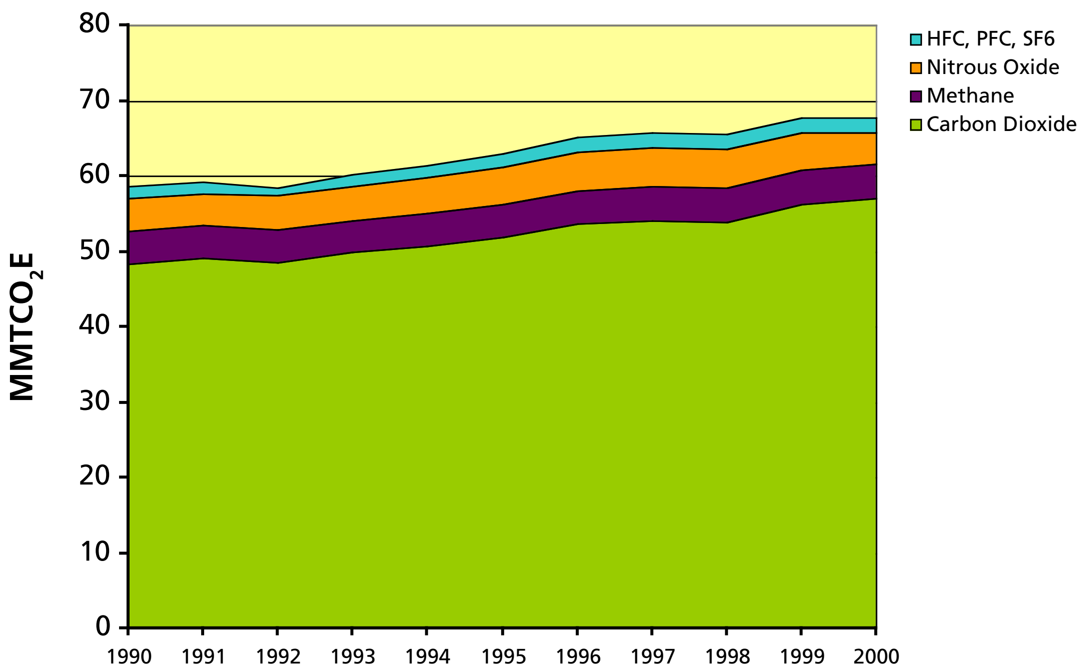
Appendix B

Inventory and Forecast of Oregon's Greenhouse Gas Emissions

In 2000, Oregon's greenhouse gas (GHG) emissions were 67.7 million metric tons of carbon dioxide equivalent[1] (MMTCO_2E).[2] That was about one percent of US GHG emissions, which exceeded 7 billion metric tons CO_2E.

By 2000, there was an 15 percent increase over Oregon's 1990 GHG emissions of 58.7 MMTCO_2E. According to its worst case forecast, the Department of Energy estimates that GHG emissions from Oregon will be 61 percent higher by 2025. Figure 1 shows change in emissions between 1990 and 2000. Table 2 shows historical emissions and Table 3 shows the forecast emissions.

Figure 1
Oregon Greenhouse Gas Emissions



[1] "Carbon dioxide equivalent (CO_2E)" refers to a comparison of the radiative force of different greenhouse gases related to CO_2, based on their global warming potential. It is a way to compare all greenhouse gases on a uniform scale of how much CO_2 would be needed to have the same warming potential as other gases over the same time scale. Following US Environmental Protection Agency (EPA) and international reporting protocols per the Second Assessment Report, methane is 21 times more powerful than CO_2 over 100°years and nitrous oxide is 310 times more powerful for example.

[2] The Department used the US Environmental Protection Agency State Tool for Estimating Greenhouse Gas Emissions to prepare its inventory except for variations in accounting for CO_2 emissions from electricity use, methane emissions from landfills, and a few minor sources. Exceptions are explained in the discussion of gases. EPA's *Emissions Inventory Improvement Program Volume VII: Estimating Greenhouse Gas Emissions* serves as a guide.

