Oregon's Greenhouse Gas Emissions through 2015:

An assessment of Oregon's sector-based and consumption-based greenhouse gas emissions

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Greenhouse Gas Reporting Program and Materials Management
700 NE Multnomah St.
Suite 600
Portland, OR 97232
Phone: 503-229-5696
800-452-4011
Fax: 503-229-5850
www.oregon.gov/DEQ

DEQ is a leader in restoring, maintaining and enhancing the quality of Oregon's air, land and water.

State of Oregon
Department of Environmental Quality

This report prepared by:

Oregon Department of Environmental Quality
700 NE Multnomah Street, Suite 600
Portland, OR 97232
1-800-452-4011
www.oregon.gov/deq

Contacts:

Oregon Department of Environmental Quality
David Allaway, allaway.david@deq.state.or.us
Elizabeth Elbel, elbel.elizabeth@deq.state.or.us
Colin McConnaha, mcconnaha.colin@deq.state.or.us

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Report authors:

- David Allaway, Elizabeth Elbel and Colin McConnaha, Oregon Department of Environmental Quality
- Graphs produced by Minal Mistry, Oregon Department of Environmental Quality

Additional contributors:

- Elaine Blatt, Martin Brown, Peter Canepa, Laura Gleim, Julie Miller, Minal Mistry, Babe O'Sullivan, Bill Peters, Jeffrey Stocum, Stephanie Summers and Chris Swab, Oregon Department of Environmental Quality
- Robbie Andrew and Glen Peters, CICERO Center for International Climate and Environmental Research, Oslo, Norway
- David Bael and Madalyn Cioci, Minnesota Pollution Control Agency
- Vincent Combreco and Mausami Desai, U.S. Environmental Protection Agency
- Leslie Wilson, Kyle Diesner and Lauren Norris, City of Portland Bureau of Planning and Sustainability
- Michael Deru, National Renewable Energy Laboratory
- Mickey Francis and Tom Lorenz, U.S. Energy Information Administration
- Massoud Jourabchi, Northwest Power and Conservation Council
- Lesley Jantarasami, Oregon Department of Energy
- Elizabeth Stanton, Applied Economics Clinic at Tufts University Global Development and Environment Institute

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Executive Summary

Increasing atmospheric concentration of greenhouse gases caused by emissions from human activities is leading to global climate change[1]. To understand Oregon's contribution to climate change we must understand the contributions of Oregon and Oregonians to global emissions of greenhouse gases. This report includes greenhouse gas emissions data compiled by the Oregon Department of Environmental Quality and a discussion of the key drivers and recent trends in these data. To better understand the extent to which Oregon contributes to climate change, we account for the emissions physically occurring within the state and the emissions occurring globally as a result of what we consume.

Oregonians generate emissions directly from activities such as cooking dinner, driving cars and heating homes. We also indirectly cause greenhouse gases to be emitted in other areas of the world when we purchase electricity, goods or food manufactured in other states or countries. In acknowledgment of these different ways we contribute to global emissions, DEQ regularly updates estimates of statewide greenhouse gas emissions in two ways:

- **Sector-based inventory:** Emissions produced in Oregon from its transportation, residential, commercial, industrial and agriculture sectors, including electricity produced elsewhere but used in state.

- **Consumption-based inventory:** Emissions produced around the world due to Oregon's consumption of energy, goods and services.

The sector-based inventory is the traditional method for tracking Oregon's emissions, and is similar to the methods many other states and countries use. The consumption-based inventory is a less common method and is increasingly being used by local governments to better understand how the choices and behaviors of their residents impact climate change. Both inventories allow us to understand how we contribute to emissions and how this is changing over time. This report covers annual sector-based emissions from 1990 through 2015, with preliminary 2016 data, and consumption-based emissions for 1990, 2005, 2010 and 2015[2].

Findings

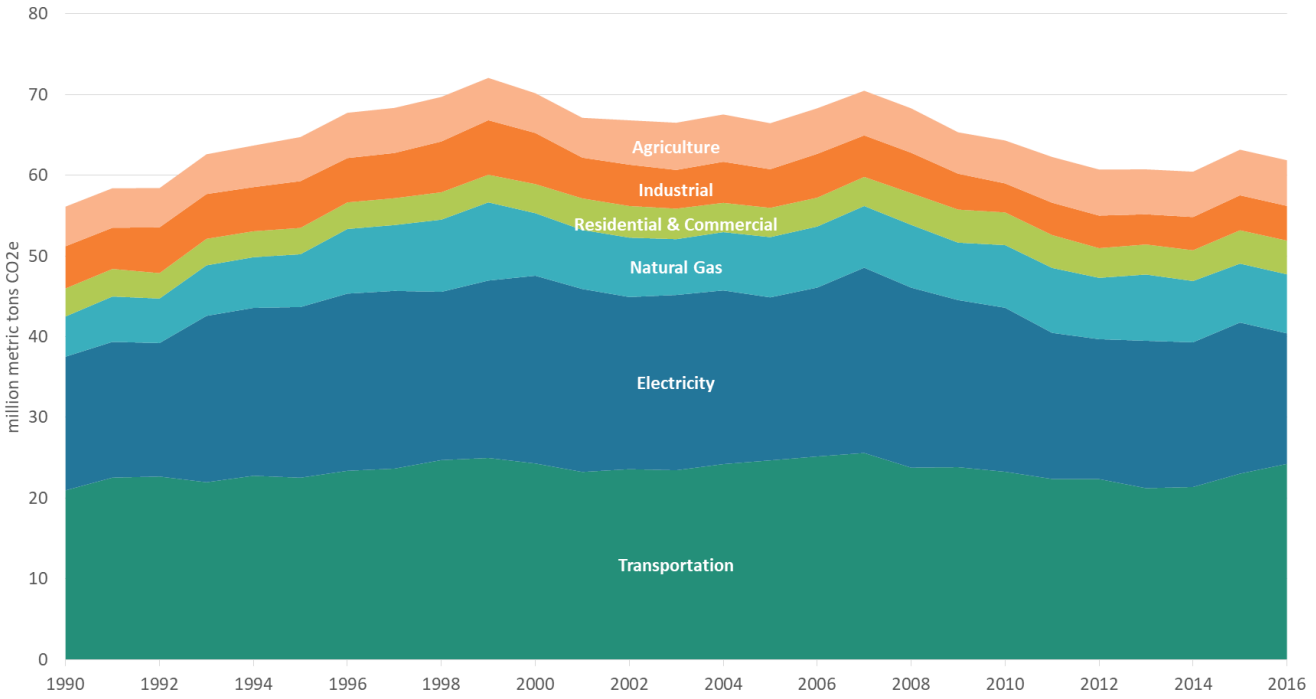
Sector-based inventory

Figure ES.1 portrays Oregon's sector-based emissions from 1990 through 2015 and preliminary 2016 emissions data. The graph illustrates trends in emissions in this period within key sectors, including emissions from the generation of electricity used in Oregon, regardless of where that electricity was generated. For example, a portion of electricity used in Oregon is generated at coal and natural gas facilities located outside of the state. Emissions from the generation of that electricity are included in this inventory. In 2015, sector-based emissions were 63 million metric tons of carbon dioxide equivalent ($MTCO_2e$). Statewide emissions declined from 2007 through 2012 but recent data do not indicate a continuation of that downward trend. Transportation continues to be Oregon's largest in-state contributor to emissions and accounted for 36 percent of the sector-based total in 2015. In fact, transportation emissions have risen during each of the past three years. The second largest in-state contributor is electricity, with the residential sector creating the greatest demand. Emissions from electricity use in any given year reflect both the impact associated with the demand for electricity and the influence of the availability of hydroelectricity, Oregon's largest source of zero-emitting energy.

[1] IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

[2] As is common practice with greenhouse gas emissions accounting, the emissions data presented in this report has been recalculated based on the best available and most current data. For this reason data in this report may differ from previous versions of the inventories.

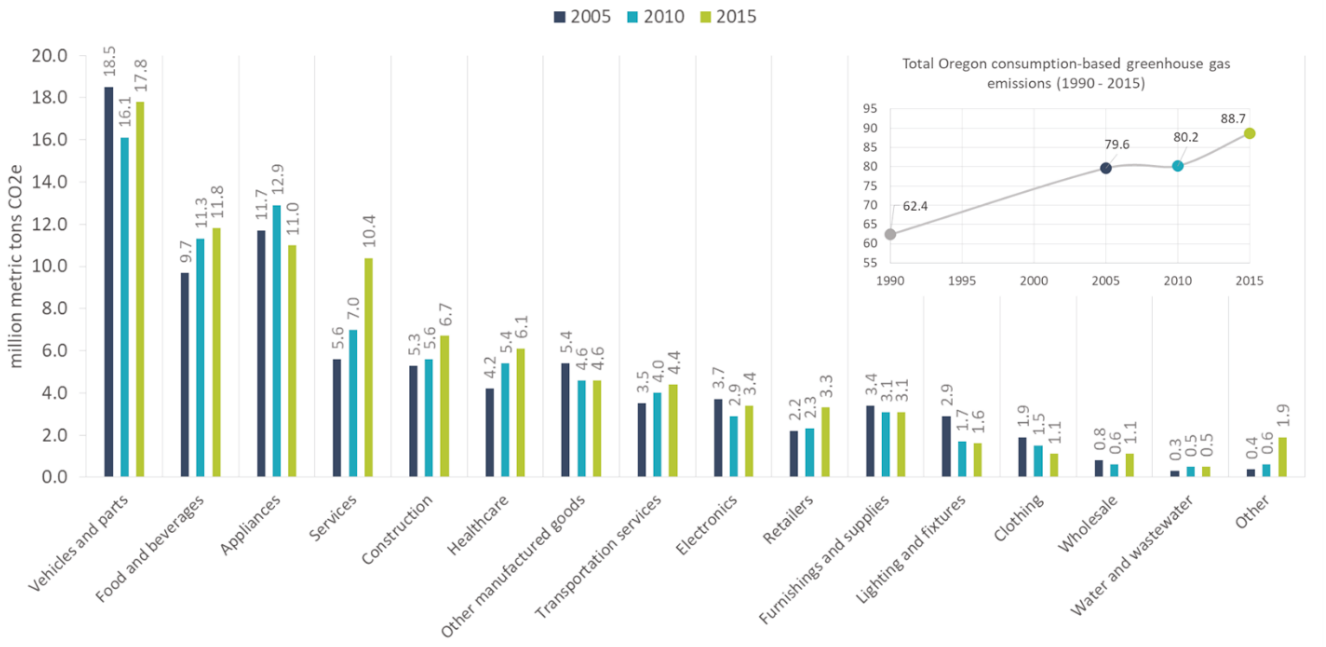
Figure ES.1
Statewide sector-based greenhouse gas emissions 1990-2016



Consumption-based inventory

Oregon's consumption-based greenhouse gas emissions in 2015 were 89 million $MTCO_2e$. The production and use of vehicles, food, and appliances (primarily for heating and cooling) contribute the most to these emissions, followed by emissions from construction, healthcare and other services, such as real estate, entertainment, and education. The consumption-based inventory takes a "cradle to grave" approach, accounting for total emissions resulting from producing and distributing a product, using the product, and disposing of the product. Figure ES.2 illustrates how these and other emissions have changed between 1990 and 2015, with a more detailed focus on the period 2005 - 2015.[3]

Figure ES.2
Consumption-based emissions by major category, 2005 - 2015



Comparison

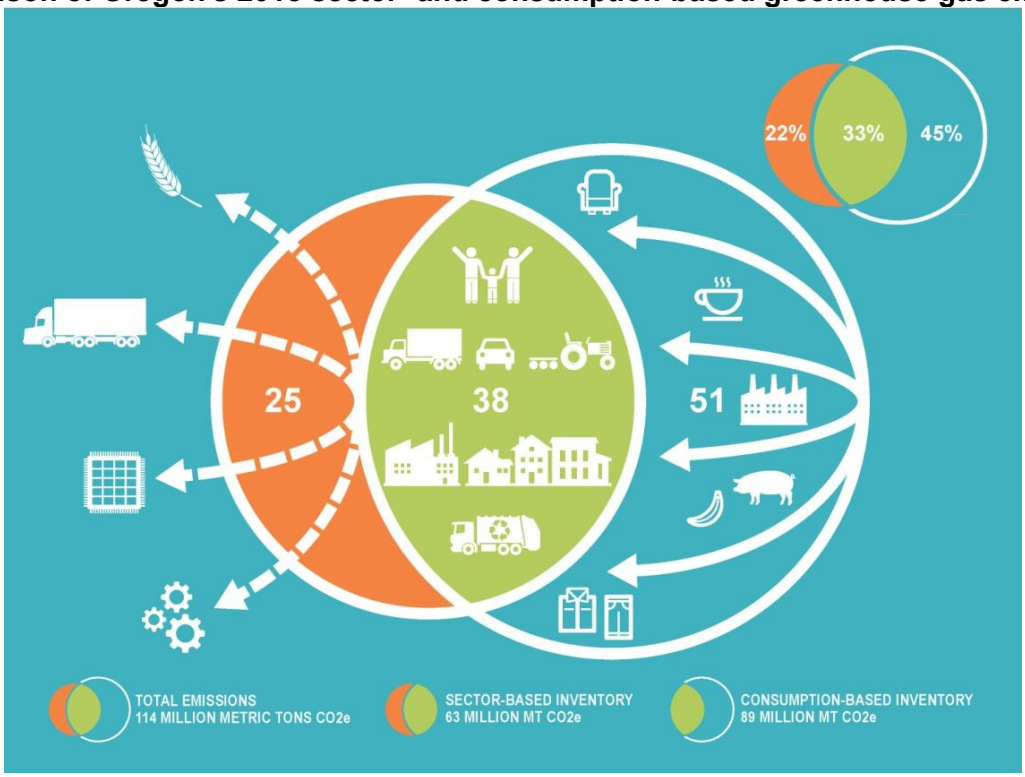
Figure ES.3 illustrates the relationship between the two inventories. Sector-based emissions for 2015 were approximately 63 million $MTCO_2e$. Consumption-based emissions were 89 million $MTCO_2e$. The inventories share about 38 million $MTCO_2e$ in common. These shared emissions are from household and government use of energy and waste disposal, as well as emissions associated with businesses producing goods in Oregon that are consumed in Oregon.

The sector-based inventory also includes emissions from the production of goods in state for sale elsewhere (exports)—the supply side of the economy—while the consumption-based inventory includes the emissions from the consumption of goods that are produced elsewhere (imports)—the demand side of the economy.

When viewed together, the two inventories provide a broader understanding of Oregon's emissions. However, the ability to consider each inventory independently from the other is essential for understanding sources of emissions and unique opportunities for reducing them.

[3] DEQ has generated detailed estimates of consumption-based greenhouse gas emissions for calendar years 2005, 2010 and 2015. A separate estimate for 1990 is not as detailed and is not broken out by the categories shown in Figure ES.2; nevertheless it provides an initial estimate of Oregon's consumption-based emissions for 1990.

Figure ES.3
Comparison of Oregon's 2015 sector- and consumption-based greenhouse gas emissions



Key Findings

Results from Oregon's two greenhouse gas inventories indicate that Oregon's contribution to global concentrations of greenhouse gases is not subsiding. The combustion of fossil fuels, whether occurring within Oregon or as a result of our consumption, is the key driver of greenhouse gas emissions.

Highlights:

- Transportation is Oregon's largest in-state sector of emissions.
- Emissions from passenger vehicle use and freight transportation are increasing.
- The purchase and use of vehicles and parts is the largest category in the consumption-based inventory.
- Households are responsible for 80 percent of consumption-based emissions meaning individual choices and behaviors overwhelmingly influence global emissions.
- Oregon's residential sector uses more electricity than any other sector.
- Lower-income households on average consume less and generate fewer emissions than higher-income households.

Oregon has goals in statute to reduce in-state emissions 10 percent below 1990 levels by 2020 and 75 percent below 1990 levels by 2050. To evaluate our progress towards these goals and make recommendations to the Legislature the Oregon Global Warming Commission primarily utilizes data from the sector-based inventory. However, assessing the consumption-based inventory relative to the goals identifies additional opportunities to reduce emissions, and helps to ensure that emission reductions occurring within Oregon, as a result of state policy, are true global reductions and Oregon is not simply shifting emissions to locations outside of the state.

DEQ's latest inventory data indicates that our current trend is not on track to achieve levels at or below 1990 levels. Total sector-based emissions are 10 percent above 1990 levels while consumption-based emissions are 42 percent higher than 1990 levels and rising. DEQ will continue to monitor Oregon's greenhouse gas emissions in future years to track the trajectory and identify key contributors to global greenhouse gas emissions.

1. Greenhouse Gas Emissions Accounting

1.1 Overview

This report is a DEQ update to the multi-agency technical report previously published on Oregon's greenhouse gas emissions through 2010. DEQ regularly updates statewide greenhouse gas emissions data in two ways, through the statewide sector-based greenhouse gas inventory (formerly referred to as the in-boundary inventory) and the consumption-based greenhouse gas inventory. The inventories have overlapping but different scopes of emissions. The dual approach to inventorying emissions provides a more comprehensive overview of Oregon's contributions to global greenhouse gas emissions and how those emissions change over time. This report discusses each inventory in detail, reviewing the scope and methods of each approach and presenting and comparing 2015 emissions data, the most recent finalized statewide data.

- **Sector-based inventory:** Emissions produced in Oregon from its transportation, residential, commercial, industrial and agriculture sectors, including electricity produced elsewhere but used in state.

- **Consumption-based inventory:** Emissions produced around the world due to Oregon's consumption of energy, goods and services.

1.2 Why inventory emissions?

Oregon's greenhouse gas inventories are developed to characterize and quantify the anthropogenic (human-caused) greenhouse gas emissions resulting from activities occurring in Oregon and actions taken by Oregonians that contribute to global climate change. These emissions estimates inform strategies and help the Oregon Global Warming Commission track progress toward goals in emission reductions. Oregon's current greenhouse gas emission reduction goals are:

- By 2010, Oregon will arrest the growth of greenhouse gas emissions and begin to reduce emissions
- By 2020, Oregon will achieve greenhouse gas levels that are 10 percent below 1990 levels, and
- By 2050, Oregon will achieve greenhouse gas levels that are at least 75 percent below 1990 levels.

In order to incorporate best available data and methodology, DEQ periodically updates these inventories so that the most up-to-date information is provided to Oregon's residents, businesses and policy-makers. These updates also allow Oregon to better understand changes in emissions relative to different drivers like policy, the economy and changes in population. This data is also the basis for statewide greenhouse gas emission projections. These projections create a foundation to better understand how policy and programs implemented now might affect emissions in the future.

