Washington's Greenhouse Gas Emissions: Sources and Trends

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Overview

Global greenhouse gas (GHG) concentrations continue to increase and many states and nations are taking actions to reduce their emissions of greenhouse gases. Washington State has joined Oregon and California in an effort to reduce emissions as part of the West Coast States Governors' Global Warming Initiative: http://www.ef.org/westcoastclimate/ . This paper reviews the sources of GHG emissions from Washington and their historical trends and is an update of the 2004 report *Washington State's Greenhouse Gas Emissions: Sources and Trends*.[1]

The principal GHG's emitted from activities in Washington include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and other gases with high global warming potentials[2]. The emission sources are categorized into three major sectors: energy, industrial processes and agriculture. There are several sources for most of these gases and they are shown in Table 1. For example, fossil fuel combustion produces mainly CO_2, but CH_4 and N_2O are also produced in significant quantities by internal combustion engines. In the agricultural sector, manure decomposition produces both CH_4 and N_2O.

Greenhouse gases differ in their impact on global warming. For example, one pound of nitrous oxide is 296 times more potent than a pound of carbon dioxide in affecting global warming. This means that emissions of relatively small quantities of gases like nitrous oxide can have significant impacts on global warming potential. Table 1 shows the global warming potential (GWP) values for the various gases taken from the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report[3]. The GWP's are used to convert emissions of the other GHG's, expressed in tons, into equivalent CO_2 emissions also expressed in tons: 1 ton of methane is equivalent to 23 tons of CO_2.

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[1] 2004 Washington State's Greenhouse Gas Emissions: Sources and Trends, Jim Kerstetter, WSU Energy Program and CTED Energy Policy Division: http://www.cted.wa.gov/site/853/default.aspx
[2] Gases with high global warming include sulfur hexafluoride (SF6), hydroflourocarbons (HFC) and perflourocarbons (PFC).
[3] Intergovernmental Panel on Climate Change, Third Assessment Report: http://www.ipcc.ch/pub/reports.htm

Table 1 Major Sources of Greenhouse Gas Emissions in Washington

Sector	Activity	CO_2	CH_4	N_2O	High GWP gases
Energy	Fossil fuel combustion	**X**	**X**	**X**	
	Coal mining & NG Distribution		**X**		
Industrial	Cement & Lime	**X**			
	Aluminum	**X**			**X**
	Solid waste/landfill	**X**	**X**	**X**	
	Semiconductor production				**X**
	Electric power transmission and distribution				**X**
Agriculture	Enteric Fermentation		**X**		
	Manure management		**X**	**X**	
	Soil Fertilizer			**X**	
Global Warming Potential (GWP)		1	23	296	Varies between 5,000-24,000

Emissions were calculated based on methodology outlined in the *State Tool for Greenhouse Gas Inventory Development*, a series of worksheets developed by the U.S. Environmental Protection Agency[4]. The worksheets provide information on data sources, emission factors, and methods that are consistent with the *Intergovernmental Panel on Climate Change Good Practice Guidance*[5]. However, in the case of the worksheet for calculating CO_2 from energy sources, the combination of worksheet emission data that was current only through 2001 and the difficulty of using non-standard data collected by the state meant it needed to be completely reconstructed. Our method is based on combining data from our previous report with more current data where it is available. The emissions of all gases are given in million metric tons (MMT) of carbon dioxide equivalents to permit easy comparisons of their impact on global climate change. All data for 2003 and 2004 are preliminary and are denoted with a P in the figures.

Substitution of Ozone-Depleting Substances-
The use of hydrofluorocarbons (HFCs) as the primary substitute for ozone-depleting substances is growing rapidly nationwide. HFCs are also used to manufacture semiconductors. Although they do less damage to the ozone layer, HFCs have a high global warming potential.
See the EIA GHG Inventory for more details, http://www.eia.doe.gov/oiaf/1605/ggrpt/index.html

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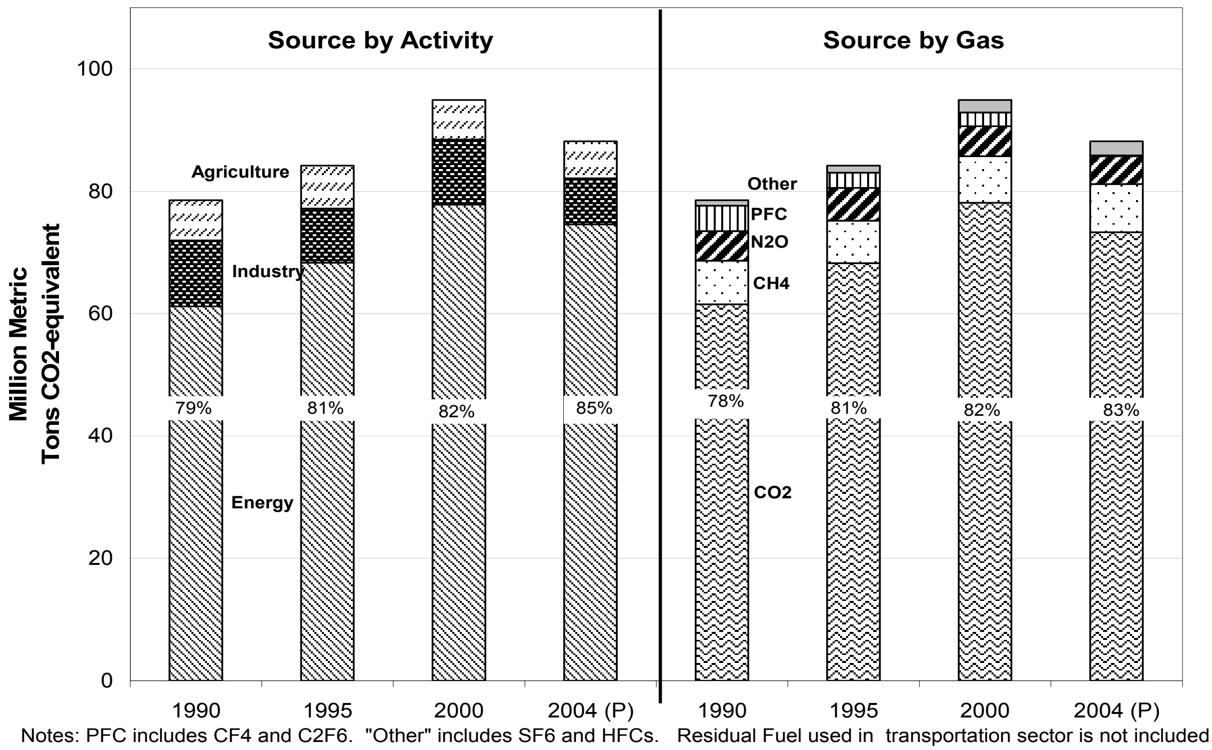
4 EPA Emission Inventory Improvement Program: http://www.epa.gov/ttn/chief/eiip/techreport/volume08/index.html
5 Intergovernmental Panel on Climate Change, Good Practice Guidance: http://www.ipcc-nggip.iges.or.jp/