Of the GHG emissions from Oregon in 2000, 84 percent came from CO_2. The primary source of CO_2 pollution came from burning fossil fuels, such as coal at power plants serving the state, gasoline, diesel, and natural gas. There were also emissions from industrial processes, such as manufacture of cement and from combustion of fossil-fuel derived products in burning municipal and industrial wastes.

Table 1
Oregon Greenhouse Gas Emissions, $MMTCO_2E$

	1990	1995	2000
Gross CO_2	**49.2**	**52.6**	**57.9**
Net CO_2	**48.4**	**51.9**	**57.0**
CO_2 from Fossil Fuel Combustion	48.5	51.9	57.0
Industrial Processes	0.3	0.3	0.6
Waste	0.3	0.4	0.3
Landfill Carbon Storage	(0.8)	(0.8)	(0.8)
Methane	**4.2**	**4.4**	**4.5**
Stationary Combustion	0.1	0.1	0.1
Mobile Combustion	0.1	0.1	0.1
Natural Gas and Oil Systems	0.6	0.6	0.6
Enteric Fermentation	2.0	2.2	2.2
Manure Management	0.3	0.3	0.3
Waste	1.0	0.9	1.1
Wastewater	0.2	0.2	0.2
Nitrous Oxide	**4.4**	**4.9**	**4.2**
Stationary Combustion	0.1	0.1	0.1
Mobile Combustion	0.6	0.8	0.8
Manure Management	0.1	0.1	0.1
Agricultural Soil Management	3.4	3.8	3.1
Waste	0.0	0.0	0.0
Wastewater	0.1	0.1	0.1
HFC, PFC, and SF_6	**1.7**	**1.8**	**2.0**
Hydrofluorocarbons	0.0	0.3	0.7
Perfluorocarbons	1.1	1.1	0.9
Sulfur Hexafluoride	0.5	0.5	0.3
Gross Emissions	**59.5**	**63.8**	**68.6**
Net Emissions (Sources and Storage)	**58.7**	**63.0**	**67.7**

The inventory includes a reduction in emissions from storage of carbon from yard trimmings, wood products, and other miscellaneous products in landfills. The inventory does not include other land use and forest-management related sources and sinks, such as forest sequestration, because data were not available. They are being collected as part of another study, the West Coast Carbon Sequestration Partnership. Because that effort was already underway when the Advisory Group on Global Warming began, the Department did not attempt to duplicate its efforts.

Table 1 provides a summary of the major sources of greenhouse gas emissions. The individual sources are described in later sections.

In 2000, emissions from methane (CH_4), primarily from cattle and landfills, contributed 7percent of greenhouse gas pollution. Nitrous oxide (N_2O) emissions, primarily from agricultural practices, contributed about 6 percent to greenhouse gas pollution. Manufactured halocarbons, which include hydrofluorocarbons (HFC), perfluorocarbons (PFC), and suflur-hexafluoride (SF_6), accounted for the remaining 3 percent.

Carbon Dioxide Emissions
Fossil fuel combustion is the primary source of CO_2 emissions. Table 2 shows the breakdown of CO_2 emissions from fossil fuel combustion for the majors sectors: electricity generation, transportation, industrial, residential, and commercial.

Table 2
CO_2 Emissions by Sector from Fossil Fuel Combustion, $MMTCO_2$

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Electricity generation	20.7	21.0	20.6	21.4	21.6	22.0	22.7	22.9	21.7	22.9	24.2
Transportation	18.2	18.7	18.5	18.5	19.2	19.4	20.1	20.2	21.2	21.6	21.5
Industrial	5.6	5.6	6.2	6.3	6.3	6.9	6.7	6.9	6.6	7.4	6.8
Residential	2.1	2.2	1.8	2.2	2.1	2.1	2.3	2.3	2.4	2.6	2.6
Commercial	1.9	1.8	1.6	1.7	1.6	1.6	1.8	1.8	1.9	1.9	1.9
TOTAL	**48.5**	**49.3**	**48.8**	**50.1**	**50.8**	**51.9**	**53.6**	**54.1**	**53.8**	**56.3**	**57.0**

Oregon has a Benchmark to hold its CO_2 emissions at 1990 levels. However, between 1990 and 2000 total net CO_2 emissions grew almost 18 percent.