These inventories also allow Oregon to meet sub-national reporting commitments making Oregon a national and global partner committed to better understanding global greenhouse gas emissions. DEQ annually reports statewide sector-based emissions to the Carbon Disclosure Project, which compiles global data on greenhouse gas emissions. Starting in 2017, data from the sector-based inventory is used to inform Oregon's commitment to The United States Climate Alliance, a coalition of states committed to reducing greenhouse gas emissions consistent

with the Paris Agreement[4]. Both the sector- and consumption-based statewide inventories also inform numerous local inventories developed at the community scale across Oregon.

1.3 Organization of this report

This chapter concludes with an introduction to greenhouse gas accounting and a comparison of the two inventory methods. Chapters Two and Three summarize data sources and high-level results of the sector- and consumption-based inventories, respectively. Additional details regarding results (including data tables) and methodologies are provided in the appendices. Chapter Four quantifies the overlap between the two inventories and compares trends and changes in the two inventories over time.

1.4 Greenhouse gas accounting

The sector-based and consumption-based inventory each encompass a unique scope of emissions. Together, they provide a more comprehensive accounting of Oregon's global contribution to greenhouse gases.

International greenhouse gas inventory accounting methods were originally developed so that inventories could be aggregated at sub-national, national and international levels. To prevent double counting, jurisdictions reported emissions using an "in-state production basis" approach, which included only emissions occurring within the reporting entity's jurisdictional boundary. Over time and in response to recommendations on improved inventory practices, Oregon modified the in-state production model to include emissions resulting from the generation of electricity used in Oregon, regardless of where that electricity was generated. A portion of the electricity used in Oregon is produced in other states, including through coal and natural gas combustion. The rationale for this change is that it more accurately reflects the impacts of state policy, like energy efficiency and renewable power requirements, on overall emissions. This approach for many years was referred to as Oregon's "in-boundary" inventory. With this report, DEQ changed the name to the "sector-based" inventory, a term more commonly used to describe the scope of emissions included in this inventory.

As our understanding of emissions and Oregon's impact continued to evolve, it became apparent that the sector-based inventory, while very useful, was conveying an incomplete perspective of how Oregonians contribute to emissions. Greenhouse gases are a global pollutant, and a kilogram of carbon dioxide emitted in Shanghai or St. Louis has the same impact on Oregon's climate as the same pollutant emitted in Salem or Sisters. Consumption by Oregonians serves as a root driver of emissions both in-state and elsewhere. In 2011, Oregon published the nation's first sub-national "consumption-based" greenhouse gas emissions inventory, which illustrates emissions occurring globally as a result of consumption by Oregonians. The consumption-based inventory shares some sources in common with the sector-based inventory but includes production and disposal emissions generated outside of the state associated with imported fuels, materials and services. While neither of the inventories offers a complete account of Oregon's emissions, the two inventories together provide a more comprehensive understanding of how the state contributes to global climate change. Table 1.1 summarizes and compares technical aspects of both inventories.

Oregon's sector-based inventory tracks anthropogenic emissions occurring within Oregon's key sectors, including agriculture, industry, residential and commercial operations and transportation. Emissions from electricity use, natural gas use and waste are estimated and apportioned to the key sectors. This method is closely aligned with conventional greenhouse gas accounting methods such as those utilized by the US Environmental Protection Agency (EPA) to develop the national greenhouse gas inventory. The sector-based inventory is utilized by the Oregon Global Warming Commission to evaluate progress toward meeting emission reduction goals, to review the performance of key sectors and to better understand how sectors interact.

[4] The United States Climate Alliance is a coalition of governors committed to reducing greenhouse gas emissions consistent with the Paris Agreement, aiming to reduce greenhouse gas emissions by at least 26-28 percent below 2005 by 2025.

The consumption-based inventory estimates global emissions resulting from Oregon's consumption. Here, emissions are organized by type of consumption (such as vehicles, food, appliances and clothing) and represent emissions over the complete life-cycle of the material, energy or service in question. These life-cycle emissions include supply chain, production, transportation, wholesale/retail, use and post-consumer disposal. Emissions in Oregon's sector-based inventory are included in the consumption-based inventory only to the extent that they ultimately result from activities that satisfy consumption (economic final demand) by Oregon. In-state emissions associated with producing goods or services that are exported (for final consumption elsewhere) are excluded from the consumption-based inventory, while imports (associated with final consumption by Oregonians) are included.

Together the two inventories provide information on Oregon's overall contribution to global climate change. These approaches also ensure that emission reductions occurring within Oregon as a result of local policy are true global reductions and Oregon is not simply shifting emissions to locations outside of the state. Looking at emissions through these two perspectives broadens our understanding of the sources of emissions and offers a wider range of emission reduction opportunities when compared to a single inventory approach.

Table 1.1
Sector- and Consumption-based technical comparison

	Sector–based	Consumption–based
General description	In-state emissions from residential, commercial, industrial, agriculture, waste. Emissions from electricity use in Oregon.	Globally-distributed emissions associated with satisfying consumption (economic final demand) by Oregon.
Inventory years available	1990-2015 and preliminary 2016	Detailed inventory for 2005, 2010 and 2015; estimate for 1990
Gases included	Fossil CO2, CH4, N2O and High Global Warming Potential gases (HFCs, PFCs, SF6, NF3)	Fossil CO2, CH4, N2O and High Global Warming Potential gases (HFCs, PFCs, SF6, NF3)
Treatment of biogenic CO2 & land use change	Not included	Not included
Transportation	Emissions from in-state use (sales) of transportation fuels by all users (Oregonians, pass-through travel); tailpipe/combustion emissions only (not life-cycle)	Life cycle emissions of: fuel used in vehicles by Oregon households and government; purchase of transport services (e.g., airline tickets) by Oregon households and government; all transportation emissions associated with the movement and supply chains of goods and services consumed
Electricity	Emissions at the points of electric power generation for all electricity used in Oregon.	Worldwide life-cycle emissions of electricity used directly by Oregon households and governments (but not businesses), and all electricity used in the provision and supply chains of goods and services consumed by Oregon
Treatment of other sources	All other in-state sources are included (e.g., heating fuels, industrial process emissions, fertilizer and landfill emissions)	Includes worldwide emissions of heating fuels used by Oregon households and governments; solid waste produced by Oregon households and governments; all other emissions from supply chains of goods and services consumed in Oregon
Primary data sources	DEQ Greenhouse Gas Mandatory reporting requirements, EPA State Inventory Tool	Oregon sector-based inventory, U.S. GHG inventory (EPA), CICERO global trade and emissions model, IMPLAN economic model, Oregon Clean Fuels Program, Northwest Power and Conservation Council, numerous federal agencies (Federal Highway Administration, Energy Information Administration, Bureau of Labor Statistics, Federal Aviation Administration, etc.)

2. Sector-Based Inventory

2.1 Introduction

Oregon's sector-based inventory estimates anthropogenic (human-caused) emissions occurring within Oregon by economic sector. These include transportation, industrial, residential, commercial and agriculture sectors and include emissions from stationary and transportation related fuel combustion, waste, industrial processes, natural gas distribution, and the use of high global warming potential (HGWP) gases such as refrigerants and aerosols. For the electricity sector, this inventory includes emissions associated with the electricity used in Oregon regardless of where that electricity is generated. Electricity emissions are estimated and apportioned to the industrial, residential, commercial and transportation sectors based on use. This report includes the most currently available sector-based information with finalized statewide data from 1990 through 2015 and preliminary estimates for 2016.

The sector-based emissions inventory accounts for anthropogenic carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and high global warming potential gases (HGWP) including hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6) and nitrogen trifluoride (NF_3). Because these different gases have different climate impacts, all are expressed on the basis of CO_2 equivalent (CO_2e). The accounting methods utilize Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) global warming potentials (GWP) using a 100-year time horizon, as currently recommended by the United Nations Framework Convention on Climate Change (UNFCCC). The sector-based inventory accounts for anthropogenic greenhouse gas emissions and does not include carbon dioxide emissions from biomass and biofuel, which is considered biogenic (related to the natural carbon cycle). Biogenic carbon is accounted for separately from the sector-based emissions inventory through the accounting of emissions and sequestration in land use, land use change and forestry known as net carbon flux[5].

Data in the sector-based inventory is compiled by integrating reported data from DEQ's Greenhouse Gas Reporting Program, waste emissions estimates from DEQ's Materials Management section and modeled emissions estimates from EPA's State Inventory Tool (SIT). The SIT is the primary source of emissions estimates for all years prior to the inception of the reporting program (1990 through 2009). For subsequent years, the SIT remains the primary source of emissions estimates for sources that do not report directly to DEQ, such as agriculture. The SIT emissions are estimated utilizing a "top down" approach in which modeling and estimation of emissions relies on the disaggregation of national data covering energy, industry, agriculture, population and socioeconomics.

Starting with the 2010 emission year, data collected through DEQ's Greenhouse Gas Reporting Program became the primary source of data used to compile the inventory. The reporting program annually collects greenhouse gas emissions information from major emitting sources in Oregon, including industrial facilities with air quality permits, fuel distributors, natural gas and electricity suppliers and large landfills. Since these data are reported directly from the emitting source and verified by the program, it is considered a "bottom-up" source of information and is state specific. Approximately 80 percent of the annual emissions in the inventory for 2010 through 2016 are derived from data reported directly to DEQ. These data are reported and published independently of the inventory by DEQ and is often available up to a year earlier than any of the SIT modeled estimates.

The integration of the modeled and reported data have allowed DEQ to update the sector-based inventory on an annual basis. Emissions are recalculated for the entire time series, 1990 through the most current year, based on

[5] In 2016 the Oregon Global Warming Commission established The Forest Carbon Task Force, a subcommittee focused on improving Oregon's understanding of natural carbon flux and the accounting of biogenic carbon.

the best available data and estimation methodology. Recalculation is best practice in international greenhouse gas inventory management and allows for DEQ to maintain a consistent time series of data. It's important to note that for this reason, historic data in the published inventory may vary from version to version. DEQ's website maintains the most up-to-date version of greenhouse gas emissions data. Details on the underlying data sources for the sector-based inventory and charts found in this section are available in Appendix A of this report.

2.1.1 An explanation of "preliminary" emissions data

DEQ frequently receives requests to provide the most up-to-date inventory data available and in response has developed a preliminary data compilation methodology that integrates the most recently available reported data from the Greenhouse Gas Reporting Program with EPA's most current SIT modeled estimates. Since EPA's tool requires extensive updates to many different data sets and emission factors, its results are often released a year to two years behind DEQ's verified reported data. For example, as of January 2018, the most recent version of the SIT provides estimates through 2015 while DEQ has verified reported data through 2016. To create a preliminary 2016 statewide emissions value, those portions of the inventory not directly reported to DEQ utilize 2015 proxy data from the SIT. More specifically, for this report DEQ integrated 2016 reported data for the industrial, natural gas, electricity and fuel sectors with the most recent data outputs from EPA's SIT model, utilizing 2015 data for the agriculture sector, a portion of the high global warming potential gases and a few small sources in other sectors. When an updated version of the SIT becomes available, DEQ will update and finalize 2016 emissions for all sectors.

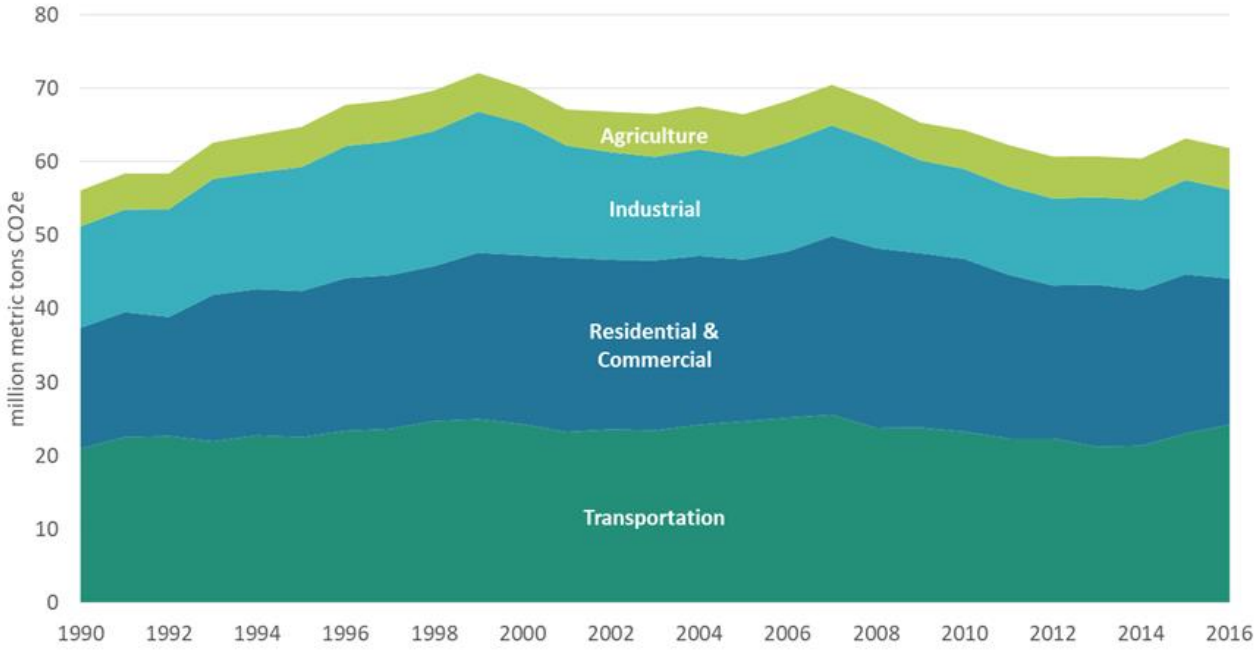
2.2 Classification of emissions and statewide data

In 2015 Oregon's sector-based anthropogenic emissions totaled to 63 million $MTCO_2e$. Oregon's emissions are approximately one percent of the world's second largest global emitter, the United States, emitting emissions equivalent to countries like Portugal and Ireland[6]. Oregon has experienced an increase in emissions within the transportation, residential, commercial and agriculture sectors when compared to 1990 levels and a small decrease within the industrial sector within the same time period. While Oregon's emissions have decreased slightly since 2007 that trend has not continued in recent years and Oregon's 2015 emissions are still 10 percent higher than 1990 levels.

An overall statewide emissions number provides a summary of emissions on an annual basis allowing us to better understand the trajectory of emissions for the state and to compare overall progress toward emission reduction goals. However, a total value does not provide details on the key drivers of emissions or reduction opportunities. For this reason, it is useful to review emissions by sector and examine the underlying drivers of emissions and energy use within each sector. Emissions within the transportation, residential/commercial and industrial sectors include the sector share of electricity use, fuel combustion, emissions from waste and high global warming potential gases (HGWP) emitted from activities originating in that sector. The transportation sector includes emissions from all mobile combustion including emissions from all highway, aviation and non-road vehicles (including farm equipment). The agriculture sector includes greenhouse gas emission unique to soil, animal rearing and farm waste management. Figure 2.1 displays Oregon's emissions by key sector from 1990 through 2016.

[6] World Resource Institute CAIT Climate Data Explorer. (2014). Total GHG Emissions Excluding Land-Use Change and Forestry Per Capita-2014. Retrieved from http://cait.wri.org/

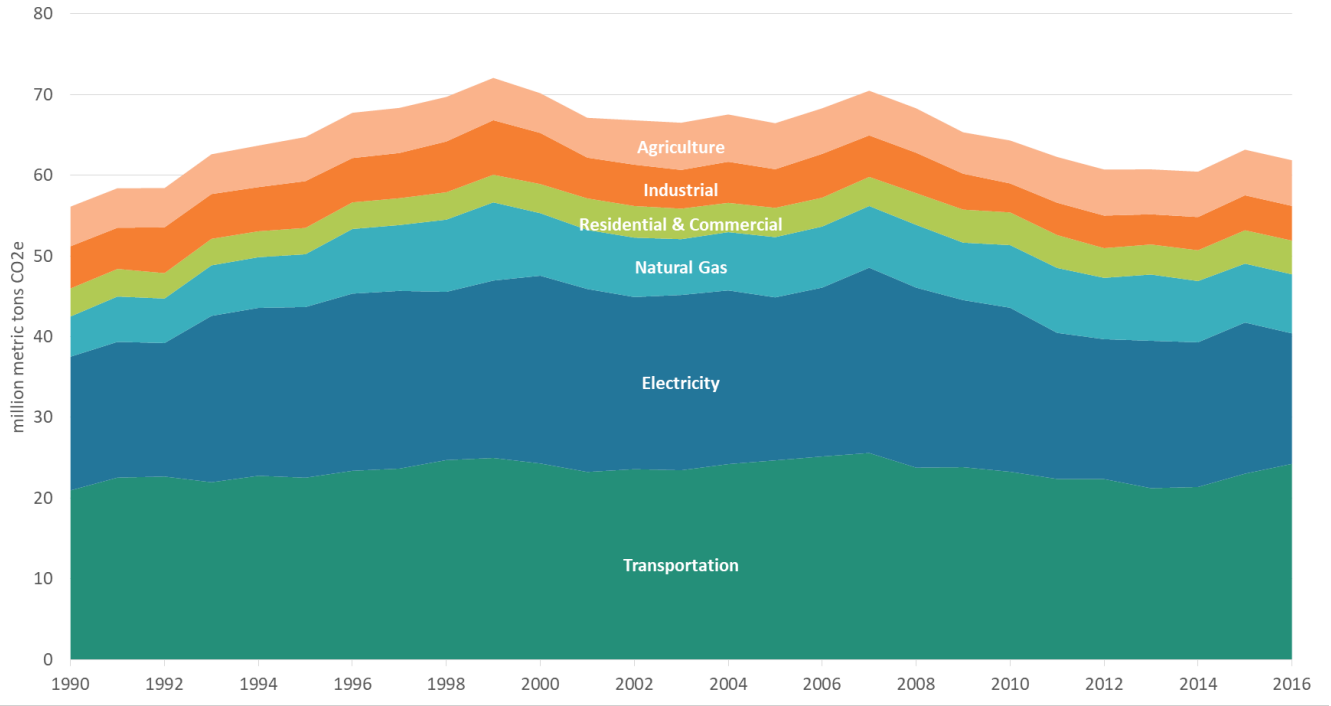
Figure 2.1
Statewide emissions by sector 1990-2016



The largest share of emissions originates from fuel combustion in Oregon's transportation sector followed by emissions from the residential and commercial sector, industrial and finally agriculture.