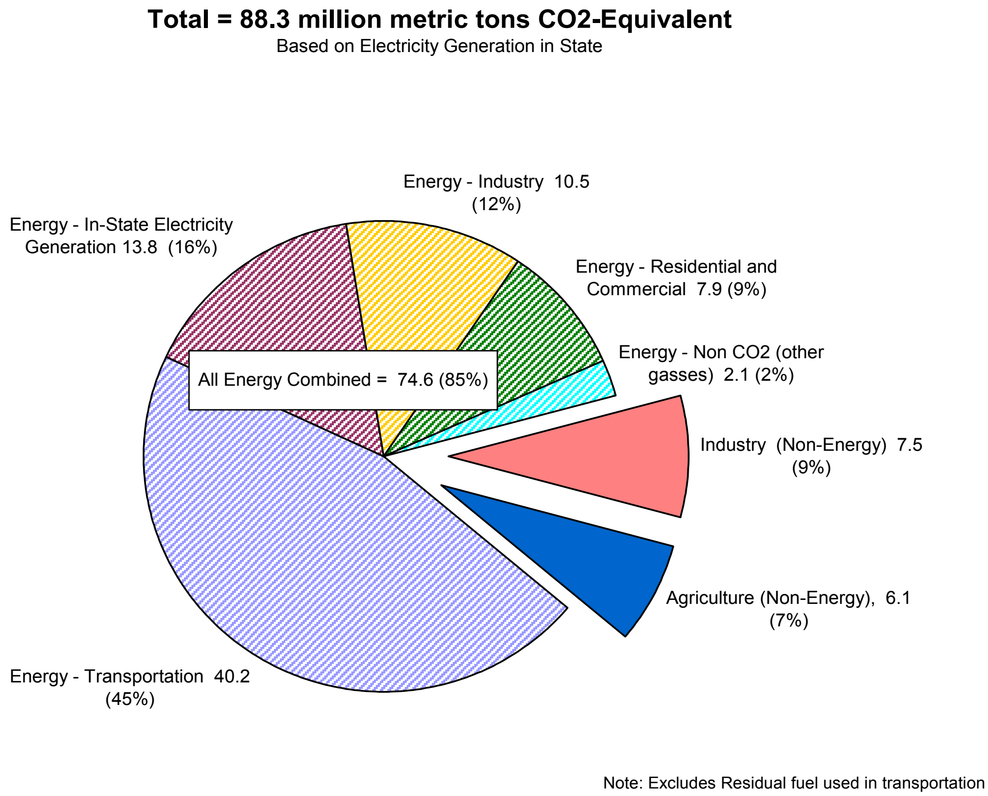
Figure 1 shows the contributions from the different sectors and gases for the years 1990, 1995, 2000 and 2004. Energy related emissions are the dominant source of GHG emissions and have increased from 61.2 MMT CO_2-equivalent (CO_2-e) in 1990 (excluding residual fuel for transportation) to 74.6 MMT CO_2-e in 2004, while their share has increased from 79 percent of total emissions to 85 percent over the past fourteen years. Carbon dioxide is the dominant GHG followed by methane, nitrous oxide, perfluorocarbons and sulfur hexafluoride.

Figure 1 Greenhouse Gas Emissions by Sector and Gas Type



Non-energy industrial sector GHG emissions have declined from 14 percent to 9 percent, primarily due to reduced emissions from aluminum production. This reduction is the result of two factors, process changes that reduced CO_2 and PFC emissions per ton of aluminum produced, and the post-2000 decline in aluminum production rates. Non-energy agricultural sector greenhouse emissions have remained relatively constant but their percentage contribution has declined as total emissions have increased.

Figure 2 All Greenhouse Gas Emissions in Washington for 2004 (preliminary estimate)



As seen in Figure 2, the majority of energy GHG emissions and almost half of total emissions are from the transportation sector. The industrial sector is separated into process-related emissions and energy-related emissions.

The remainder of this paper only examines energy-related CO_2 emissions, as they are the dominant source of GHG emissions in the State of Washington.

<u>Energy –Related Greenhouse Gas Emissions</u>

Figures 3 and 4 show carbon dioxide (CO_2) emissions from the combustion of fossil fuels in the residential, commercial, industrial, transportation, and electric power sectors from 1960 to 2004. Emissions for 2003 and 2004 are preliminary values.

1. Residential, Commercial and Industrial Sectors

Some obvious trends and changes are apparent. Emissions from the use of fossil fuels in the residential, commercial and industrial sectors have been relatively constant over the past 40 years, even though the use of energy in these sectors has increased. Two factors have allowed this to occur. First, there has been fuel switching from coal and petroleum fuels to natural gas. Since natural gas emits fewer pounds of carbon dioxide per million Btu of heat content than coal or petroleum fuels, fuel switching has moderated CO_2 emissions. The second factor is the increasing efficiency with which fossil fuel energy is utilized in these sectors. In the commercial and residential sectors, new buildings are significantly more efficient than those built in 1960. In the industrial sector efficiency often means replacing older boilers or heating devices with more efficient modern units.