Electricity Generation. Electricity was the major source of CO_2 from fossil fuels in 2000, representing 42 percent of those emissions. Emissions from electricity grew 17 percent from 1990 to 2000, but its relative contribution stayed the same.

The Department calculates emissions from electricity generation based on the carbon content of the regional mix of electricity for the 11 contiguous western states. The Department took the average carbon content from 1990 through 2000 and applied that to electricity loads. While some states inventory only emissions from generating facilities within the state, the Department believes a regional carbon mix better reflects the carbon mix associated with the delivery of electricity to Oregon's consumers.

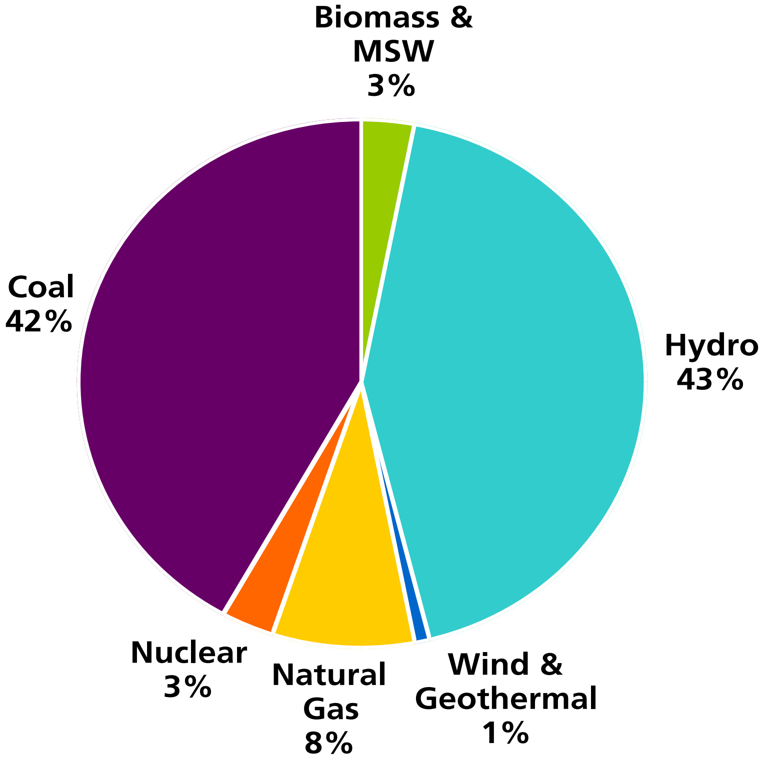
The regional approach better reflects carbon emissions for the following reasons: 1) The regional grid provides electricity to the state. 2) Taking credit for the hydropower generated for the Bonneville Power Administration from dams on the Columbia River, as it is allocated to Oregon in national inventories, does not reflect the way that electricity is distributed in the region. 3) Oregon's second-largest investor-owned utility, PacifiCorp, has most of its generation out of state, and most of that is coal-fired.

Although the comprehensive emissions inventory stops at 2000, the Department does have data from 2002 that reflect the carbon content of the electricity serving the state. This is based on data specific to Oregon utilities, rather than the more general regional average. However, it does not differ significantly from the regional number. Figure 2 shows the sources of electricity that supplied the state in 2002.

The generation mix for 2002 in Figure 2 is based on power plants whose output is dedicated to Oregon utilities. Utilities can generate this output at facilities that they own, either in-state or out-of-state. It also includes cases where a utility purchases the output of a specific power plant. For Portland General Electric, the total of such purchases and ownership is less than its total electric load. In that case, the calculations for the figure assume that the remainder of the electricity is supplied by a mix of resources from the Northwest Power Pool. Utility purchases from the Bonneville Power Administration (BPA) under long term contracts are credited with the BPA resource mix.