Within the transportation, industrial, residential and commercial sector the primary driver of greenhouse gas emissions is fossil fuel combustion. This includes fuel combusted to generate heat and electricity in the residential, commercial and industrial sector and fuel to power vehicle engines in the transportation sector. Figure 2.2 highlights the influence of emissions from energy use by creating a different view of statewide emissions, breaking out and aggregating electricity and natural gas emissions from all sectors. When viewed this way transportation is still Oregon's largest sector of emissions, however the influence of emissions from electricity use and natural gas combustion is more visible.

Figure 2.2
Emissions with electricity and natural gas aggregated for all sectors 1990-2016



While Oregon's emission reduction goals apply to in-state total annual emissions, as Oregon's population grows it is also helpful to understand emission trends from a population perspective. Oregon's population has increased 43 percent since 1990 while in-state emissions per capita have decreased in the same time period[7]. Since 2011, Oregon's in-state production emissions per capita have stayed relatively flat, around 13 $MTCO_2e$ per person[8].

EPA estimates that U.S. national per capita emissions are higher and closer to 20 metric tons per person[9]. In general, developed countries like the U.S. tend to have higher per capita emissions while countries that are developing have a higher rate of emissions growth[10]. For example, China, the world's largest emitter of greenhouse gas emissions, has per capita emissions of approximately 8 metric tons per person[11].

[7] Portland State University Population Research Center. (July, 2017) Certified Population Estimates July 1, 2017. Retrieved from https://www.pdx.edu/prc/population-reports-estimates
[8] Total in-state production emissions differ from the sector-based emissions discussed in this chapter for the electricity sector. In-state emissions do not include emissions from imported power but do include emissions from electricity generated in Oregon and exported. In-state production emissions align more directly with national production emissions for a per capita comparison.
[9] United States Environmental Protection Agency. (April 13, 2017). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015. Retrieved from https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2015.
[10] Union of Concerned Scientists. (November 20, 2017). Each Country's Share of CO2 Emissions. Retrieved from https://www.ucsusa.org/global-warming/science-and-impacts/science/each-countrys-share-of-co2.html#.WmJyBbynFEZ
[11] World Resource Institute CAIT Climate Data Explorer. (2014). Total GHG Emissions Excluding Land-Use Change and Forestry Per Capita-2014. Retrieved from http://cait.wri.org/

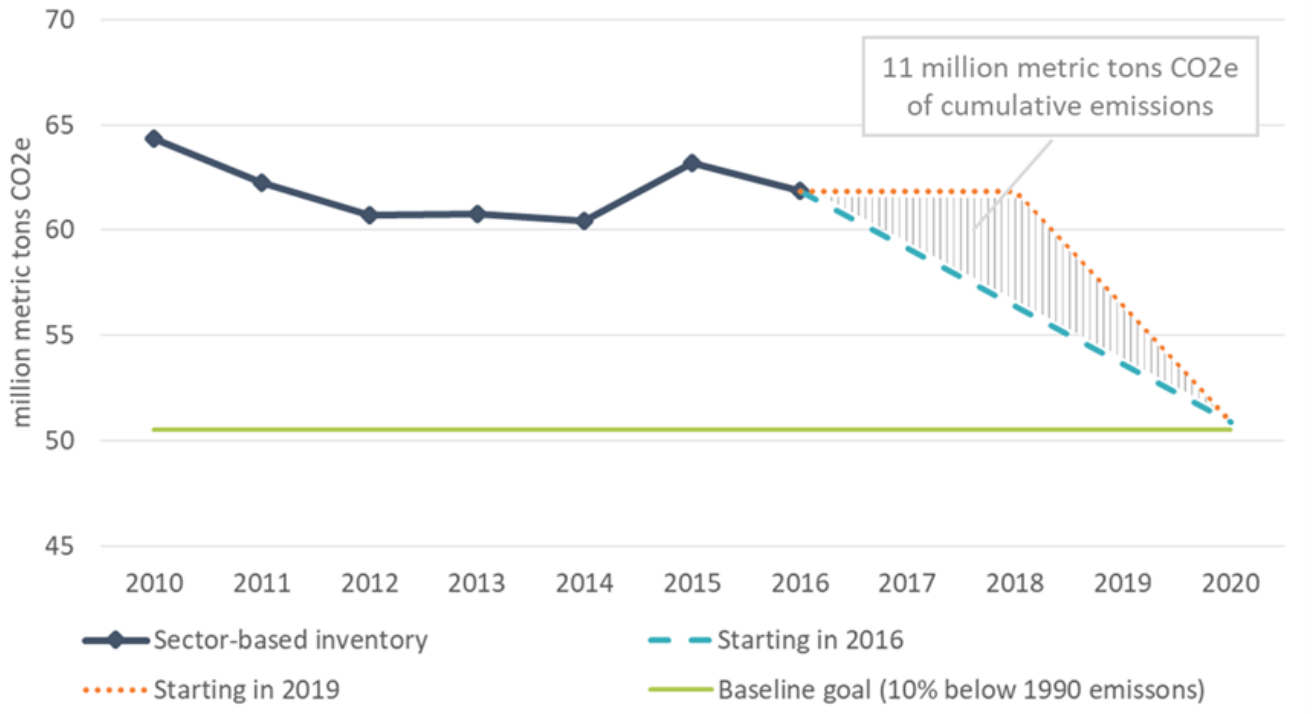
2.2.1 Cumulative emissions

Oregon's cumulative emissions for the sector-based inventory time period, including all anthropogenic emissions emitted from 1990 through 2016, total 1.75 billion $MTCO_2e$. Although traditional accounting methods and Oregon's greenhouse gases emission reduction goals focus on annual emissions, greenhouse gases persist in the atmosphere and influence the climate for long periods of time. Emissions occurring in 1990 still have an impact on our climate. Since the effects on Earth's climate stem from the overall concentration of emissions in the atmosphere and not just what is emitted in a single year it is important to acknowledge both our current and historic contribution to global concentrations.

Viewing emissions from a cumulative approach also allows us to better understand how the timing and trajectory of emission reductions affect our ability to reduce global concentrations of greenhouse gases. Delaying emissions mitigation results in a need for a more rapid decline in emissions in later years while more immediate action allows for a less steep trajectory to meet the same targets.

Figure 2.3 illustrates the impacts of an emission reduction trajectory on annual reduction requirements and cumulative emissions. To meet Oregon's 2020 goal of 10 percent below 1990 levels, Oregon needs to reduce emissions by 11 million $MTCO_2e$, from an estimated 62 million $MTCO_2e$ in 2016 to 51 million $MTCO_2e$ in 2020. A steady reduction over that time period requires an annual reduction of approximately 3 million $MTCO_2e$ to achieve the goal. If emission reductions are delayed until 2019, Oregon would need to annually reduce emissions by more than 5 million $MTCO_2e$ in 2019 and again in 2020 to achieve the same goal. In addition to a more gradual reduction, the scenario in which mitigation starts in 2016 actually reduces cumulative emissions during that time period by 11 million $MTCO_2e$ when compared to the delayed reduction scenario.

Figure 2.3
Emission reduction trajectories for scenarios beginning 2016

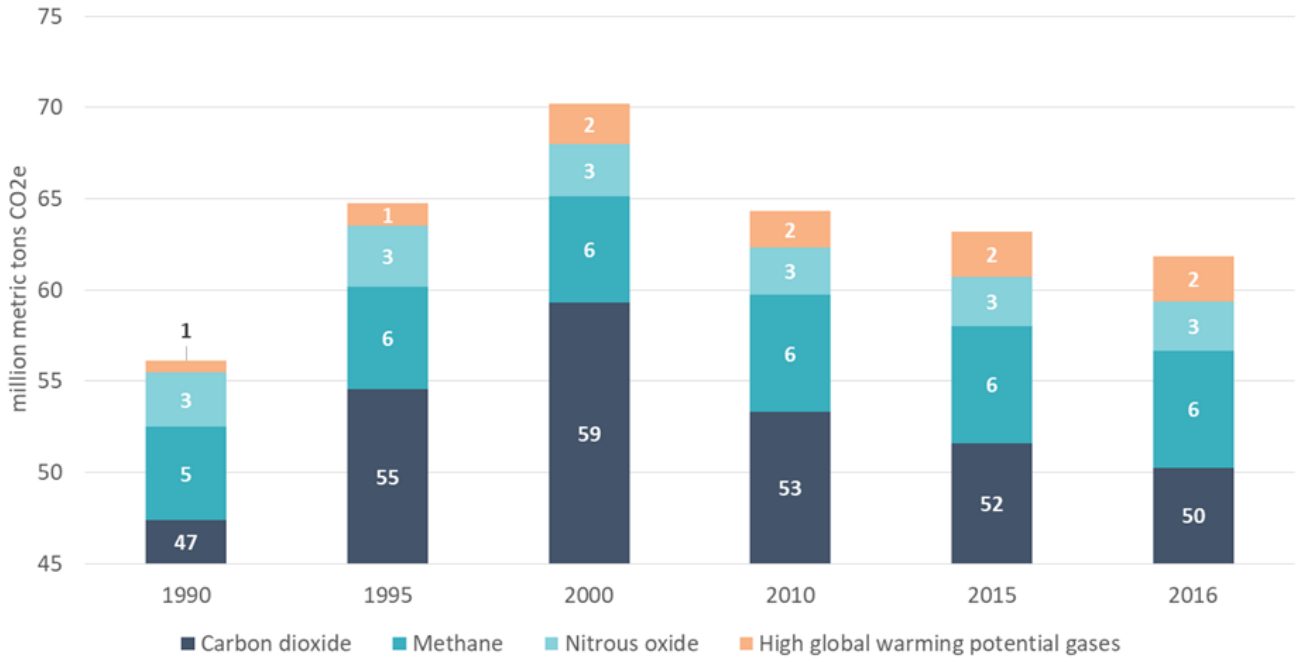


2.2.2 Emissions by greenhouse gas

Figure 2.4 represents Oregon's greenhouse gas emissions by individual gas including carbon dioxide, methane, nitrous oxide and high global warming potential gases. Carbon dioxide comprises approximately 80 percent of statewide emissions and primarily originates from fossil fuel combustion in vehicle engines and to generate electricity. The second highest emissions are of methane, which comprises approximately10 percent of the statewide sector-based total. Methane is primarily a result of agricultural activities but also originates from landfills and natural gas distribution.

Over time the relative contributions from carbon dioxide, methane, and nitrous oxide have stayed relatively constant while the share of HGWP gases has grown from 1 percent of statewide emissions in 1990 to 4 percent of emissions in 2016. Although HGWP gases are emitted in small quantities, their climate impact is significant due to their long atmospheric lifetimes and their ability to trap heat in the atmosphere, which is hundreds to thousands of times higher than that of carbon dioxide[12].

Figure 2.4
Statewide greenhouse gas emissions by gas over time



[12] DEQ utilizes Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment (AR4) 100-year Global Warming Potentials to quantify greenhouse gas emissions in accordance with the most current accounting guidance from the United Nations Framework Convention on Climate Change (UNFCCC).

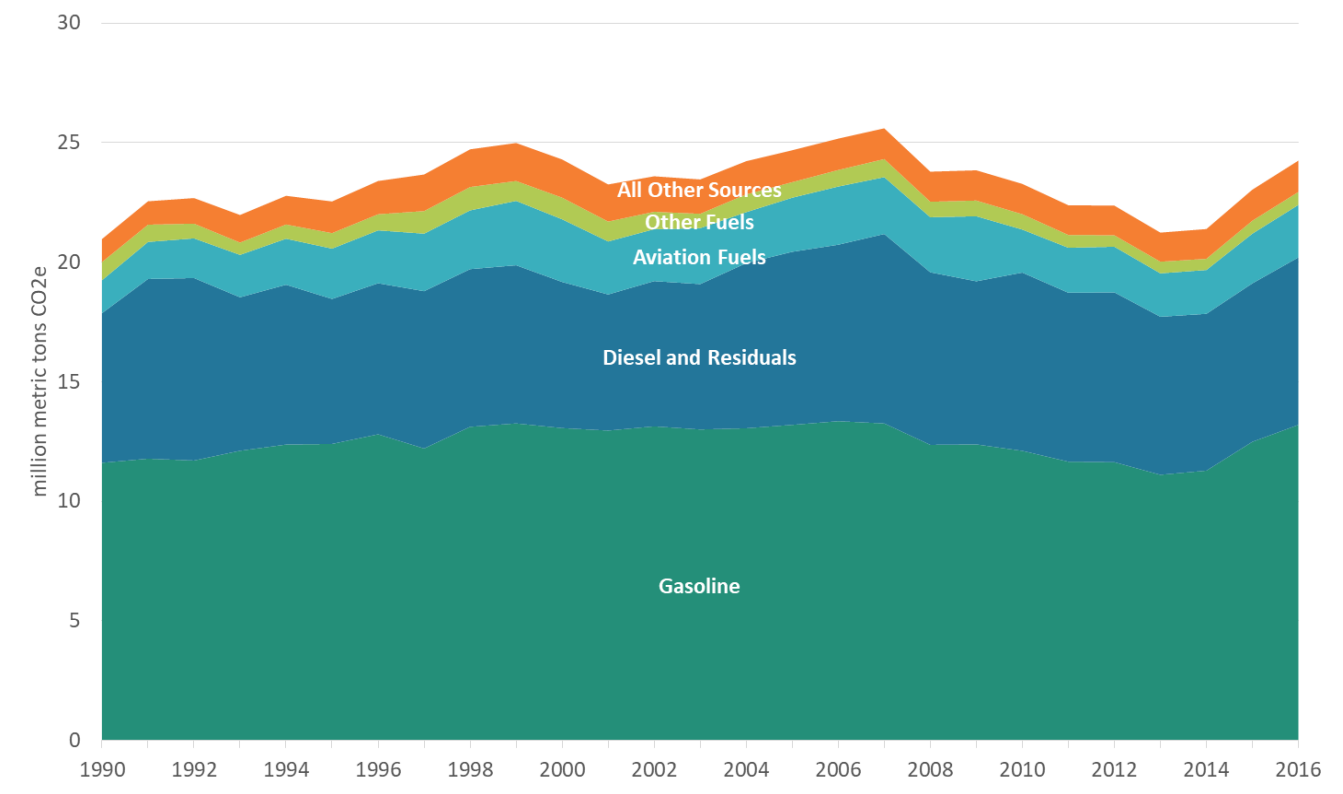
2.3 Transportation

The transportation sector includes carbon dioxide, methane and nitrous oxide emissions from the use of cars, trucks, boats, aviation and non-road vehicles but excludes bunker fuel used in international marine vessels. Starting with the 2010 emissions year, estimates are based on imported fuel volumes reported to DEQ's greenhouse gas reporting program. This method allows for the calculation of emissions associated with vehicles purchasing fuel within Oregon, however, it does not account for users that purchase fuel outside of the state and operate their vehicles within Oregon. This sector also includes emissions from refrigerant used in vehicle air conditioning equipment and refrigeration systems in freight.

Transportation is Oregon's largest in-state sector contributing to global greenhouse gases and on-road transportation is the largest sub-sector of transportation emissions. In 2015, the transportation sector comprised 36 percent of statewide emissions (23 Million $MTCO_2e$). Within the sector, DEQ estimates that in 2015 47 percent of combustion emissions are generated from passenger vehicles and light duty trucks and approximately 23 percent from heavy-duty vehicles. Statewide passenger vehicles and light duty trucks are responsible for approximately 17 percent of emissions from all sources.

2016 data indicates that emissions in the transportation sector have increased 15 percent since 1990 along with a 37 percent increase in vehicle miles traveled (VMT)[13]. Not only has VMT increased in Oregon but recently VMT per capita has increased annually starting in 2012.

Figure 2.5
Oregon emissions from transportation



[13] Oregon Department of Transportation. (2017). Oregon Statewide VMT Data. Retrieved from http://www.oregon.gov/ODOT/Data/documents/VMT_Statewide.pdf

2.4 Residential and commercial sectors

In 2015, the residential and commercial sectors accounted for 34 percent of statewide emissions (22 million $MTCO_2e$). Within the sectors, emissions are primarily a result of energy use including emissions from electricity use and natural gas and petroleum combustion. Emissions from these specific sources total to 18 million $MTCO_2e$ and make up 85 percent of residential and commercial sector emissions. The other 15 percent of emissions in this sector include emissions from sources such as waste and the use of high global warming potential gases in refrigerants and air conditioning.

Emissions within the residential and commercial sector have increased from 1990 to 2015 by 20 percent. Within the sector, emissions from electricity use increased by 28 percent and emissions from fuel combustion increased by 22 percent. After electricity use and fuel combustion, the third largest emissions source within the residential and commercial sector is waste.