Figure 3 Historical Trends of Energy CO_2 Emissions by Sector

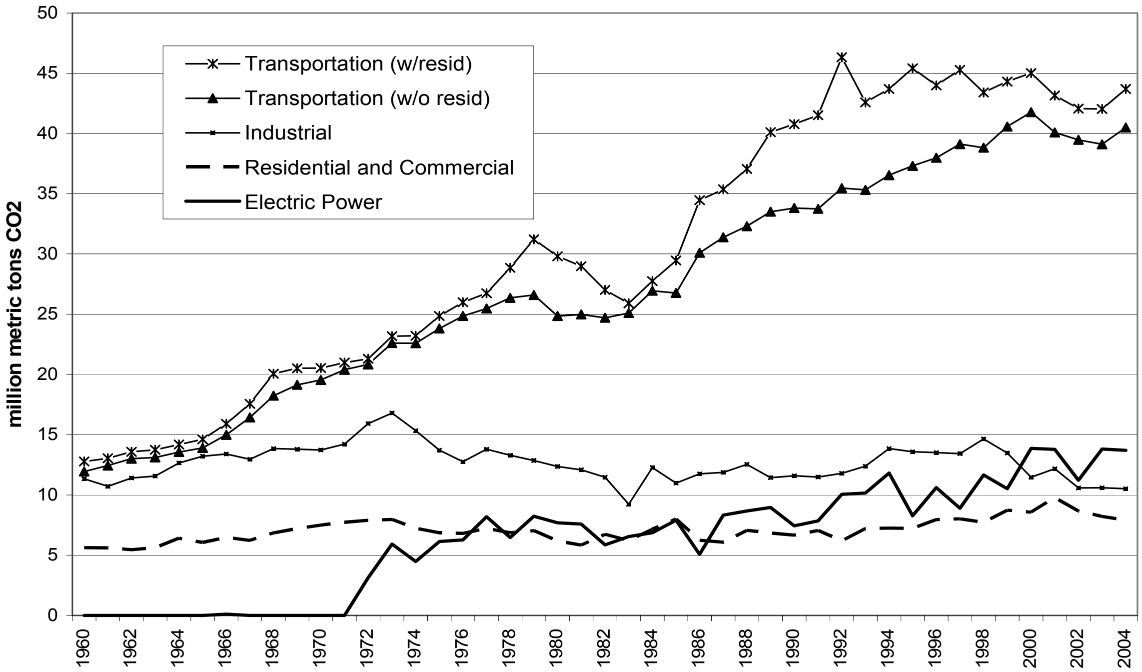
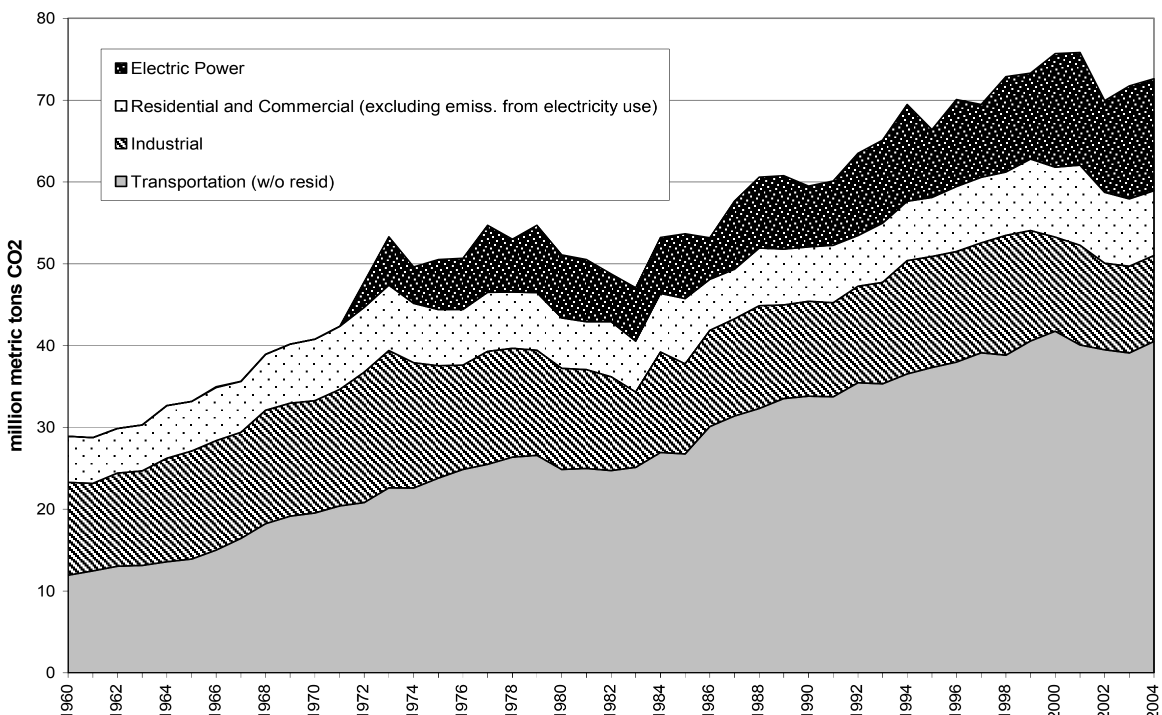


Figure 4 Cumulative Energy-related CO_2 Emissions by Sector



In the following three figures, the lower, dotted line shows the emissions from the direct use of fossil fuels for each of the sectors. The upper, solid line shows the impact of adding CO_2

emissions from electric power generation in proportion to the electricity consumed by that sector. Note that all data is current through 2003 and is in million metric tons (MMT).

Figure 5 Industrial Sector CO_2 Emissions (MMT)

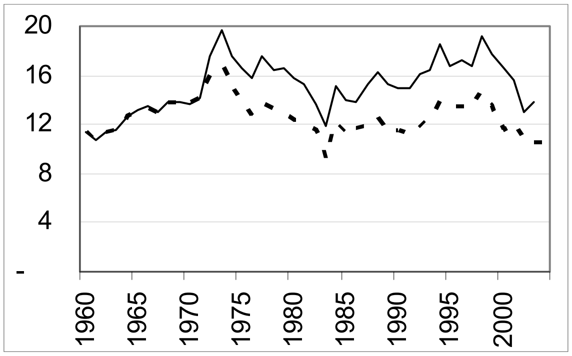
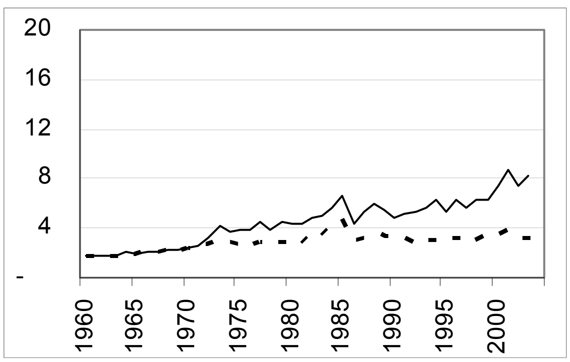


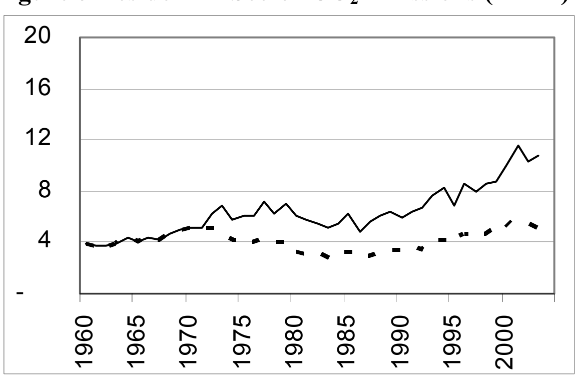
Figure 5 shows the direct use of fossil fuels in the industrial sector has remained relatively flat over the last 40 years. Through the mid 1990's this is due largely to increased efficiencies. The steep decline beginning in the late 1990's reflects the decline of the manufacturing sector in Washington State.

Figure 6 Commercial Sector CO_2 Emissions (MMT)



In Figure 6, the emissions from the direct use of fossil fuel (dotted line) increases slightly over the 40 year time-period. This is notable when considering the large addition in square footage of commercial buildings over this time period and the fact that the line reflects primarily space heating.

Figure 7 Residential Sector CO_2 Emissions (MMT)



In Figure 7, it is notable that since the mid 80's, the direct use of fossil fuels in residential buildings, primarily used for space heating, has increased more than the other two sectors. Between 1991 and 2000, the state added 305,000 single family homes (35% electrically heated, the remainder primarily gas) and 100,000 multi-family units (74% electrically heated). The square footage of the average single-family home has increased significantly over this time.

For the commercial and residential sector, emissions from electricity use more than doubles the emissions attributed to these sectors.

In order to obtain a historical series, the electricity emissions in these figures are based on electricity generated in-state, as opposed to electricity sold by utilities to consumers in Washington. This is discussed in more detail in the electricity section. The electricity used by consumers in Washington is associated with emissions approximately 30 percent higher than what is shown here.