The mix of sources shows hydropower, which has no direct emissions, at 43 percent and coal at 42 percent. At 8 percent, natural gas-fired plants were the third largest source of electricity supply. Non-fossil fuel sources also included biomass and municipal solid wastes, shown as one category, and nuclear, which each supplied about 3 percent. Wind and geothermal together supplied only 1 percent.

Figure 2
Electricity Generation Mix Supplying Oregon 2002



Transportation. Gasoline and diesel fuel use in transportation[3] were the second largest sources of emissions from fossil fuels at 38 percent in 2000. Emissions from transportation grew 18 percent from 1990 to 2000, but the relative contribution has not changed.

Direct Natural Gas and Distillate Use. CO_2 emissions from the industrial and residential sector from direct natural gas and distillate fuel combustion grew by 22 and 23 percent, respectively, from 1990 to 2000. Other sources were asphalt and petroleum coke in the industrial sector and liquefied petroleum gas in the residential sector. Emissions from the commercial sector were flat.

Methane

Methane emissions contributed about 4.5 $MMTCO_2E$ in 2000. That represented about 7 percent of Oregon's 2000 greenhouse gas inventory. The distribution of methane emissions for 2000 is shown in figure 3.

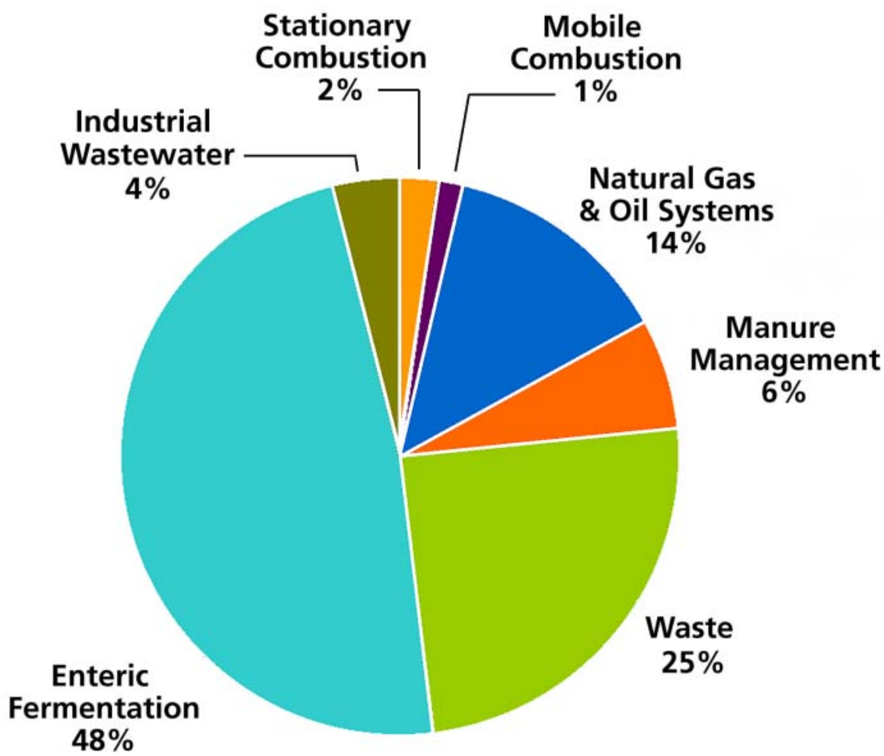
More than half of methane emissions came from agricultural practices. Enteric fermentation, or burps from cattle and other domesticated animals, contributed 48 percent. The methane is generated in the rumen, or first stomach, of cattle and other ruminants. Another 6 percent came

[3] Residual fuels use by vessels is not included because international ships are the primary purchasers. They purchase fuel at any port, based on price. Therefore combustion of the fuel is not directly related to economic activity within Oregon.

from manure management, both from that managed in lagoons on farms or that simply deposited on the ground.