Figure 2.6
Emissions from the residential and commercial sector 1990-2016

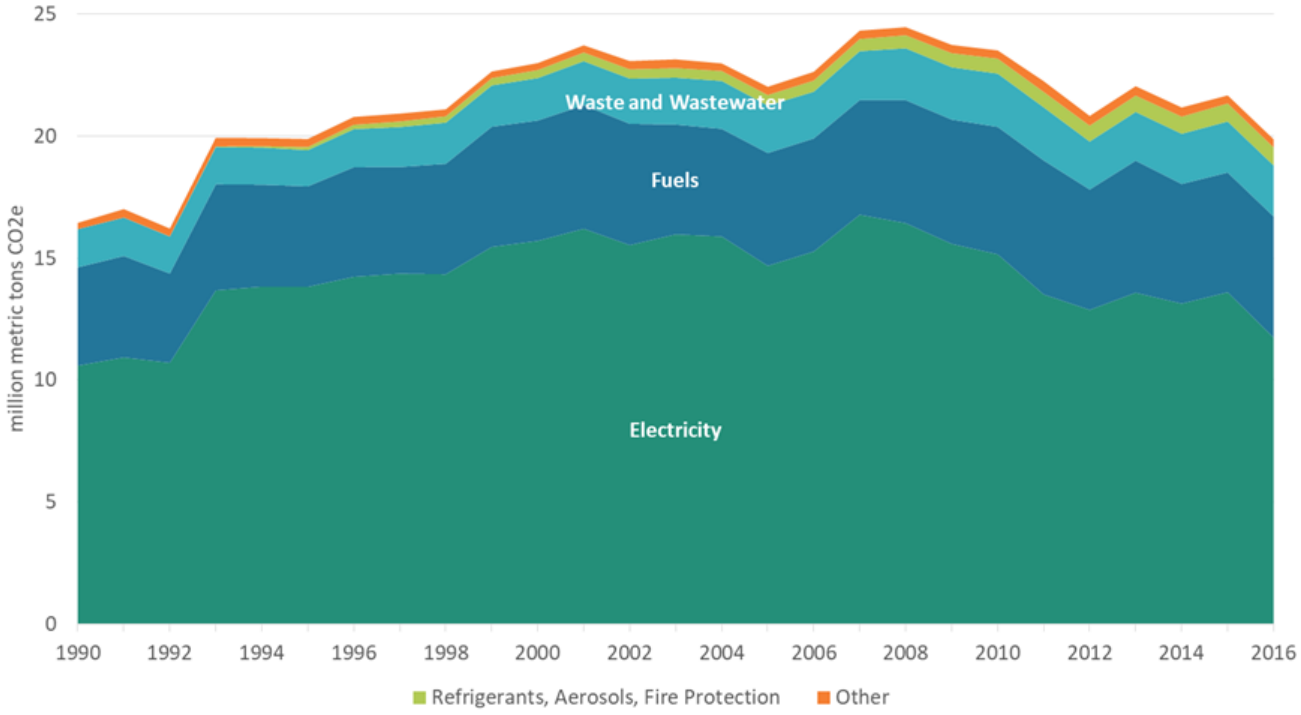
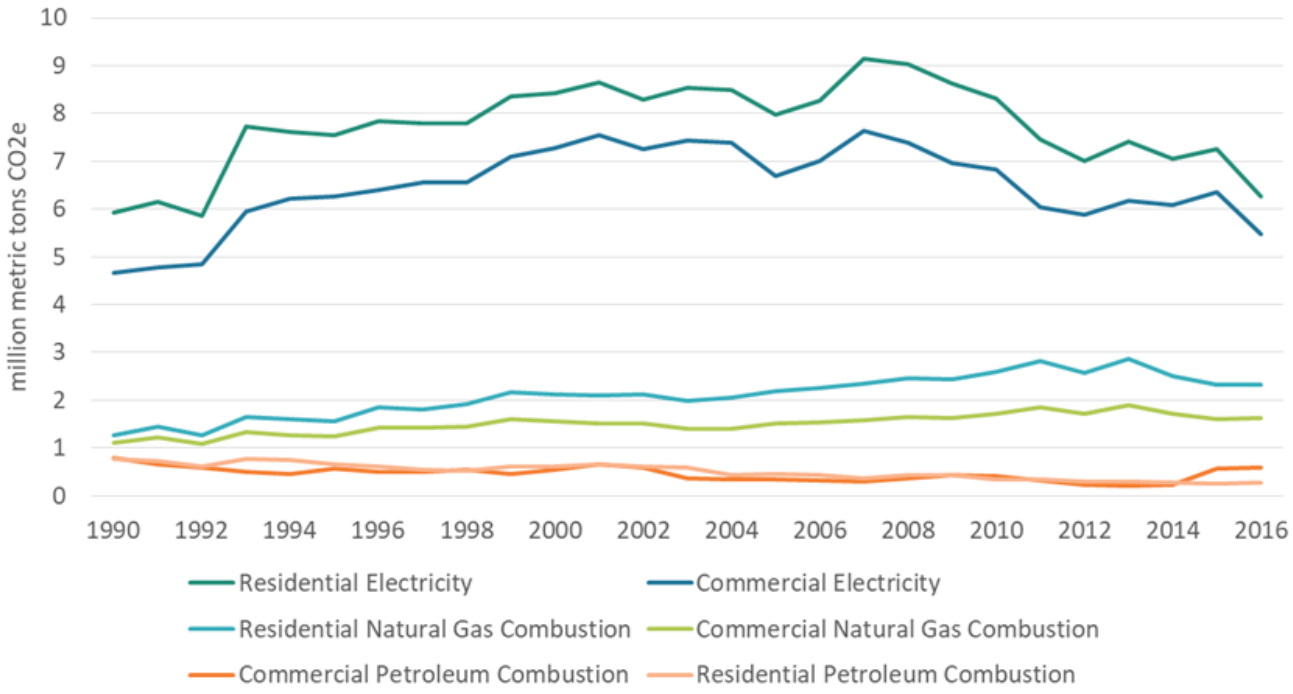


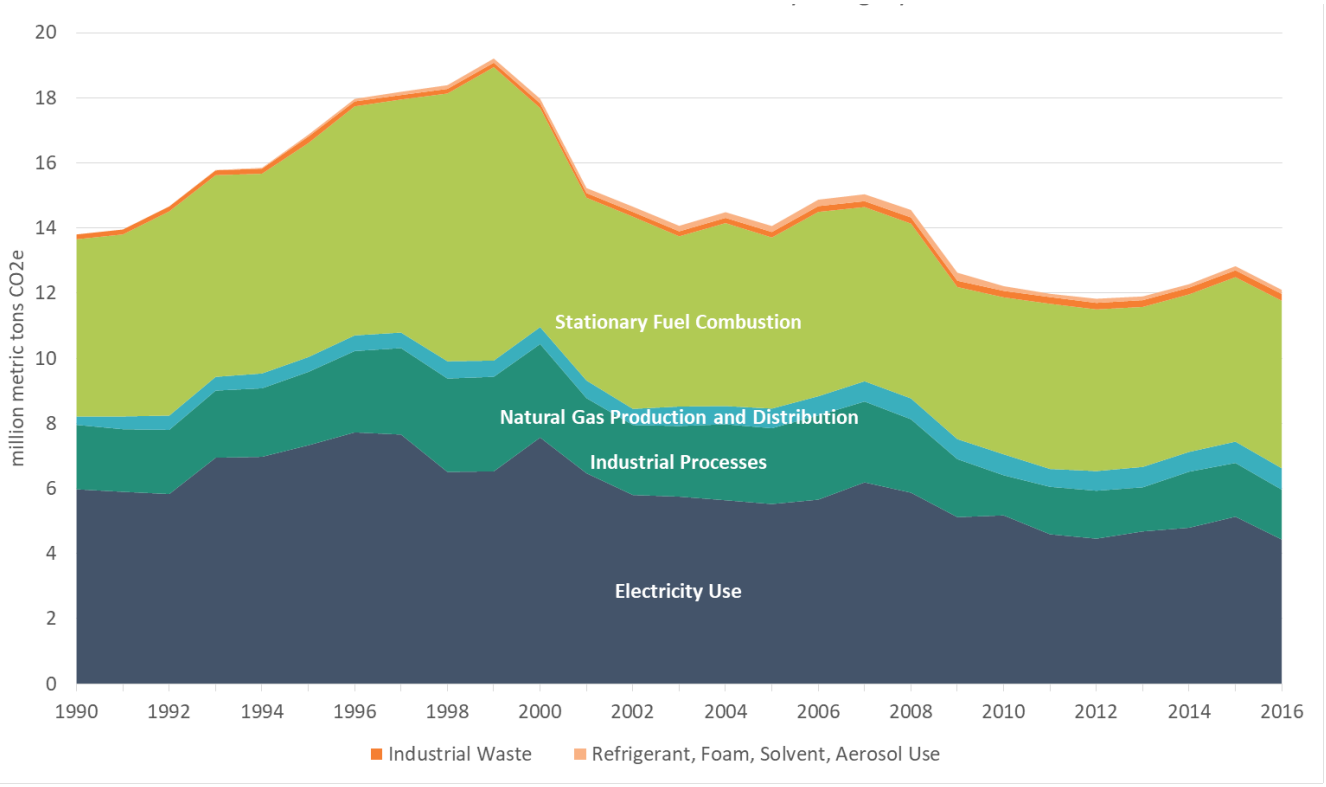
Figure 2.7
Emissions from residential and commercial electricity, natural gas and petroleum use 1990-2016



2.5 Industrial sector

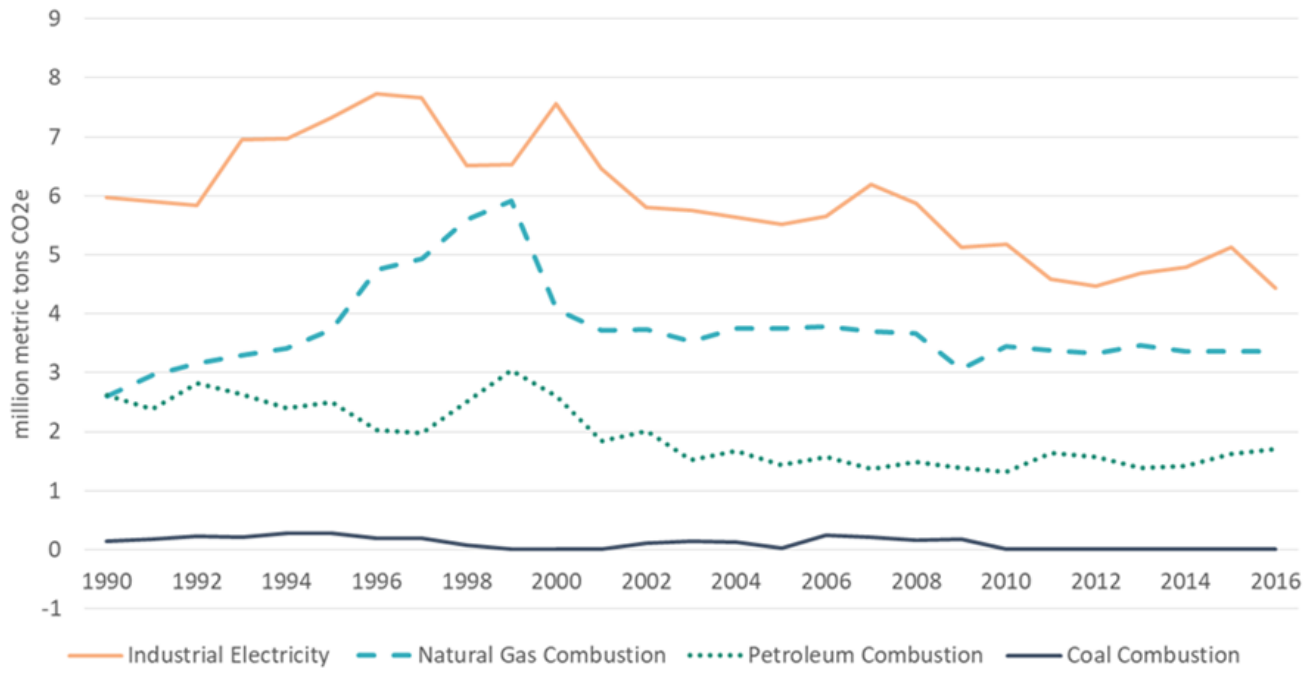
Starting in 2010 industrial facilities located within Oregon with an air quality permit that emit over 2,500 $MTCO_2e$ of greenhouse gases have been required to report annual greenhouse gas emissions to DEQ. Reported data includes emissions from onsite stationary combustion and emissions from industrial processes that emit greenhouse gases, such as cement manufacturing or iron and steel production. Other emissions attributed to this sector include emissions from waste and high global warming potential gases from the use of refrigerants, foams and aerosols. The largest contributor to emissions within this sector are emissions from stationary combustion and emissions from electricity use at the industrial facilities.

Figure 2.8
Industrial sector emissions



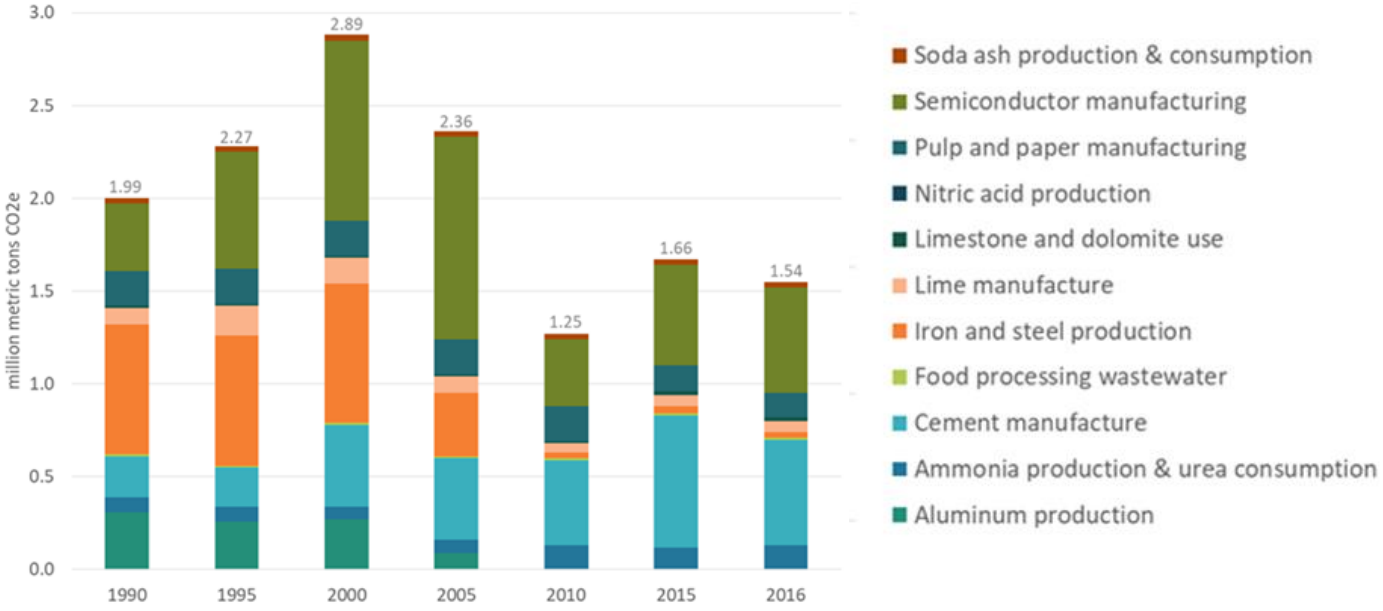
In 2015, Oregon's industrial sector emitted 12.8 million $MTCO_2e$ which accounted for 20 percent of statewide emissions. In 1990 industrial emissions, at 14 million $MTCO_2e$, this sector accounted for 25 percent of statewide emissions. The reductions in this sector are primarily the result of the reduction of emissions from electricity use and reductions in petroleum combustion.

Figure 2.9
Industrial electricity and stationary combustion



Industrial processes emit greenhouse gases which are accounted for separately from energy related activities within the industrial sector, called process emissions. Process emissions data reported for the 2016 emissions year from industrial facilities accounted for 13 percent of the industrial sector and 2 percent of total statewide emissions. In the 1990s, Oregon's largest source of industrial process emissions came from the production of aluminum, iron and steel. More recently, emissions from those industries in Oregon have either reduced dramatically or stopped completely. Data from the greenhouse gas reporting program now indicates that the primary sources of process emissions arise from cement and semiconductor manufacturing.

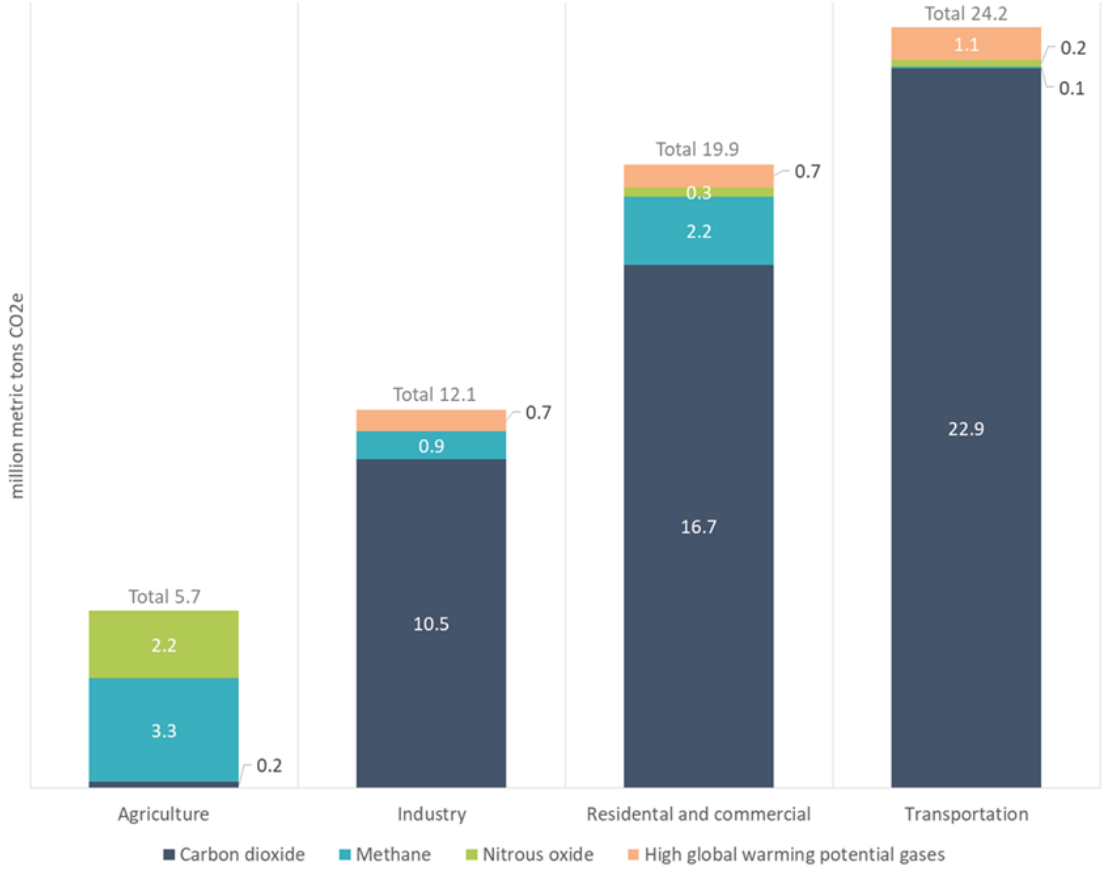
Figure 2.10
Industrial process emissions



2.6 Agricultural emissions

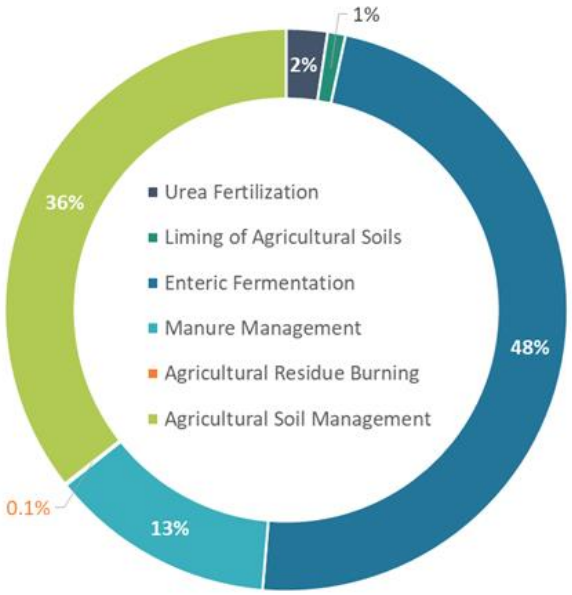
Emissions from the agriculture sector include emissions from agricultural activities such as managing soils, emissions from livestock and livestock-related waste, and methane and nitrous oxide emissions from the burning of agricultural residual waste. Emissions from fuel combusted for farm equipment use, such as for the operation of tractors, are included within the transportation sector emissions. Unlike other sectors, where carbon dioxide is overwhelmingly the primary greenhouse gas emitted, in the agricultural sector the majority of emissions are methane followed by nitrous oxide.