2. Transportation sector

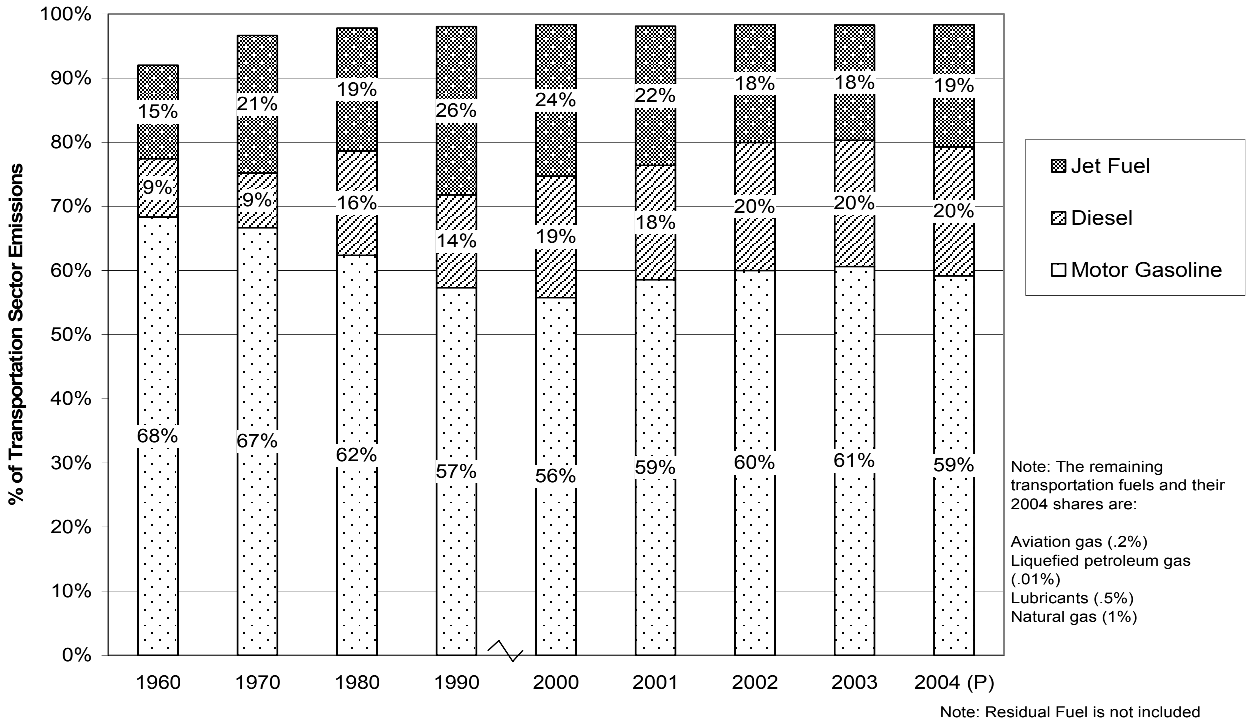
The other obvious characteristic of Washington's energy related CO_2 emissions profile shown previously in Figures 3 and 4 is the dominant role played by the transportation sector, which includes emissions from highway vehicles and non-highway vehicles, ships, trains and planes. Most of the growth in overall CO_2 emissions in Washington State is from the transportation or electricity generation sectors.

In 1960, transportation (excluding residual fuel) accounted for 41 percent of energy related CO_2 emissions. The percentage increased to 49 percent by 1980 and 57 percent by 1990. Through the 1990s and early 2000s, transportation's share of energy-related emissions has remained between 52 – 56 percent. Of course, the transportation percentage share is also influenced by emission increases or decreases in the other sectors. The total CO_2 emissions are more than three times higher today than in 1960.

Figure 8 shows the dominance of motor gasoline, diesel and jet fuel CO_2 emissions within the transportation sector, accounting for 98 percent of this sector's emission in the year 2004. While absolute CO_2 emissions have increased for the transportation sector, the share of CO_2 emissions within this sector corresponding to motor gasoline use declined through 2000. There are several causes of this share decline including the rise in federal vehicle fuel efficiency standards through the 1970s and1980s, and the more rapid increase in the use of jet fuel for personal travel and diesel fuel for moving freight: consequently the percentage shares for jet and diesel fuel have risen, while that for motor gasoline has fallen.

Use of Residual Fuel for Transportation
Bunker fuel makes up the majority of residual fuel used for transportation. Data for residual fuel are very volatile because large ships can buy fuel at any port and don't refuel often. The consumption data which is the basis of the emissions estimate includes both fuel consumed on ships and fuel transported via ships. Which political entity is ultimately responsible for these emissions is not clear. Residual fuel used in transportation is not included in most presentations of data in this report due to an inventory agreement between the west coast states and is in accordance with federal guidelines.

Figure 8 Transportation Emissions



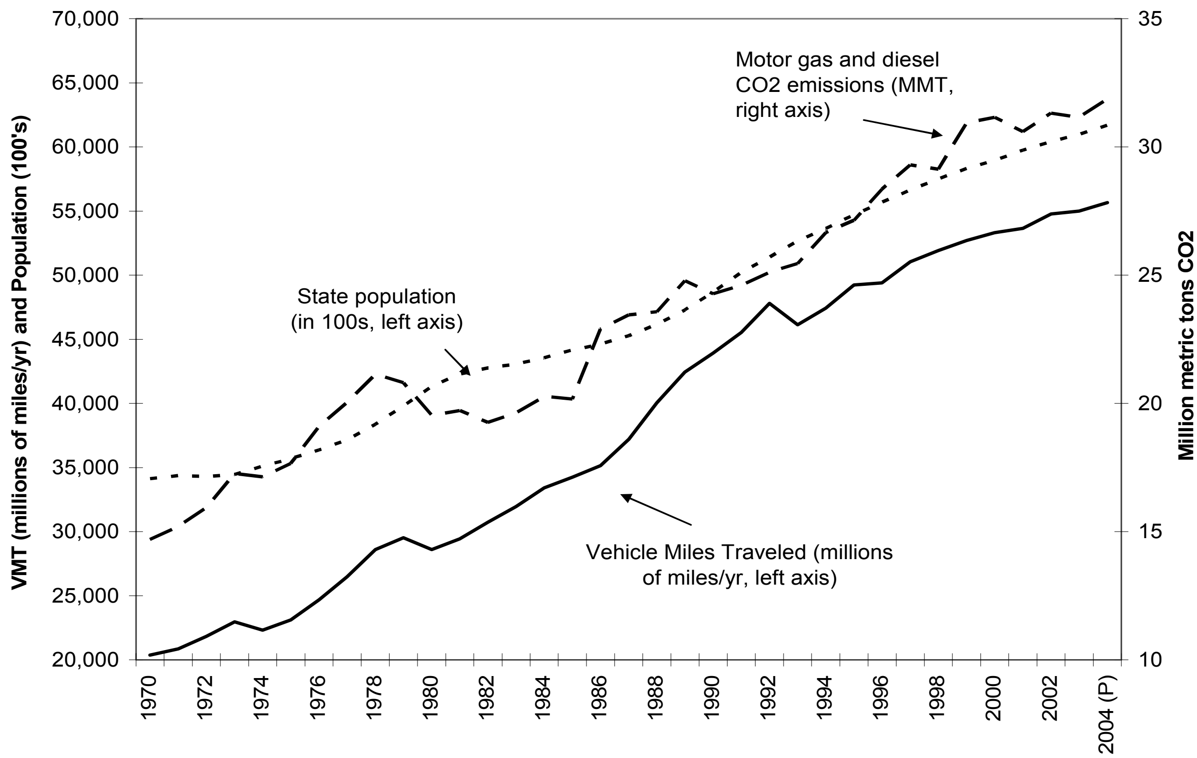
Because transportation is the largest sector, and a growing source of CO_2 emissions for Washington State, a more detailed evaluation of transportation is warranted. Figure 9 below illustrates the trend in ground-based transportation CO_2 emissions (motor gas and diesel consumption used as basis,) vehicle miles traveled (VMT) and state population.