The second largest source of methane was from waste in municipal and industrial landfills at 26 percent.[4] Another 4 percent came from wastewater from pulp and paper production, fruit and vegetable processing, and red meat and poultry processing.

Figure 3
Methane Emissions in Oregon



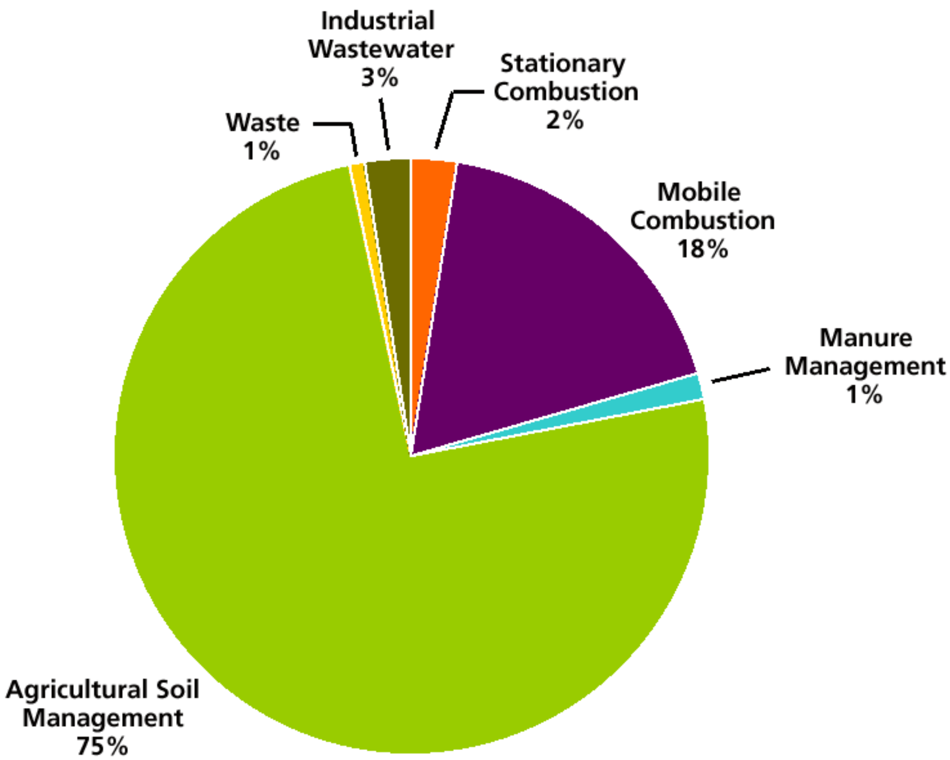
Other sources include leaks from natural gas and oil systems (calculated from miles of pipeline and number of services), emissions from vehicles, and emissions from combustion of natural gas, distillate, residual fuel, and wood in homes and businesses.

Nitrous Oxide
Nitrous oxide (N_2O) emissions contributed about 4.2 $MMTCO_2E$ in 2000. That represented about 6 percent of Oregon's 2000 GHG emissions. The distribution of N_2O emissions for 2000 is shown in figure 4.

[4] This represents an estimate of methane actually released to the atmosphere. The amount of methane produced in landfills is significantly higher, but some is converted to CO_2 as it passes through surface soils and some Oregon landfills also capture and flare methane. Since the CO_2 released from landfills is not fossil-based, it is not calculated separately. It is assumed to be recycling through the biosphere.

The primary source of N_2O emissions is from agricultural soil management through numerous pathways. N_2O is emitted from agricultural soils due to synthetic and organic fertilizer use, application of animal wastes through daily spread activities, application of managed animal wastes, crop residues remaining on agricultural fields, biological nitrogen fixation by certain crops, cultivation of highly organic soils, and land application of sewage sludge. N_2O also is emitted from soils from direct deposit of animal wastes in pastures, ranges and paddocks. There are also indirect emissions from fertilizers and from leaching and runoff. In addition to agricultural soils management, N_2O is directly emitted from the manure decomposition process.