Figure 2.11
2015 emissions by greenhouse gas for each sector



In Oregon agricultural emissions consistently account for 8-9 percent of statewide emissions from 1990 through 2015; around 5-7 million $MTCO_2e$ annually. Within this sector, the largest contributor to greenhouse gas emissions is a result of enteric fermentation (methane emissions resulting from fermentation occurring in the digestive systems of ruminant animals, primarily cows). It is estimated that in 2015 enteric fermentation resulted in 2.7 million $MTCO_2e$ of greenhouse gas emissions. The next largest contributing source, at 2 million $MTCO_2e$, is from the application of nitrogen fertilizers to agricultural soils. The remaining emissions within this sector include emissions from manure management, urea fertilization, liming of soils, and the burning of agricultural residue which accounts for less than 1 million $MTCO_2e$. Since carbon dioxide from the burning of agricultural residue is considered biogenic carbon, only the methane and nitrous oxide emissions from combustion are included in the sector-based inventory.

Figure 2.12
2015 Agriculture emissions by sub-category



2.7 Additional Considerations

2.7.1 Electricity Use

Oregon's electricity use emissions are associated with the generation of electricity serving Oregonians, regardless of where that electricity is generated. Some of the electricity used in Oregon is generated in other states, and the emissions associated with the generation of that electricity are included in the electricity use sector of this inventory. Similarly, there are emissions from electricity generated in Oregon that are utilized outside of the state. Those emissions are not included in the electricity sector of this inventory. Since a large portion of the electricity utilized in Oregon comes from hydropower, the emissions profile of Oregon's electricity is influenced annually by stream flow. In years when there is less hydropower available, utilities must supplement with other sources and this may include electricity from greenhouse gas emitting sources such as natural gas or market purchases of unspecified electricity. This purchased power can increase the emissions intensity of electricity used in Oregon.

Annual emissions from electricity use in Oregon are influenced by both the emissions intensity of the electricity provided to end users (measured in $MTCO_2e$ per megawatt-hour) and the amount of electricity utilized. Based on data reported to DEQ in 2016, Oregon's statewide emissions per megawatt-hour were 0.338 $MTCO_2e$/MWh and total emissions from the electricity sector were 16 million $MTCO_2e$. However, depending on the individual provider of electricity, the emissions intensity for electricity can vary across different parts of the state. In regions that are served by consumer-owned utilities (COUs), which receive a majority or all of their electricity from the Bonneville Power Administration (BPA), the intensity of the electricity per megawatt hour can be up to 95 percent less than the statewide average. This is because BPA's electricity provided to COUs comes primarily from hydropower. In regions served by one of Oregon's investor-owned utilities (IOUs), average emissions per megawatt hour are higher than the statewide average. Additionally, Oregon's IOUs provide approximately 65 percent of Oregon's total electricity resulting in more than 90 percent of the emissions in the electricity use sector.

Total emissions within the electricity use sector are also influenced by the amount of power that is consumed. Fortunately, a history of energy efficiency programs in Oregon has helped to reduce the overall demand for electricity. However, overtime the residential sector is consistently the greatest consumer of electricity for activities like heating, running electrical equipment, lighting and refrigeration. This is followed by the commercial and industrial sectors.

Figure 2.13
Emissions from electricity use by sector 1990-2016

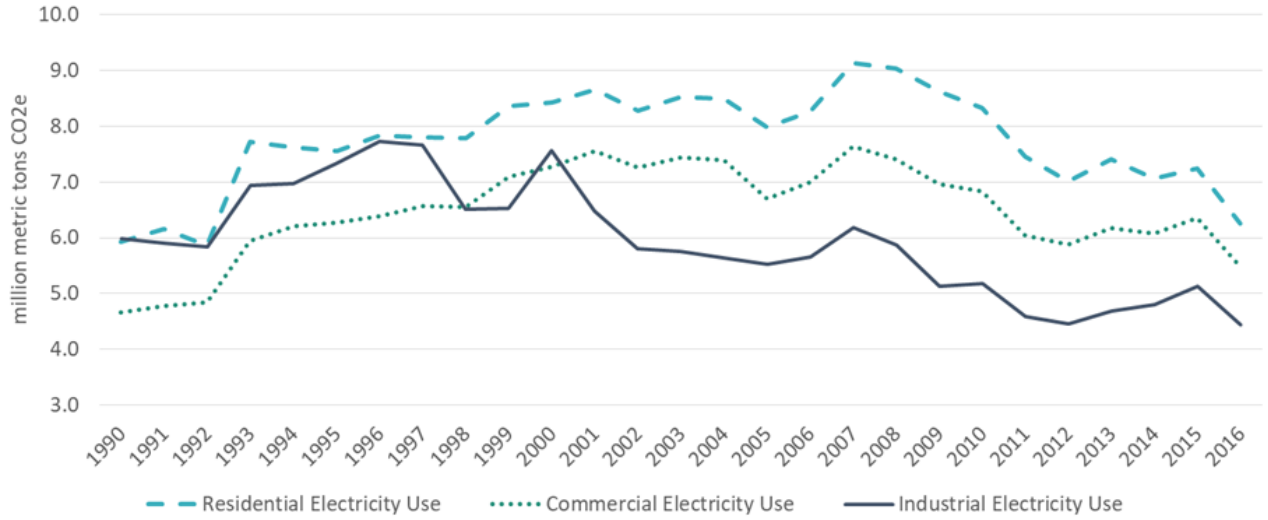


Figure 2.14
Electricity emissions by end use in the residential sector 1990-2016

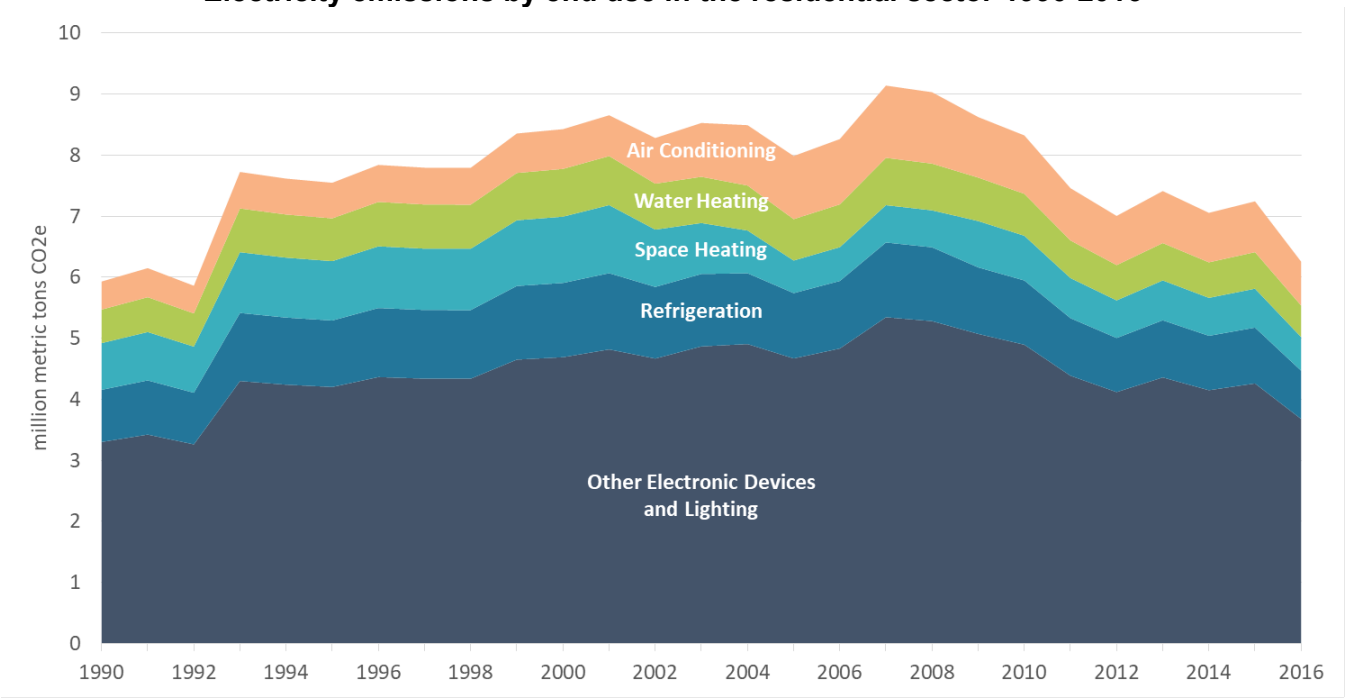


Figure 2.14 illustrates how emissions from residential electricity use have changed since 1990. Emissions from lighting and other uses (clothes dryers, small appliances, consumer electronics) contribute approximately 60 percent of emissions from electricity use in the residential sector. In the commercial sector lighting has historically consumed the greatest amount of electricity as shown in Figure 2.15. However, since 2000 the share of emissions from lighting has decreased while electricity use emissions from cooling, refrigeration, and the use of computers and office equipment has increased. Unlike the residential and commercial sectors, lighting in the industrial sector is less of a driver of overall electricity use. Emissions in the industrial sector primarily result from electricity needed to power machinery (machine drive) or equipment for industrial processes, as shown in Figure 2.16.

Figure 2.15
Commercial sector electricity emissions by end use 1990-2016

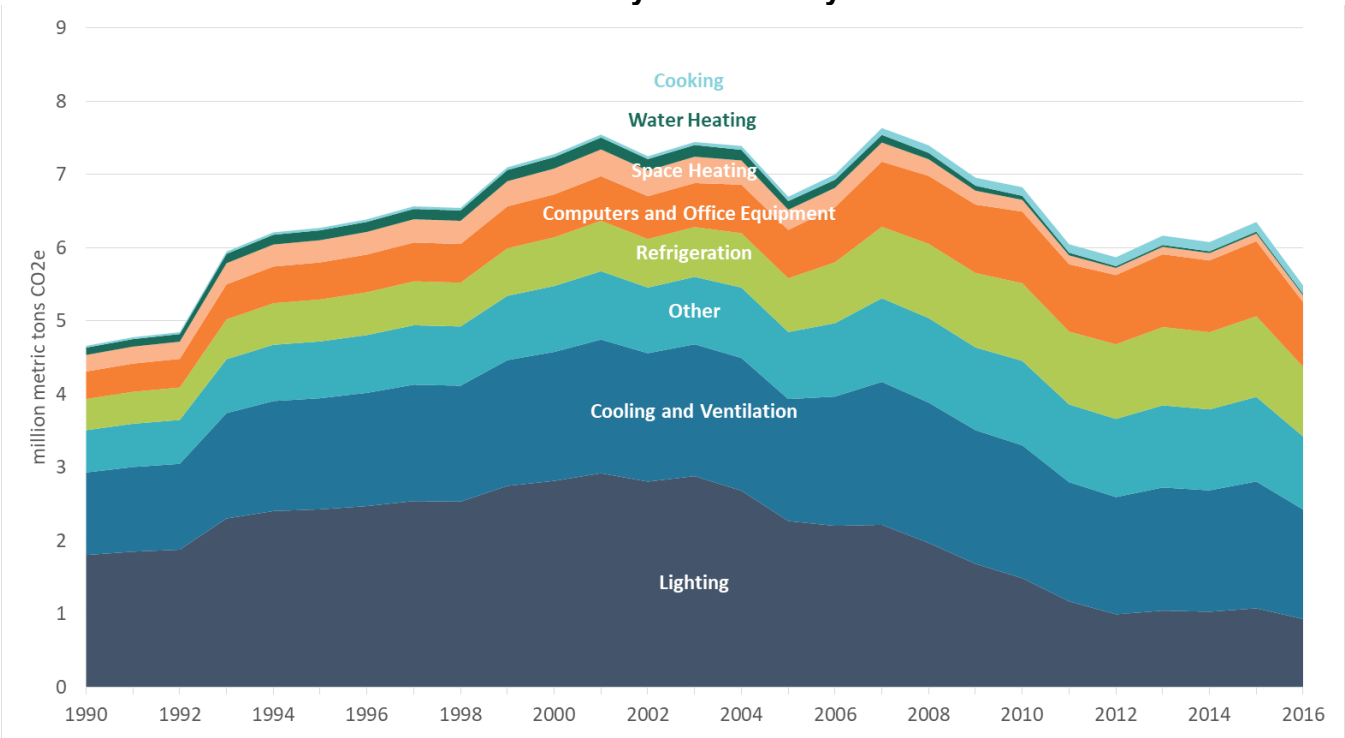
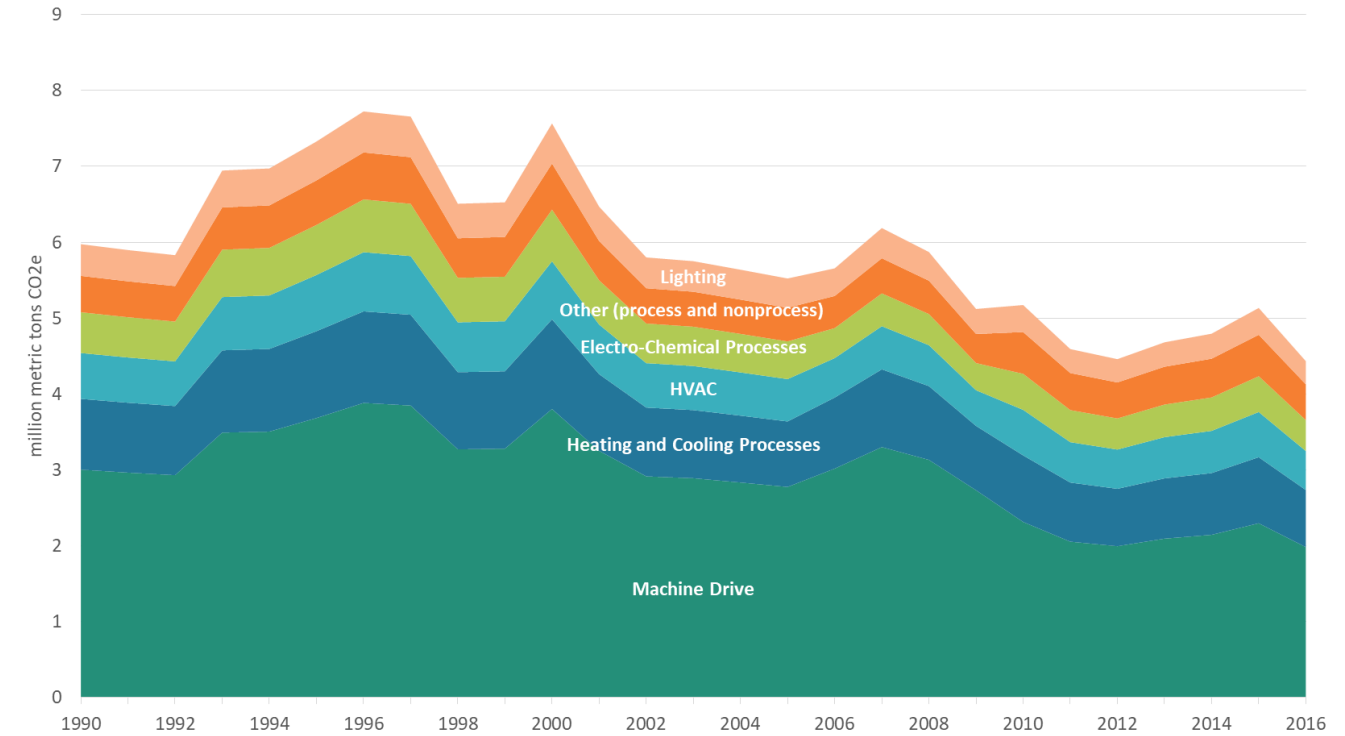


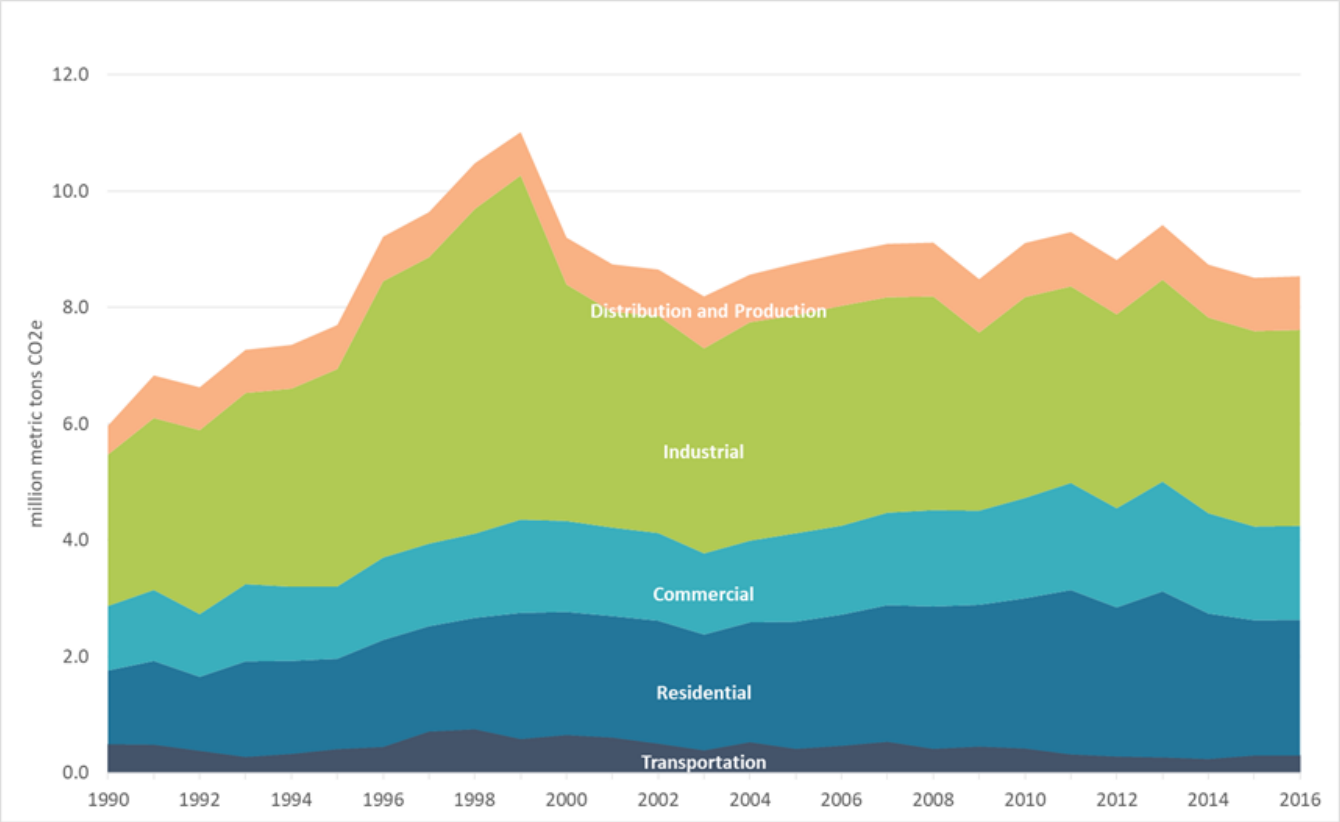
Figure 2.16
Industrial sector electricity emissions by end use 1990-2016



2.7.2 Natural Gas Use

The sector-based inventory accounts for emissions from natural gas occurring at the point of combustion and fugitive methane emissions from pipeline and compressor stations in Oregon delivering natural gas to end users. Emissions are attributed to the combustion, production and distribution of natural gas by individual sector. When looked at collectively, natural gas use is the third largest source of in-state emissions. In 2016, reported data indicates that natural gas combustion from the transportation, residential, commercial and industrial sources (not including emissions from distribution or in-state electricity generation) emit 7 million $MTCO_2e$. In 1990, emissions from natural gas combustion were closer to 5 million $MTCO_2e$. The percentages of statewide emissions from natural gas combustion have increased over time and in 2016 natural gas represented 12 percent of statewide emissions.