The most obvious relationship in Figure 9 is that population growth is causing the increase in ground transportation CO_2 emissions and VMT. A closer look at Figure 9 reveals two critical factors besides population that affect transportation CO_2 emissions.

First, from 1970 to 1990 VMT rose faster than population growth, but over the last ten years or so the rate of change in VMT has decreased significantly, and is now more closely paralleling population growth. The recent change in the relationship between VMT and population growth, may be the result of increasing traffic congestion, growth management practices, and over the last few years higher fuel prices. The message from Figure 9 is that VMT -and especially per capita VMT- is a determinant of ground-based transportation CO2 emissions.

The second feature of note in the chart is that from the late 1970s to the early 1990's ground transportation CO_2 emissions grew more slowly than VMT (more closely paralleling population), and from the early 1990's emissions have grown more rapidly than either VMT and population. This is a reflection of increasing vehicle fuel economy from the late 1970' through about 1990, and then slightly decreasing fuel economy thereafter (due to increasing numbers of light duty trucks and heavy duty truck freight). Vehicle fuel economy then is the second critical factor in determining ground-based transportation CO_2 emissions.

Figure 9 Vehicle Miles Traveled, Population and Transportation CO_2 Emissions for Washington State

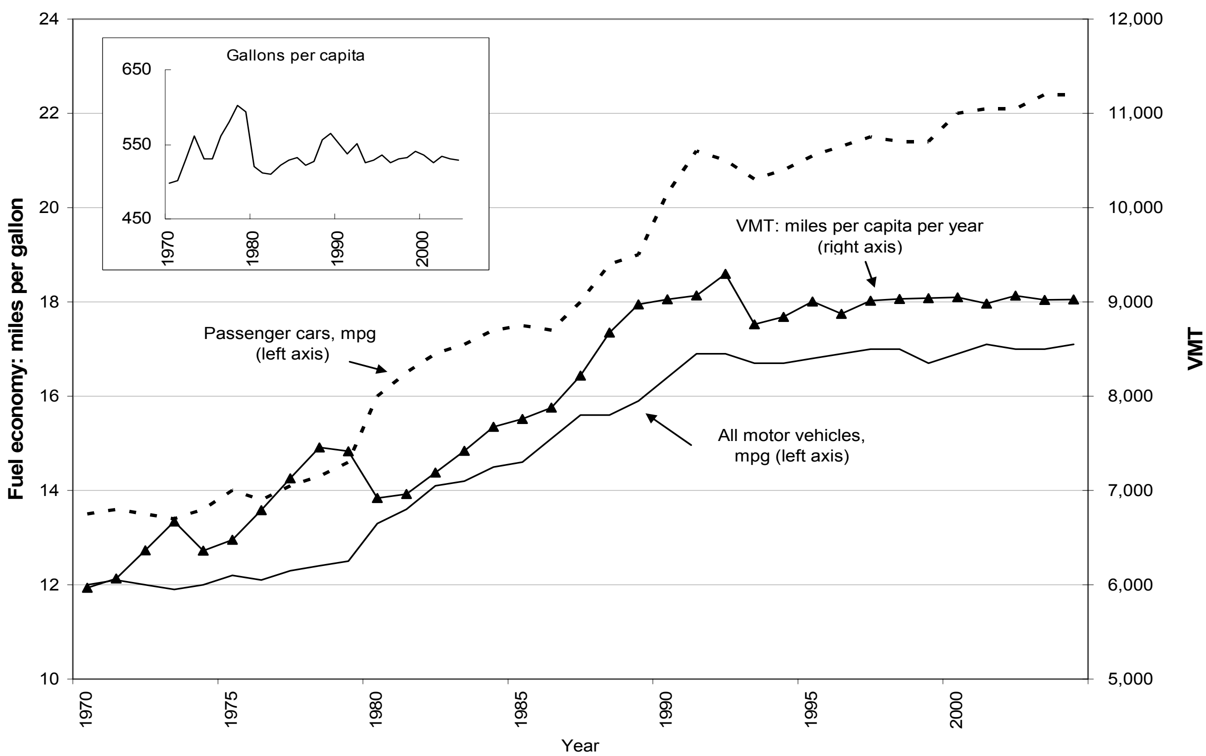


Source: Federal Highway Administration: Federal Highway Statistics 2005, Section V.

Since 1970 several factors besides population growth have influenced the trend line for transportation CO_2 emissions, as shown in Figure 10 below. From the late 1970's through 1985 automotive fuel economy standards (CAFE standards) and high fuel prices resulted in a rapid increase in vehicle fuel economy and put a check on the steady increase in per capita VMT that had been going on for decades. These two factors halted and briefly reversed the trend of rapidly increasing per capita consumption of gasoline and diesel (see insert in Figure 10) and caused ground-based transportation CO_2 emissions to decline for several years.

During the mid 1980's the inflation adjusted price of transportation fuels declined rapidly and per capita VMT began to increase at its previous rapid rate. Countering this resurgent trend in VMT (and consequently fuel consumption) somewhat were the last required increases in CAFE standards and the continuing replacement of older inefficient vehicles from the 1970's. The net effect was that per capita consumption of gasoline and diesel rose a bit (essentially a proxy for per capita transportation CO_2 emissions). A combination of the waning effects of vehicle fuel efficiency standards, increasing per capita VMT and population resulted in the resumption of growth in transportation CO_2 emissions.

Figure 10 Transportation Fuel Efficiency and Vehicle Per Capita VMT



Source: Federal Highway Administration: Federal Highway Statistics 2005, Section II and V.