Figure 4
Nitrous Oxide Emissions 2000



Small amounts of N_2O are emitted from internal combustion engines and during the catalytic after-treatment of exhaust gases, but these processes are not well understood. In any case, those emissions stayed relatively flat over the period 1990-2000.

Perfluorocarbons (PFCs)
Aluminum production was the major source of PFCs between 1990 to 1996. The emissions occur during the reduction of alumina in the primary smelting process. (As of 2001, aluminum is no longer produced from alumina in Oregon, and recycling aluminum does not produce PFC emissions.)

Beginning in 1997, emissions from PFCs for plasma etching and chemical deposition processes in the semiconductor industry exceeded aluminum production, and by 2000 represented about 70 percent of PFC emissions. However, total emissions of PFCs dropped from 1.2 $MMTCO_2E$ in

1990 to 0.9 $MMTCO_2E$ in 2000. Overall, PFC emissions were about 1 percent of the state's GHG emissions in 2000.

Hydrofluorcarbons (HFCs)
HFCs are most commonly used as a replacement for CFC in cooling and refrigeration systems. (CFC was formerly the most common refrigerant. However, CFC destroys the stratospheric ozone layer. Its production is banned by international treaty.) Use and discharge of HFC is controlled as a refrigerant, but not for other uses.

HFCs are used for foam blowing, fire extinguisher applications, aerosols, sterilization, and as solvents. HFCs are also used in plasma etching and chemical deposition processes in the semiconductor industry. While HFCs do not damage the ozone layer, they are powerful greenhouse gases. HFC emissions rose from nearly zero in 1990 to about 0.7 $MMTCO_2E$ in 2000, when they accounted for about 1 percent of Oregon's GHG emissions.

Sulfur Hexafluoride (SF6)
SF_6 is one of the most powerful greenhouse gases. It is 23,900 times more powerful than CO_2. The largest use of SF_6 is as an electrical insulator in transmission and distribution equipment. SF_6 is also used for plasma etching and chemical vapor deposition processes in the semiconductor industry. There was some SF_6 emitted from aluminum production as well.

SF_6 emissions dropped from 0.5 $MMTCO_2E$ in 1990 to 0.3°$MMTCO_2E$ in 2000, primarily because of declines in emissions from the electricity sector due to better control practices. SF_6 was about 0.5 percent of total GHG emissions in 2000.

Forecasts

The Department forecasts that Oregon's greenhouse gas emissions will grow by 36 $MTCO_2E$, or 61 percent, in the worst case (business-as-usual) estimate from 1990 to 2025. That rate assumes no change from current practices. In reality, it will probably grow less. Table 3 shows the forecast by sources of gases. The following discussion highlights major elements of the forecast.

Electricity and Natural Gas. For CO_2 emissions from electricity and natural gas, the Department used a growth rate of 1.6 percent, which is a composite of Northwest Power and Conservation Council forecasts and forecasts in the integrated resource plans of Portland General Electric, PacifiCorp, and Northwest Natural.

Transportation. For transportation, the 1990 Oregon emissions were 18.3 $MMTCO_2$, according to the Federal Energy Information Administration (EIA) data. By the year 2000, emissions reached 21.5 MMT CO_2, for an annual growth rate of 1.6 percent. Based on the Oregon Department of Transportation's forecast for taxed fuels and U.S. Department of Energy forecasts for jet fuel and freight diesel, the Oregon Department of Energy forecast an annual growth rate of 1.6 percent, leading to emissions of 32.0 MMT CO_2 by the year 2025. The base case transport CO_2 emissions grow 33 percent between 2000 and 2025.

Methane. The forecast for methane emissions from landfills is described in the introduction to the section on materials use in the main report. In summary, the historic trend is used as the starting point for projecting future growth in waste generation. Using Department of Environmental Quality and US EPA data, estimates were made of the rate of change in per-capita waste generation during the period 1993 to 2002 for 30 different categories of wastes. The rates of adjusted growth in per-capita waste generation (by material) were then related to the rate of growth in inflation-adjusted Oregon personal income during the same period.