Figure 2.17
Natural gas emissions from the sector-based inventory 1990-2016

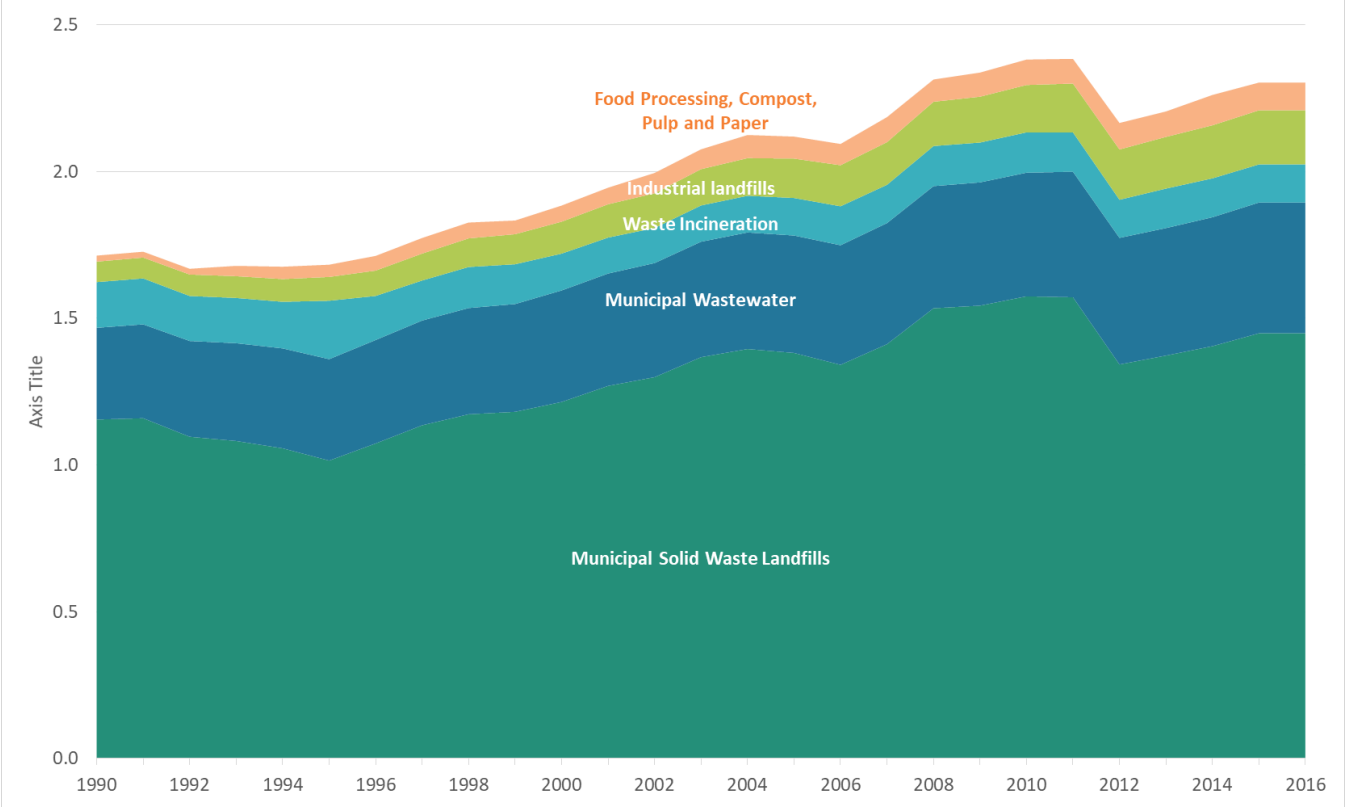


2.7.3 Waste

The sector-based inventory relies on mandatory reports from Oregon's waste incinerators and larger landfills (beginning in 2010), coupled with estimates provided by DEQ's Materials Management Program to develop the majority of waste sector estimates. This includes emissions from waste incineration, municipal solid waste and wastewater, and compost in the Residential and Commercial sector, as well as industrial waste, industrial landfills, food processing wastewater, pulp and paper, and waste incineration in the industrial sector. EPA's SIT tool provides statewide estimates on emissions from wastewater, including emissions from municipal wastewater and from industrial sources such as food production and pulp and paper manufacturing.

Since 1990, statewide emissions from waste have increased from 1.7 million $MTCO_2e$ to 2.3 million $MTCO_2e$. Additionally, while statewide emissions decreased from 2005 through 2011, emissions from waste increased during the same time period[14]. The majority of emissions from waste are fugitive methane emissions from municipal solid waste landfills in Oregon. When waste decomposes naturally under aerobic (with oxygen) conditions, it primarily produces carbon dioxide. Under these natural conditions, the carbon dioxide is considered biogenic and not typically included in a greenhouse gas inventory. However, waste in landfills decomposes under anaerobic conditions generating methane. Since the majority of the methane emitted does not result from natural decomposition, these emissions are considered anthropogenic and are included in the sector-based inventory. Methane captured by landfills and burned (either to produce energy or simply for destruction) primarily produces carbon dioxide as an emission, this carbon dioxide is considered biogenic and not included in the inventory.

Figure 2.18
Emissions from waste from all sectors 1990-2016



[14] The drop in emissions from 2011 to 2012 in Figure 2.18 is a result of to changes in emissions estimation methodology

2.8 Sector-Based Summary

Oregon's sector-based emissions declined from 2007 through 2012 but have fluctuated and flattened in recent years. Preliminary 2016 sector-based emissions data indicates that Oregon's emissions are 10 percent higher than 1990 levels and that we are not on track to achieve statewide emission reduction goals.

Recent data indicates that growth in the transportation sector is the primary driver of overall statewide sector-based emissions. This trend is supported by the observed increase in statewide vehicle miles traveled reported by the Oregon Department of Transportation. Oregon's increase in VMT and emissions is not only a product of an increase in population but also an increase in the miles driven per individual. Emissions from passenger vehicles are the largest sub-group within the transportation sector and account for 17 percent of statewide emissions.

As Oregon's population increases achieving emission reduction goals will become a greater challenge. The residential and commercial sectors contributed 35 percent of statewide emissions in 2015 and the residential sector continues to create the greatest demand for electricity, particularly to power appliances, electronics, and lighting.

Fortunately, Oregon's electricity sector continues to benefit from the availability of hydropower and an increase in adoption of renewable electricity. The availability of zero-emitting electricity along with a history of energy efficiency measures have helped to reduce emissions within that sector and offset emissions growth in other sectors.

As discussed above, Oregon's statewide trend in emissions has flattened and is no longer decreasing. Additional measures will need to be taken in all sectors to meet emission reduction goal.

3. Consumption-based inventory

3.1 Introduction

We live in a globally integrated economy, and so consumption in one geographic area often results in emissions elsewhere. For example, Oregonians' demand for electricity is satisfied by electricity generation at facilities across the Western U.S. The resulting emissions are counted in Oregon's sector-based inventory regardless of whether they occur in Oregon, Montana, or elsewhere. The consumption-based inventory extends this method to all purchases by Oregon consumers: cars from Michigan, bananas from Mexico, petroleum from Saudi Arabia and clothes from China, as examples. All of these consumption activities result in industrial or agricultural activities that release greenhouse gases, and these emissions have the same effect on global climate patterns as emissions that physically originate within the state.

Oregon estimates consumption-based greenhouse gas emissions because a significant portion of Oregon's collective carbon footprint occurs in other states and nations, and the sector-based inventory does not include most of these emissions. Evaluating consumption-based emissions alongside the traditional sector-based inventory provides Oregonians with a more complete understanding of how we contribute to global climate change and by extension, additional opportunities to reduce it. Greenhouse gases affect the global climate regardless of where they are emitted, hence reducing in-state emissions while driving increases in emissions elsewhere is not a solution that will reduce or avoid the negative impacts of climate change.

Oregon was the first state in the U.S. to produce a sub-national consumption-based greenhouse gas inventory (for calendar year 2005, published in 2011). It produced an update for calendar year 2010 (published in 2013), and this report represents the third comprehensive assessment (for calendar year 2015). In addition, this year's report also includes an initial estimate of Oregon's consumption-based emissions for 1990.

Oregon's consumption-based emissions inventory estimates the global greenhouse gas emissions that result from Oregon's consumption. These emissions may occur during the extraction, manufacturing, transport, use, or disposal of commodities (energy, materials, and services), but in all cases, stem from consumption as the root driver of emissions. "Consumption" here includes purchases by households and governments, and, to be consistent with standards for national economic accounting, capital investments by Oregon businesses.

The consumption-based inventory has significant overlap with Oregon's sector-based inventory: both include emissions resulting from the use of fuels and electricity by Oregon households and government operations, and both include emissions from in-state industrial, commercial and agricultural activities that satisfy demand for goods and services by Oregonians. This overlap between the two inventories creates the potential for double-counting, and for this reason the inventory totals are never simply added together. Chapter 4 quantifies the emissions shared by both inventories, as well as those that are unique to each one, allowing for an estimate of Oregon's total contribution to global emissions.

Although the two inventories share some emissions, they also have significant differences, which are also explored in Chapter Four. In short:

- Oregon's sector-based inventory uniquely includes emissions associated with goods and services that are produced here but exported to satisfy consumption elsewhere.
- The consumption-based inventory uniquely includes emissions associated with the out-of-state production and transport of imported goods and services.

Electricity generated out-of-state and imported for use in Oregon is the one exception. The sector-based inventory includes emissions at the point of generation for all electricity used in Oregon (by all users), regardless of where the electricity is produced. In contrast, the consumption-based inventory only includes imported emissions from electricity used by consumers (households and governments), and the portion of electricity used by business and industry for satisfying in-state consumption. It also includes both emissions at the point of generation as well as upstream of generation; these emissions are termed supply chain emissions. Supply chain emissions include fugitive emissions from coal mines and natural gas wells, as well as the energy required to transport fuels and prepare them for use in generation units.

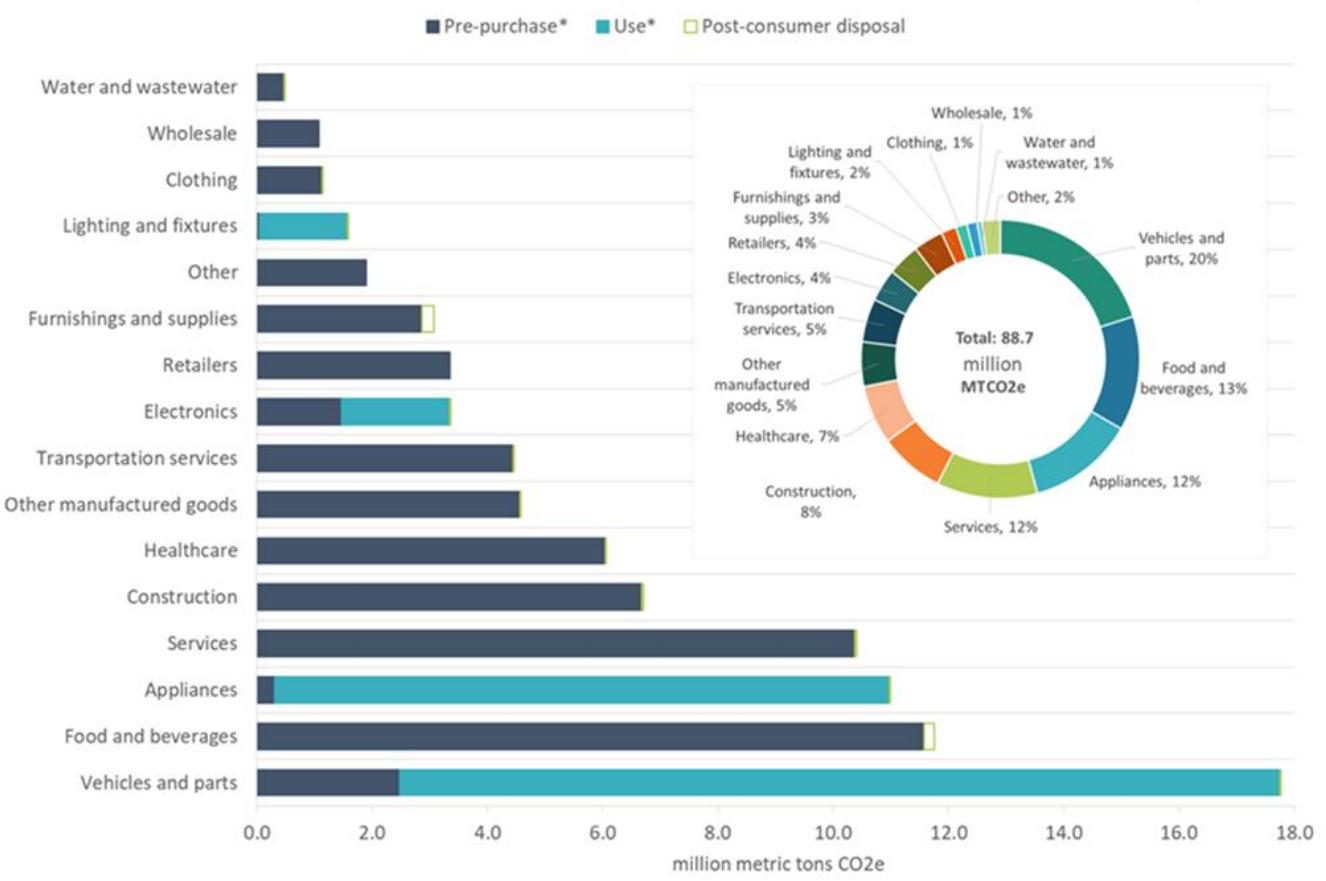
This chapter presents a high-level overview of the 2015 consumption-based inventory results, changes in consumption-based emissions between 2005 and 2015, and an initial estimate of consumption-based emissions for 1990.[15] Appendix B provides all supporting data tables, additional data and analysis, and a detailed explanation of the consumption-based inventory methodology.

[15] As with the sector-based inventory, updates to historic data sets (inventory inputs) have resulted in some updates to previously published results (for 2005 and 2010). Select methodological improvements implemented in the 2015 inventory have also been carried backward into the 2005 and 2010 inventories, resulting in further changes to results for those years. These details are also described in Appendix B, and this report presents updated inventory results for prior years.

3.2 Oregon's 2015 Consumption-Based Emissions

Oregon's consumption-based greenhouse gas emissions in 2015 were 88.7 million $MTCO_2e$. Figure 3.1 illustrates these emissions, grouped by major category of consumption and life-cycle stage. The categories represent all forms of consumption (drawn from 536 different commodities), collapsed into 16 basic categories.

Figure 3.1
2015 Oregon consumption-based greenhouse gas emissions, by category and life-cycle stage



* "Pre-purchase" are all emissions that occur prior to final purchase, including production, supply chain, transport, retail and wholesale. "Use" refers to emissions resulting from the use of vehicles, appliances, electronics and lighting. Other categories (e.g., food and clothing) have use phase emissions that are accounted for elsewhere. For example, emissions from cooking and laundering are both assigned to the category of "appliances", which include ranges and clothes dryers.

One category – vehicles and parts – represents 20 percent of all of Oregon's consumption-based emissions. Nearly two-thirds of all emissions are associated with just the five highest-emitting categories: vehicles, food and beverages, appliances, services, and construction.

The major life-cycle stages are expressed relative to the end-user.

- "Pre-purchase" includes most emissions prior to the point of purchase, including supply chain, supply chain transport, and final assembly/production. For services (including healthcare), pre-purchase emissions include all of the emissions associated with providing services.
- "Use" includes the life-cycle emissions of fuels and electricity used to power lights, electronics, appliances and personal vehicles, as well as trace emissions from refrigerants and vehicle lubricants.
- "Post-consumer disposal" are the emissions from landfilling and incineration of the goods purchased.

Sixty-six percent of all emissions occur upstream of the consumer as "pre-purchase" emissions. Emissions from the consumption of energy, refrigerants and lubricants (to operate vehicles, appliances, electronics and lighting) contribute another 33 percent. One percent of emissions stem from post-consumer disposal of wastes. Within different categories, the relative contribution of different life cycle stages varies. For appliances and lighting, the vast majority of emissions are a result of use, while production of the appliances and lighting fixtures contribute very little. Tailpipe emissions during the use of vehicles also dominate that category, although emissions from production (auto manufacturing) and parts are not trivial. In contrast, food-related emissions are almost entirely upstream of the consumer, in farms and factories and their supply chains.