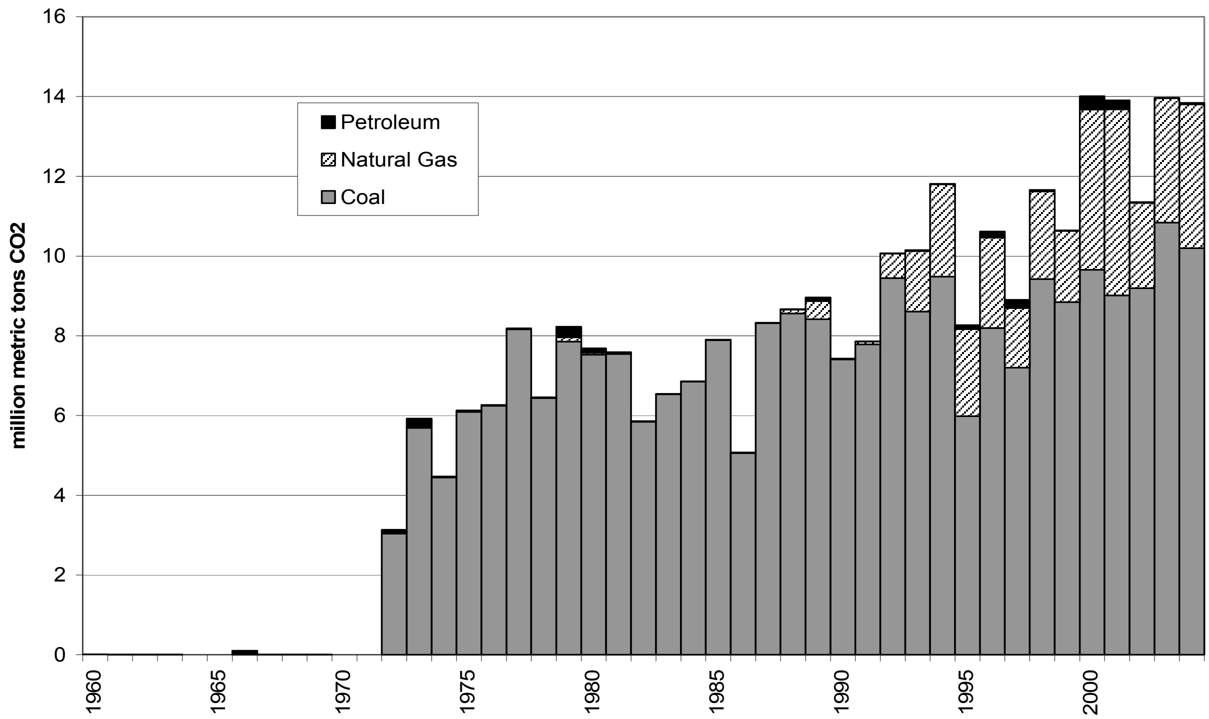
As shown in Figure 10, while the overall efficiency of the *passenger* car fleet continued to slowly increase through the 1990's, the efficiency of the *entire* vehicle fleet (cars, light duty trucks, sport utility vehicles (SUVs), buses and heavy freight trucks) flattened out by 1990 as people began to replace cars with light duty trucks and SUVs. In addition the amount of freight moved by heavy duty trucks has increased very rapidly over the past twenty years and represents a growing fraction of ground based transportation CO_2 emissions. At the same time that overall fleet fuel efficiency began to stagnate, the rise in per capita VMT ground to a halt, fortuitously preventing an even more rapid rise in transportation CO_2 emissions

3. Electric power sector

Carbon dioxide emissions from electric power generation are quite different from the other sectors. Up until 1972, there were virtually no carbon dioxide emissions, as electric power in Washington was generated almost entirely by hydropower. When the coal fired Centralia power plant came on line there was an obvious and dramatic increase in emissions from the electric power sector. Emissions stayed relatively constant until the early 90's when natural gas began to be used for electrical generation and the emissions increased, although emissions from Centralia are still the majority. Over the last 40 years, about a third of the increase in Washington's CO_2 emissions has been from the electric power sector.

Figure 11 shows CO_2 emissions by fuel type since 1990 for the generation of electricity. Notice the jump in emissions associated with natural gas fired generation during the West Coast electricity market crisis during the year 2000 and the drought of 2001.

Figure 11 Carbon Dioxide Emissions from In-State Electric Power Generation by Fuel Type

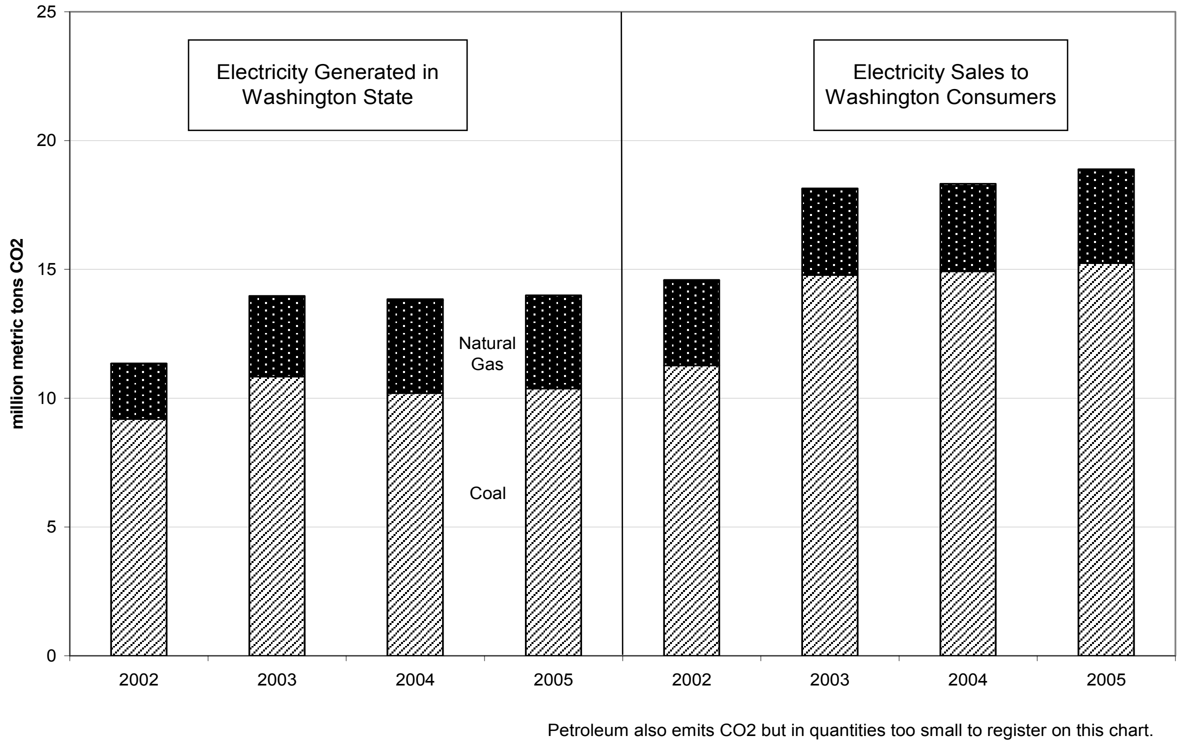


Another method of accounting for electricity emissions is to look at the electricity *purchased or generated* for use by electric utility customers in Washington (often referred to as load based CO_2 emissions) rather than the electricity that is generated in Washington but not necessarily for consumers here.

Utilities can purchase or generate electricity from sources outside the state to serve their customers. Much of this out-of-state power is from fossil-based power plants, which impacts the emissions for Washington State associated with electricity consumption. Additionally, our hydro system is highly seasonal with much of the power being generated in the spring and early summer when the snow melts. Annually, Washington State is a net exporter of electricity but during the winter season, we rely on imports to meet our needs. Our excess electricity in the spring and summer is traded out of state in exchange for electricity that arrives when we need it most. However, this imported power is generally fossil and nuclear-based.