TABLE 3
Historical and Forecast Oregon Greenhouse Gas Emissions, $MMTCO_2E$

	1990	1995	2000	2015	2025
Gross CO_2	**49.2**	**52.6**	**57.9**	**70.6**	**80.3**
Net CO_2	**48.4**	**51.9**	**57.0**	**69.6**	**79.0**
CO_2 from Fossil Fuel Combustion	48.5	51.9	57.0	69.4	78.8
Industrial Processes	0.3	0.3	0.6	0.9	1.1
Waste	0.3	0.4	0.3	0.3	0.4
Landfill Carbon Storage	(0.8)	(0.8)	(0.8)	(1.0)	(1.2)
Methane	**4.2**	**4.4**	**4.5**	**5.9**	**6.5**
Stationary Combustion	0.1	0.1	0.1	0.1	0.0
Mobile Combustion	0.1	0.1	0.1	0.1	0.0
Natural Gas and Oil Systems	0.6	0.6	0.6	0.7	0.8
Enteric Fermentation	2.0	2.2	2.2	2.6	2.9
Manure Management	0.3	0.3	0.3	0.3	0.3
Waste	1.0	0.9	1.1	1.9	2.3
Wastewater	0.2	0.2	0.2	0.2	0.2
Nitrous Oxide	**4.4**	**4.9**	**4.2**	**5.5**	**6.0**
Stationary Combustion	0.1	0.1	0.1	0.1	0.0
Mobile Combustion	0.6	0.8	0.8	1.0	1.1
Manure Management	0.1	0.1	0.1	0.0	0.0
Agricultural Soil Management	3.4	3.8	3.1	4.3	4.7
Waste	0.0	0.0	0.0	0.0	0.0
Wastewater	0.1	0.1	0.1	0.1	0.2
HFC, PFC, and SF_6	**1.7**	**1.8**	**2.0**	**2.5**	**3.3**
Hydrofluorocarbons	0.0	0.3	0.7	1.9	2.6
Perfluorocarbons	1.1	1.1	0.9	0.5	0.5
Sulfur Hexafluoride	0.5	0.5	0.3	0.2	0.1
Gross Emissions	**59.5**	**63.8**	**68.6**	**84.6**	**96.0**
Net Emissions (Sources and Storage)	**58.7**	**63.0**	**67.7**	**83.6**	**94.8**

The estimate is that per-capita waste generation, aggregated across all 30 material categories, will grow to 10.1 pounds per person per day in 2025 under the "business as usual" scenario. This assumes that relationships between personal income and materials use/waste hold constant and is based on projections of inflation-adjusted personal income from the Oregon Department of Administrative Services. Coupled with projected population increases, total in-state waste generation (all discards, including recycling and composting) is projected to grow from 5.1 million tons in 2003 to 8.4 million tons in 2025. The recovery rate (recycling and composting) of these rates, currently at about 46 percent, is assumed to hold constant, so not all discards end up in landfills.[5]

Oregon also imports significant quantities of municipal solid waste (garbage) from other states. Waste imports are modeled, growing at a rate of about 4.6 percent per year, from about 1.5 million tons projected in 2003 to 4.0 million tons in 2025. Only emissions associated with the disposal portion of the life cycle are counted for these imported wastes.

Other GHG. Most other projection sources are forecast based on linear regressions or exponential regressions of historical data. The Department did not have source-specific forecasts for the many minor contributors. Because most major semiconductor manufacturers have programs to reduce HFC, PFC, and SF_6, we forecast that those emissions from that sector will return to 1995 levels in the future. The 1995 level is therefore the value in the 2015 and 2025 forecast for that sector.

[5] The non-landfill benefits of recycling, composting, and waste prevention, such as reduced fossil fuel use and increased carbon storage in forests and landfills, were included in estimates of the greenhouse gas benefits of specific measures. However, the state inventory does not account for non-landfill offsets, such as savings in industrial processes from using recycled feed-stocks, in part because many of the benefits involve emission reductions outside of Oregon.