A few categories benefit from additional explanation:

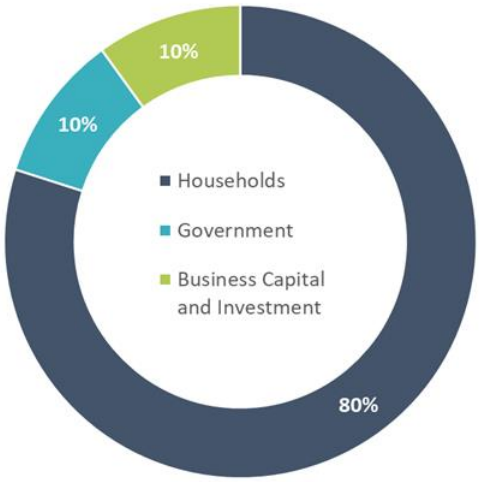
- "Retailers" and "Wholesalers" represent the energy-related and other direct emissions from retail and wholesale operations, such as lighting and refrigeration. They also include emissions from their supply chains *other than* the goods that are being sold (e.g., emissions from manufacturing grocery bags, receipt paper, advertising, etc.).
- "Transportation services" includes all transportation of finished goods from final producers through wholesale channels to retailers. It also includes emissions from services that transport consumers directly, such as airplane flights.

For any other category of goods shown, life cycle emissions may appear in several categories. Using food as an example:

- All emissions up to the point of final production are assigned to the category itself (emissions from manufacturing food are reported as "food and beverages" as are all supply chain emissions, such as growing and transporting wheat used to make bread);
- Emissions from transporting finished food from the final producer to the retailer are included in "transportation services"; and
- Emissions from wholesale activities and retailing (e.g., grocery store operations) are included in the "wholesale" and "retail" categories.

Figure 3.2 illustrates that 80 percent of Oregon's consumption-based emissions stem from household consumption activities, with the remainder evenly divided between governments and business capital formation and investment. Households contributed about 68 percent of Oregon's 2015 consumption as measured in dollars, but their relative contribution to greenhouse gas emissions is higher. The reason for this is what they buy: households spend proportionately more of their money on goods and services with higher carbon-intensities than do governments or business capital investments.

Figure 3.2
2015 Oregon consumption-based greenhouse gas emissions by consumer type



- For households, the three categories of purchases with the highest emissions are vehicles and parts (15.9 million $MTCO_2e$), food and beverages (10.9 million $MTCO_2e$) and appliances (9.0 million $MTCO_2e$).
- Government's three largest categories of emissions are construction (2.1 million $MTCO_2e$), appliances (1.9 million $MTCO_2e$) and vehicles/parts (0.9 million $MTCO_2e$).
- For business capital and investments, the three largest categories of emissions are "other manufactured goods" such as machinery (2.7 million $MTCO_2e$), construction (1.9 million $MTCO_2e$) and vehicles and parts (1.0 million $MTCO_2e$).

While households contribute most of Oregon's consumption-based emissions, not all households are the same. Not surprisingly, lower-income households consume less, and their average carbon footprint is also lower. Higher-income households on average generate more consumption-based emissions. This is illustrated in Figure 3.3.

This raises issues of equity and environmental justice. Lower-income households are more vulnerable to the effects of climate change, while higher-income households have greater ability to adapt to and cope with such impacts.[16] Higher-income households also have greater ability (both in terms of real potential and financial resources) to reduce emissions, as well as greater responsibility to do so, by virtue of their proportionately larger contribution to this problem.

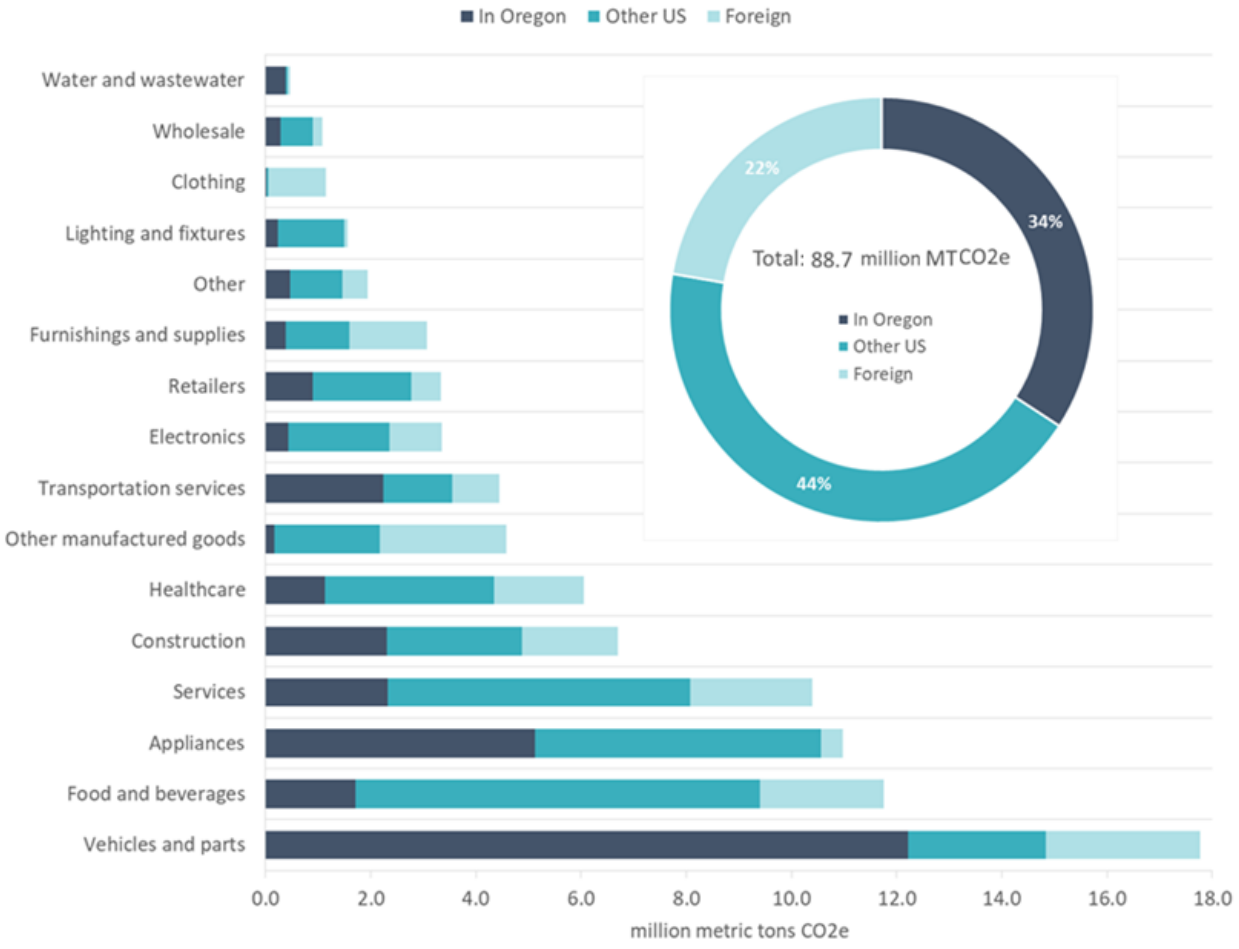
[16] Gamble, J.L., J. Balbus, M. Berger, K. Bouye, V. Campbell, K. Chief, K. Conlon, A. Crimmins, B. Flanagan, C. Gonzalez-Maddux, E. Hallisey, S. Hutchins, L. Jantarasami, S. Khoury, M. Kiefer, J. Kolling, K. Lynn, A. Manangan, M. McDonald, R. Morello-Frosch, M.H. Redsteer, P. Sheffield, K. Thigpen Tart, J. Watson, K.P. Whyte, and A.F. Wolkin (2016) Ch. 9: Populations of Concern. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. U.S. Global Change Research Program, Washington, DC. http://dx.doi.org/10.7930/J0Q81B0T

Figure 3.3
Average Oregon per-household consumption-based greenhouse gas emissions ($MTCO_2e$/household), by income group

As noted earlier, many of Oregon's consumption-based emissions, while driven by consumption in Oregon or by Oregonians, actually occur elsewhere. While this is difficult to estimate precisely, over one-third (34 percent) of Oregon's consumption-based emissions are estimated to physically originate within Oregon's borders. Forty-four percent are estimated to originate elsewhere in the U.S., while approximately 22 percent occur in other nations.

Figure 3.4 illustrates that the location of emissions varies by type of consumption. For example, nearly all emissions associated with clothing are a result of foreign manufacturing, while food-related emissions primarily occur elsewhere in the U.S., such as in California and the Midwest. The only two categories where more than half of emissions occur in Oregon are vehicles and parts (due to vehicle use) and transportation services.

Figure 3.4
2015 Oregon consumption-based greenhouse gas emissions, by location of emission



3.3 Oregon's Consumption-Based Emissions Over Time: 1990 to 2015

Oregon has robust estimates of consumption-based emissions for three years: 2005, 2010 and 2015. 2010 started just six months after the end of the Great Recession[17]. In contrast, 2005 and 2015 both occurred several years into periods of economic expansion. In addition, Oregon has a less detailed estimate of consumption-based emissions for 1990.

Figure 3.5 illustrates how Oregon's consumption-based greenhouse gas emissions changed during this time period, both in total (1990 to 2015) and for each of the major categories of consumption (2005 – 2015 only). Total consumption-based emissions in 2005 were considerably higher than in 1990. While total 2010 emissions were only slightly above emissions from 2005 levels, emissions rose about 10 percent between 2010 and 2015.

[17] The Board of Governors of the Federal Reserve describes the Great Recession as beginning in the United States during December of 2007 and ending in June of 2009.

Figure 3.5
2005-2015 Oregon consumption-based greenhouse gas emissions by category

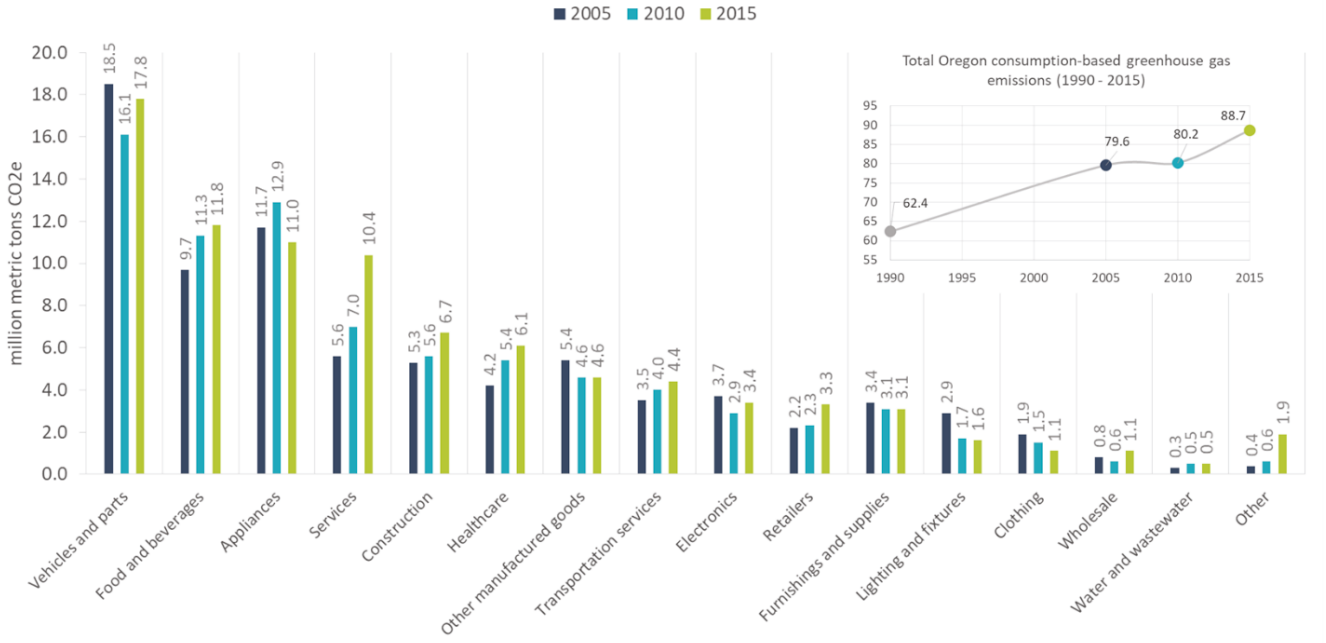


Figure 3.6 illustrates a similar change (for 2005 – 2015 only), this time grouping all Oregon consumption into four major "meta-categories" of direct purchases of electricity, direct purchases of fuels, services, and materials. These meta-categories represent the type of final demand (consumption) by households and governments, as well as business capital investments or material inventory formation. In 2015, only 11 percent and 22 percent of Oregon's consumption-based emissions were a result of direct purchases of electricity and fuels (for both vehicles and appliances) by consumers, respectively. The purchase of services resulted in approximately 26 percent of emissions, while materials (which include food) contributed 41 percent. Additional details on these meta-categories are included in Appendix B.

Figure 3.6
2005-2015 Oregon consumption-based greenhouse gas emissions by meta-category

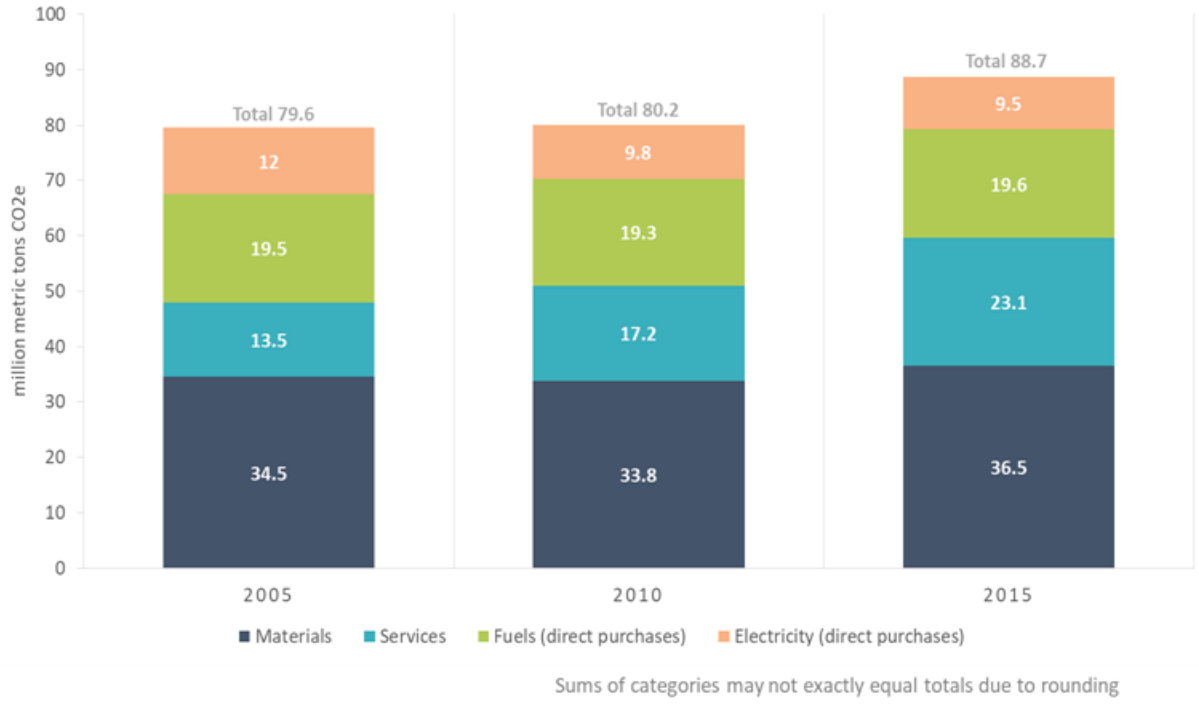


Figure 3.6 illustrates some high-level findings. While most of the emissions resulting from the consumption of materials and services are a result of energy use by producers, when viewed through the lens of the consumer, the direct purchase of energy contributes only about one third of their carbon footprint. Because of high emissions intensities (emissions per dollar spent; see Appendix B for details), efforts to engage consumers to reduce their purchases of electricity and fuels, a historic focus of many climate programs, will likely result in smaller rebound effects, which is desirable from a climate perspective. That is, consumer savings from these types of programs, when subsequently spent on other commodities, will typically increase other emissions by a lesser amount, resulting in a net reduction of emissions. But by themselves, such consumer-facing energy strategies address less than half of emissions from consumer activities as detailed in the consumption-based inventory. Materials (such as food and furnishings) and services (including air travel) are also important as they represent a combined total of 67% of emissions from the consumption-based inventory.

Between 2005 and 2015, emissions from direct purchases of electricity by Oregon consumers have fallen, both in absolute terms (12.0 million $MTCO_2e$ in 2005 to 9.5 million $MTCO_2e$ in 2015) and as a percent of the total. Emissions from fuel purchases for all three years evaluated by the consumption-based inventory (2005, 2010 and 2015) show little long-term change: neither a significant decrease nor increase (19.3-19.6 million $MTCO_2e$), despite a growing population (although the sector-based inventory shows more recent growth in transportation fuel-related emissions, during the period 2013 – 2016)[18]. Efforts during the ten-year period to address emissions from electricity and fuels (such as electricity conservation, renewable power programs, fuel efficiency standards

[18] The divergent trend here is caused by two factors. First, the recent increase in transportation-related emissions in the sector-based inventory is for a shorter and more recent time period (2013 to 2016, vs. 2010 to 2015). Second, while overall fuel-related emissions in the consumption-based inventory increased 0.3 $MMTCO_2e$ between 2010 and 2015, increases in vehicle-related emissions of 0.5 $MMTCO_2e$ were partially offset by decreases elsewhere, primarily fuel use in appliances such as furnaces.

and land use changes to effect transportation patterns) are showing benefits. Yet overall consumption-based emissions have continued to rise, primarily due to increases in emissions in two areas: services and materials.

Appendix B provides additional details including an examination of some of the changes within individual categories in Figure 3.5. As examples:

- Vehicle-related emissions dipped in 2010 and then returned close to 2005 levels in 2015. While the use of vehicles (fuel emissions) dominate this category, more than half of the decline and two-thirds of the subsequent increase was a result of changes in vehicle *purchases* (as opposed to use). Households and industry car purchases were dramatically lower in 2010 than in 2005, while 2015 saw robust sales.
- Most of the increase in food and beverage emissions are a result of three subcategories of purchases: restaurants (up 0.7 million $MTCO_2e$ from 2005 to 2015), beef and pork (up 0.5 million $MTCO_2e$) and grains/baked goods/cereals/nuts (also up 0.5 million $MTCO_2e$). Emissions from pet food also saw a moderate increase. Emissions from most other major food types, such as dairy, other beverages and fruits/vegetables were essentially flat.
- Between 2005 and 2015, emissions from household use of appliances has declined, while government use appears to have increased. Fuel switching has also occurred; electricity has fallen in importance while other fuels (primarily natural gas) have grown.
- Other significant increases in emissions between 2005 and 2015 are observed in some interesting areas, including emissions associated with construction, real estate transactions, education, religious organizations, investments by industry in scientific research, transportation services, and spending on hotels/motels. One other area with a significant increase in emissions is a result of consumer spending on telecommunications services - not emissions to power hand-held devices, but rather emissions from "behind the scenes" services such as cloud storage and wireless communications.