Beginning in 2000, Washington State began tracking the electricity sold to Washington consumers as a result the Fuel Mix Disclosure law. As shown in Figure 12 below, the data collected through this process allows us to compare the emissions from our electricity generation in Washington to the electricity generation that serves Washington consumers. It is apparent that some utilities in our state rely heavily on out-of-state fossil-based electricity generation to serve their customers and to balance seasonal electricity needs. Figure 12 reveals that CO_2 emissions associated with electric consumption are actually 30 percent higher than estimated using generation based data. Other states that have developed GHG inventories are also beginning to differentiate between CO_2 associated with in-state electricity generation and load based electricity sales. An additional chart is shown in the appendix.

Figure 12 Washington State Electricity Sector CO_2 Emissions: Generation vs. Sales Basis.



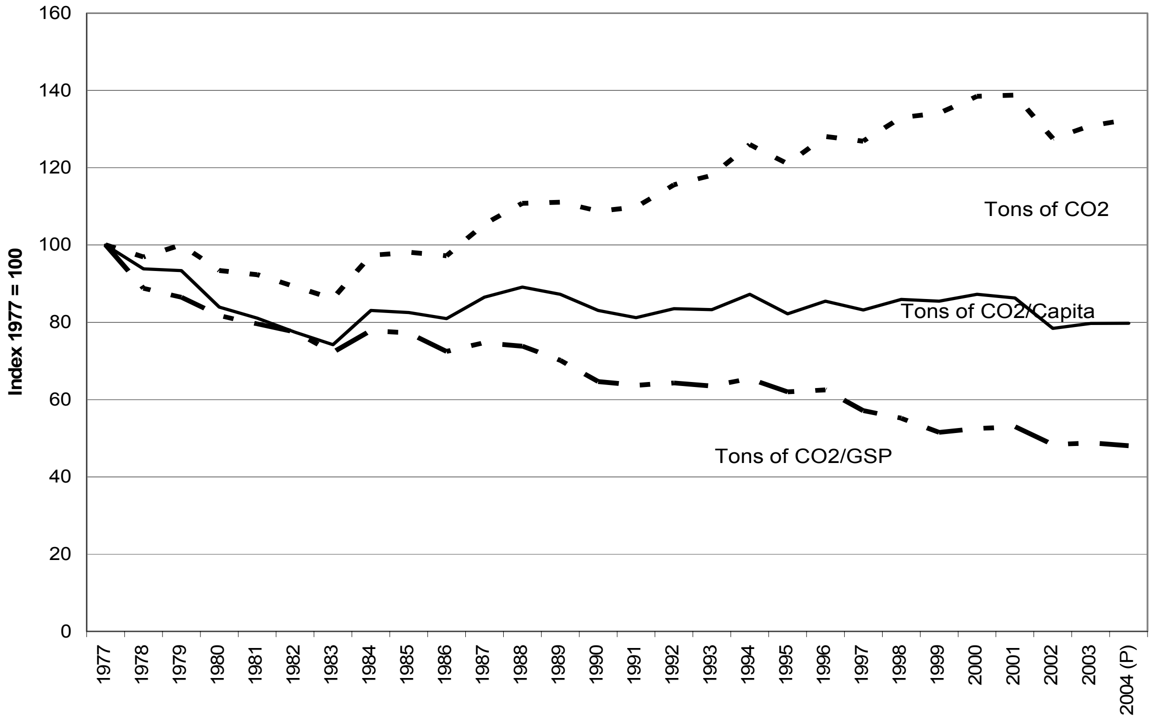
Perspectives

An examination of the historical trend in CO_2 and GHG emissions is useful as it can provide some perspective in determining strategies to mitigate our GHG emissions. Since 1960 CO_2 emissions within Washington State have increased at an average annual rate of 3.3 percent. The primary driver for this increase has been population growth, but other factors have contributed to the growth in emissions, while some factors have acted to restrain growth. Most of the growth in CO_2 emissions[6] has occurred in the transportation and electricity generation sectors (refer to Figures 3 and 4). If Washington state elects to slow or reduce its' GHG emissions, it is very likely that the primary efforts will have to be directed towards the transportation and electricity generation sectors.

Figure 13 below shows the trends for total carbon dioxide emissions, the per capita emissions and emissions per dollar of gross state product ($GSP) from 1977 to 2004. $GSP is expressed in constant 2003 dollars. The values are indexed so that the amounts in 1977 are equal to 100 (1977 is the first year that $GSP data became available). Over this period, total emissions have increased about 32 percent (average annual increase of 1.2 percent), the emissions per capita have dropped 20 percent (average annual decrease of 0.75 percent), and the emissions per constant dollar of gross state product have decreased by 52 percent (average annual decrease of 1.9 percent).

[6] The transportation and electricity generation sectors are responsible for 42.1 of the 43.5 MMT increase over the last 45 years (1960-2004), or 96.7 percent of the total. Note industrial emissions have declined 1.2 percent over this same time period.

Figure 13 Trends in CO_2 Emissions: Actual, Per Capita, Per $GSP.



A number of factors contributed to the trends shown in Figure 13. First, after declining in the face of high energy prices and a prolonged recessionary period during the late 1970's and early 1980's, total CO_2 emissions have increased slowly since the mid 1980s at about 1.8 percent per year. This is somewhat faster than the state's population growth rate, but slower than the long-term rate of increase from 1960-2004 (3.3 percent).

Second, per capita carbon dioxide emissions remained roughly constant over the past 20 years, despite increasing per capita consumption (house size, vehicle miles traveled, etc.). This is a result of efficiency improvements in direct fuel use (homes and vehicles) and electricity consumption, as well as fuel switching to less carbon intensive fuels.

Finally, carbon dioxide emissions per $GSP (expressed as constant 2003 dollars) has declined markedly over the past 25 years. The reasons for this decline include the efficiency improvements and fuel switching factors mentioned above, plus the continuing transformation of our society from a manufacturing based economy to a less energy-intensive services and information-based economy.

An example of this continuing transformation is the emergence and growth of the software industry during the 1980s and 1990s. The software industry contributes significantly to GSP, but consumes relatively small amounts of energy, which consequently results in lower relative CO_2 emissions. Our society still consumes products requiring energy intensive manufacturing but more of these products are being manufactured overseas and their associated emissions are beyond the scope of this inventory[7].

