2025. Coal decreases to 0% of PSE's portfolio in 2025.
    - **Note:** In 2025, natural gas is at 40% of PSE's portfolios and renewables are 29% (excluding hydro). Natural gas decreases gradually to 20% in 2030, with additional renewable sources making up the difference. Then a slower linear increase in renewables decrease in natural gas generation to 0% by 2045.

Remaining Emissions

In 2030, the largest source of emissions under this scenario will be personal vehicles, representing about 20% of 2030 emissions, followed by residential fuels (11%) and commercial vehicles (10%), as shown in

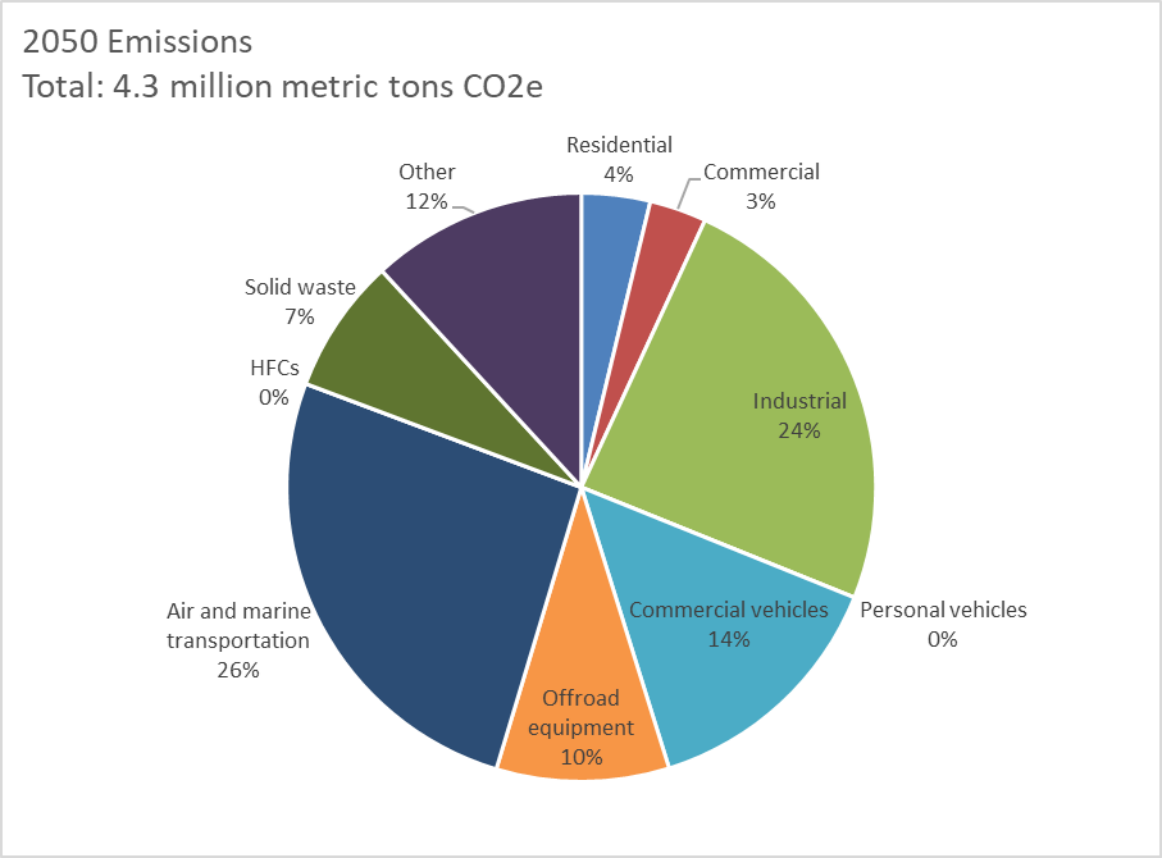
Figure 15. Emissions associated with electricity use (across residential, commercial and industrial sectors) will decrease from 28% of the 2017 inventory to 10% in 2030.

Figure 15: 2030 emissions with reduction scenario



In 2050, the largest source of remaining emissions will be air and marine transportation (26% of 2050 emissions), followed by commercial vehicles (14%), as shown in Figure 16. Industrial processes, industrial fuels and 'other' each contribute 12% of 2050 emissions ('other' includes land use change, agriculture, and wastewater treatment emissions). Emissions from electricity use and from personal vehicles are completely eliminated, while emissions from residential and commercial fuels are greatly decreased (4% and 3% of 2050 emissions, respectively).

Figure 16: 2050 emissions with reduction scenario



Conclusion

From 2008 to 2017, King County saw a net 1.4% decrease in geographic plus based GHG emissions. The contribution analysis shows that a substantial emissions increase from population growth was offset by a combination of multiple emissions decreases. These include greater efficiency, both for vehicles and for electricity use in residential and commercial buildings, decreased emissions from industrial energy, decreased vehicle miles per person and waste sent to landfill per person, and a shift to cleaner fuels both in electricity generation and in buildings.

While most indicators, such as kWh per household, VMT per person, electricity fuels mix, and vehicle emissions per mile are moving in the right direction, the rate of change for each indicator will need to be significantly accelerated to meet emissions reduction goals. The wedge analysis shows the level of change in each sector that will need to be needed in order to achieve emissions reductions in line with goals of a 50% reduction by 2030 and an 80% reduction by 2050. Four of the nine actions modeled are already enacted as Washington State or Federal policy. But additional local action is needed, particularly to drive building efficiency and reductions in VMT per person, and to promote a switch to electricity to replace fossil fuels in both vehicles and buildings.

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