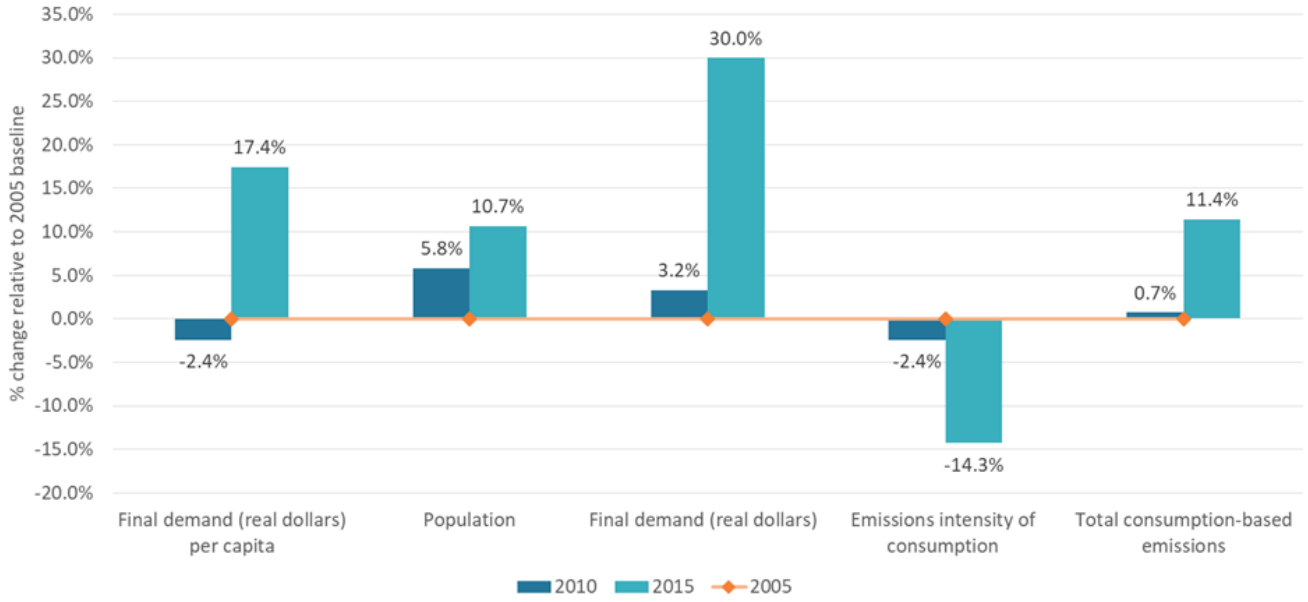
Additional details on these and other trends are included in Appendix B.

Figure 3.7
2005-2015 Oregon consumption-based greenhouse gas emissions, by life-cycle stage

Figure 3.7 illustrates the changes in emissions over time, organized by life-cycle stage. Use-phase emissions, dominated by fuel and electricity use for vehicles, appliances, lighting and electronics fell steadily from 2005 levels. Waste disposal emissions are also down from 2005 levels, reflecting a mix of more recycling, lightweighting of some materials (less material overall, such as newspapers and packaging), and improvements in landfill gas controls. Emissions from wholesale and retail stages have grown, perhaps reflecting changes brought about by the growth of e-commerce platforms. So have transportation services, which include the transport of finished goods from producers to retailers, as well as personal services such as airplane travel. But the life-cycle stage that has seen the strongest growth is the one that is both the largest and also the least visible to consumers: the production (including associated supply chain inputs) of materials and services, which added 9.1 million $MTCO_2e$ to Oregon's emissions between 2005 and 2015.

Overall, Oregon's consumption-based greenhouse gas emissions rose approximately 11.4 percent between 2005 and 2015. Figure 3.8 explores some of the factors behind this increase. It shows changes in several key drivers for 2010 and 2015, relative to a 2005 baseline. After adjusting for inflation, statewide consumption (in dollars) divided by Oregon's population ("final demand per capita") was lower in 2010 than in 2005; this may reflect the lingering effects of the Great Recession. But by 2015, per-capita consumption in real (inflation-adjusted) dollar terms was 17.4 percent above 2005 levels. At the same time, Oregon's population had grown 10.7 percent. More people, each spending more on average (including government and business capital/investment spending) resulted in overall consumption (again, in real, inflation-adjusted terms) being 30 percent higher in 2015 than in 2005.

Figure 3.8
Drivers of change in Oregon consumption-based greenhouse gas emissions, 2005-2015



Other factors helped to mitigate, to some extent, the impacts of this growth in consumption, as shown in emissions intensities. Emissions intensities are a measure of emissions per dollar of economic activity. Sector-based inventories often express emissions intensities on the basis of economic production, but here, intensities are expressed on the basis of consumption: the amount of global greenhouse gas emissions associated with satisfying one average dollar of Oregon consumption. After adjusting for inflation, Oregon's emissions intensities in 2015 were 14.3 percent lower than 2005. This reflects both limited decarbonization and shifts in consumption. Industry in Oregon - and many other areas - produced more output with fewer emissions in 2015 than in 2005. And consumers had shifted their basket of consumption, favoring more services, which tend to have lower emissions intensities than materials or fuels (see Appendix B for more details on this point).

However, the benefits of these efficiency improvements that result in lower emissions intensities - fuel switching, cleaner energy mixes and consumption shifts - were over-ridden by the effects of rising overall consumption. Between 2005 and 2015, consumption rose faster (up 30 percent) than emissions intensities fell (down 14 percent). The result was an overall increase in emissions of 11 percent.

Several alternative scenarios illustrate how Oregon might have achieved different outcomes. For example, if *per-capita* consumption, after adjusting for inflation, had remained constant between 2005 and 2015, overall consumption would have grown in step with Oregon's population, a 10.7 percent increase. Coupling this with a 14.3 percent drop in emissions intensities would have resulted in about a 5 percent decline in consumption-based emissions. Instead, these emissions rose 11.4 percent.

Alternatively, without any efficiency improvements or other reductions in emissions intensities, consumption-based emissions would have risen 30 percent. This illustrates the benefits of reductions in emissions intensities. Efficiency improvements are one of many emissions reduction strategies that will be required to reduce both in-state emissions (as reflected in Oregon's sector-based inventory) and consumption-based emissions. During the ten-year period studied in detail here, Oregon, U.S. and global emissions reductions have not kept pace with the increase in our overall consumption, the root driver of emissions at the global scale.

4. Comparison of results

4.1 Comparing Sector- and Consumption-Based Emissions

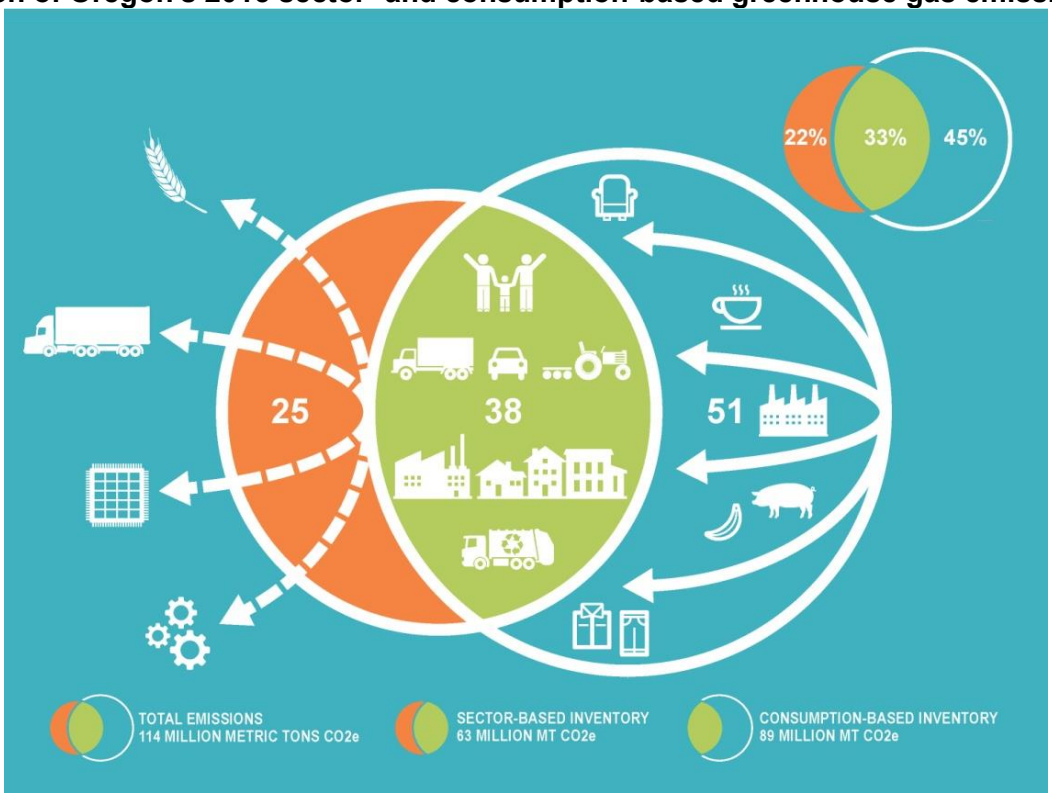
The sector-based and consumption-based inventories both estimate emissions from multiple types of sources, including transportation, residential, commercial, industry and agriculture. But how they account for some of these emissions differ significantly.

The sector-based inventory accounts for all emissions that physically originate within Oregon's borders, and the emissions at the point of generation for all electricity used in Oregon regardless of where that electricity is produced.

The consumption-based inventory includes the global emissions involved in satisfying consumption by Oregon households, governments, and business investments and capital formation. Emissions inside Oregon's borders are included only if they result from satisfying Oregon's consumption, while all other in-state emissions associated with exported goods and services are excluded.

Figure 4.1 illustrates the relationship between the two inventories. Sector-based emissions for 2015 were approximately 63 million $MTCO_2e$. Consumption-based emissions were about 89 million $MTCO_2e$.

Figure 4.1
Comparison of Oregon's 2015 sector- and consumption-based greenhouse gas emissions



The inventories share about 38 million $MTCO_2e$ in common. These are emissions from household and government use of energy and waste disposal, as well as commercial and industrial emissions associated with producing goods in Oregon that are consumed in Oregon, such as Oregonians' purchases of local ice cream or lumber.

Approximately 25 million $MTCO_2e$ of emissions are unique to the sector-based inventory, and are associated with the in-state production of exported goods and services. These include all of Oregon's signature exports: foods, semiconductors and electrical devices, and machinery. It also includes services that are "exported" to the extent that they are purchased by non-Oregonians, such as hotel stays and restaurant visits by tourists.

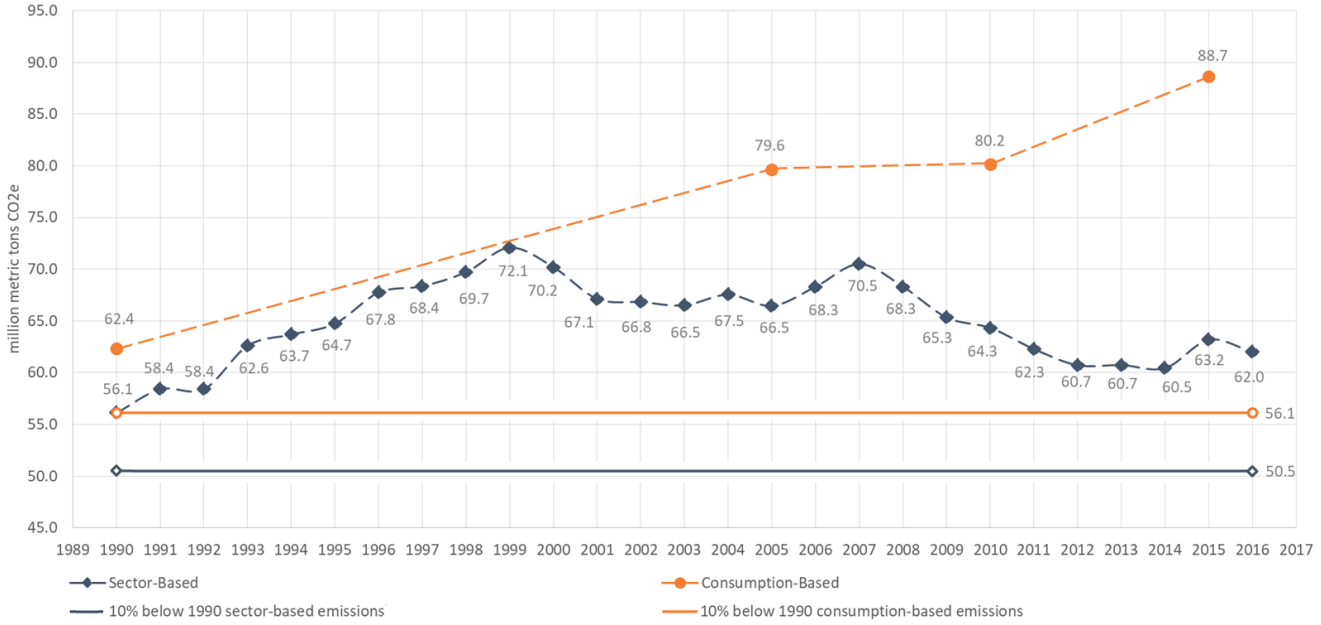
Oregon's imported emissions – at 51 million $MTCO_2e$ – are double those of our exports. These imported emissions are unique to the consumption-based inventory, and include emissions associated with a wide variety of imported finished goods such as furniture, coffee, tropical fruit, pork, cars, and clothing, as well as capital equipment purchased by Oregon businesses. It also includes additional out-of-state emissions that are not otherwise included in the sector-based inventory. These include out-of-state refinery emissions associated with producing fuels consumed in Oregon, out-of-state emissions associated with mining or processing coal and natural gas that is subsequently burned to produce electricity, and the out-of-state supply chain emissions of many services and goods consumed by Oregonians, such as medical supplies used in Oregon hospitals, electricity used by telecommunications companies serving Oregonians, or dishes and napkins used by Oregon restaurants (although only to the extent that they serve Oregon consumers).

Together, the two inventories demonstrate a carbon footprint in 2015 of 114 million metric tons of CO2e. Oregon contributes to climate change in many different ways, and the use of these two inventories provides a more complete understanding of that contribution.

4.2 25-Year Change (1990 – 2015)

Oregon has estimated sector-based emissions for every year between 1990 and 2016. Consumption-based emissions estimates are available for only four years: 1990 (in total only), and detailed estimates for 2005, 2010 and 2015. Focusing on the four years with data points for both inventories, several important observations can be made.

Figure 4.2
Trends in Oregon sector-based and consumption-based greenhouse gas emissions, 1990-2015



As shown in Figure 4.2, emissions for both inventories are consistently higher than 1990 levels. Additionally, the gap between the two inventories has grown overtime. Consumption-based emissions were approximately 6 million $MTCO_2e$ higher than sector-based emissions in 1990. Fifteen years later, in 2005, that gap doubled: consumption-based emissions were 13 million $MTCO_2e$ higher than sector-based emissions. Ten years later, that gap doubled again, to 26 million $MTCO_2e$. Starting in 2007 sector-based emissions declined annually but that trend has reversed recently with emissions increasing in 2015.

Several factors might explain the different trajectories of the two inventories. First, consumption in Oregon has risen sharply. Second, even as Oregon's in-state emissions intensity (as measured by emissions per dollar of economic output) fell, other areas of the world may not have made as much progress on a relative basis – particularly areas from where Oregon purchases more of our imported material, energy and services.

Policy interventions may also have contributed to the pattern of changes observed. Sector-based emissions are more widely discussed and understood, and more amenable to familiar policy interventions. Emissions for which the state of Oregon can directly regulate primarily fall in the sector-based inventory, whereas Oregon's consumption-based emissions are most directly addressed by policies enacted where the products and services we purchase are generated.

4.3 Conclusions

Both the sector- and consumption-based inventories offer important perspective and insight into how Oregon contributes to greenhouse gas emissions, and by extension, opportunities to reduce those emissions.

Oregon's sector-based greenhouse gas emissions rose steadily throughout the 1990s, from 56 to 72 million $MTCO_2e$ in 1999. After that peak year, emissions began to trend downward, but have more recently shown mixed results in the different sectors. Electricity emissions have fluctuated, which may result from differences in stream flows affecting the annual availability of hydropower. Reported data indicates that transportation fuel use has increased steadily for the past three years. Sector-based emissions in 2015 were estimated at 63 million $MTCO_2e$ and preliminary 2016 data indicates increased emissions in the transportation sector are offset by emission reductions in the electricity sector.

Detailed estimates of consumption-based emissions are now available for a 10-year period, starting in 2005. A less detailed estimate is available for 1990. Consumption-based emissions have trended upward during this period: from approximately 62 million $MTCO_2e$ in 1990 to 80 million $MTCO_2e$ in both 2005 and 2010. The very slight change between 2005 and 2010 perhaps reflects the lingering effects of the Great Recession. But by 2015, consumption-based emissions were up again, to almost 89 million $MTCO_2e$. During the 2005 – 2015 period studied in greater detail, emissions reductions resulting from efficiency improvements and other changes were overwhelmed by an increase in both overall and per-capita consumption.

Oregon has statutory goals to reduce in-state emissions 10 percent below 1990 levels by 2020 and 75 percent below 1990 levels by 2050. These statutory goals apply to emissions that occur inside Oregon. Both sector-based and consumption-based inventories include portions of these in-state emissions, but also include emissions that occur outside of Oregon. Current trends in emissions are not moving in the direction of these goals. Both inventories compiled by DEQ are above their respective 1990 levels. Consumption-based emissions are rising, while sector-based emissions are no longer decreasing.

Current data suggest that Oregon is not on track to achieve the near-term 2020 target of 10 percent below 1990 levels. Existing programs and policies (both regulatory and non-regulatory) in Oregon may further reduce emissions in both our sector-based and consumption-based inventories. Similarly, there are indications that other states and nations from which Oregon imports goods and services are adopting comprehensive requirements to reduce their greenhouse gas emissions. Together, these actions may allow for Oregon and Oregonians to reduce our contribution to global greenhouse gas emissions.