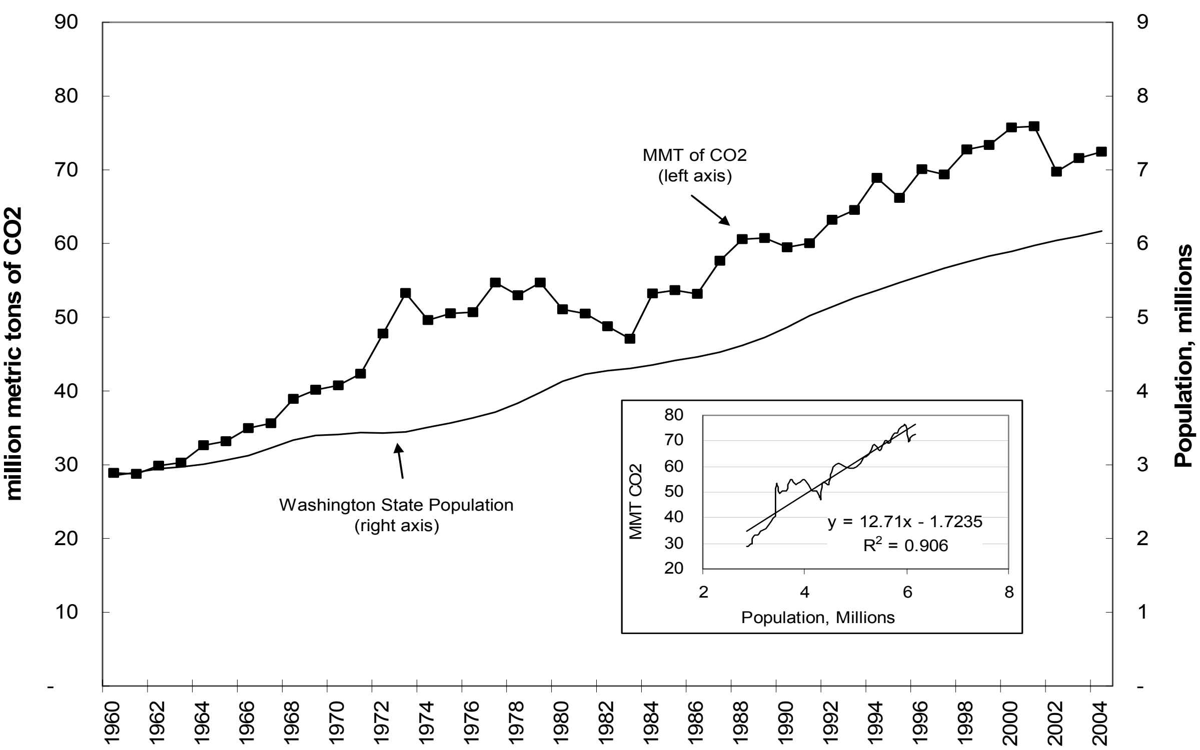
[7] Refer to Shui, Bin and Robert Harriss, "The Role of CO_2 embodiment in US-China trade", Energy Policy 34, 4083-4068, 2006

The correlation of carbon dioxide emissions with population is also of interest. Figure 14 below present data for energy related emissions and population from 1960 through 2004. Over the entire time period the relationship is mostly linear and has a correlation coefficient of 90 percent indicating a strong relationship between the growth in population and increased carbon dioxide emissions. During periods within this 45 year time frame there have been subtle excursions from the direct relationship between population and CO_2 emissions.

From 1960 to about 1978 CO_2 emissions increased notably faster than population largely due to the rapid increase in per capita wealth (resulting in additional fuel consumption), inexpensive fuel, and the development of in-state coal-fired electricity generation. From 1979 to 1984 high fuel prices, a series of recessions, and wage stagnation caused emissions to grow a bit more slowly than population. Since the mid 1980's, emissions and population growth have largely mirrored each other.

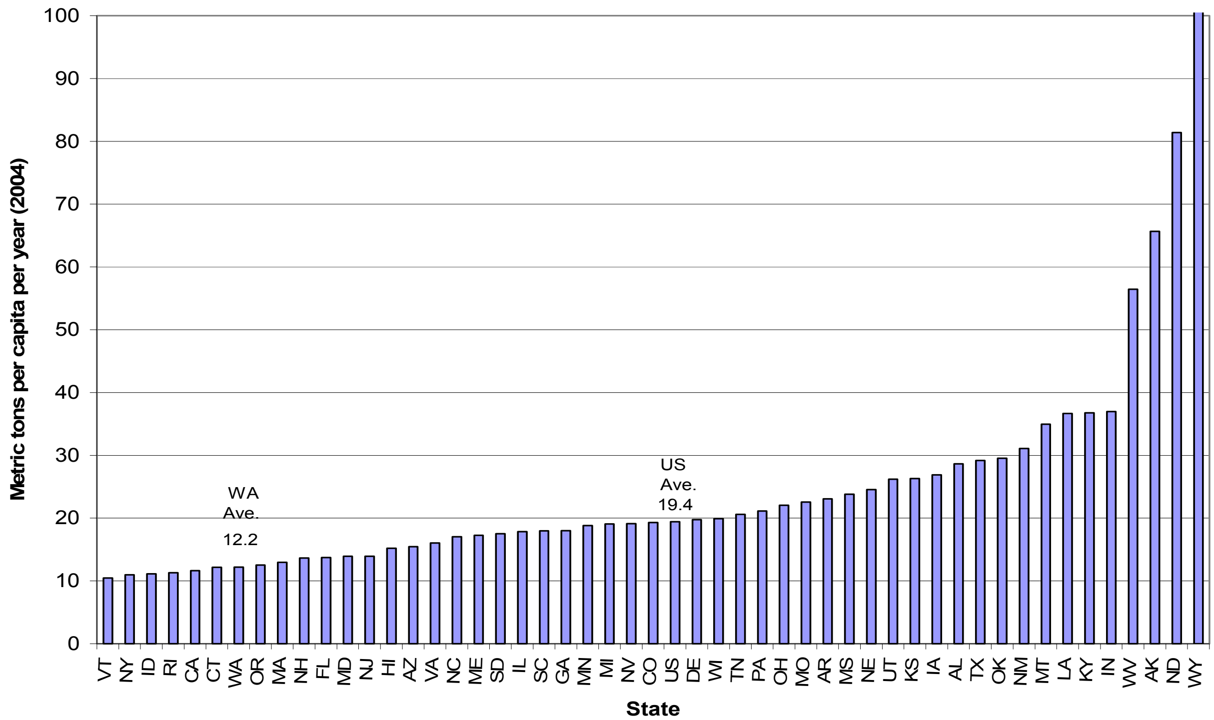
There have been many changes over that period of time as discussed above, including fuel switching, efficiency improvements, increased use of fossil fuels for electric power generation, and a change to a more service oriented and high-tech economy. Nevertheless, CO_2 emissions have remained strongly correlated with population level.

Figure 14 Correlation Between Population and CO_2 Emissions



Also of interest is Washington States rank relative to other states. Because of the wide range in state populations, the most reasonable way to compare states is using per capita emissions. Figure 15 below illustrates state per capita CO_2 emissions for 2004. Washington's per capita CO2 emissions are 12.2 metric tons per year, which is about two-thirds of the national average and puts the state in a tie for sixth place. The states with the highest per capita emissions (Wyoming, North Dakota, Arkansas, and West Virginia) all have a significant number of coal-fired electricity generation facilities. Since these generation facilities often export power to neighboring states, a portion of the CO_2 emissions should be attributed to the states where the electricity is consumed[8]. Some states with lower per capita CO_2 emissions than Washington would probably have higher emissions if those associated with imported electricity were accounted for. The primary reason our state has relatively low per capita CO_2 emissions is that two-thirds of our electricity is generated using hydropower. Looking at per capita emissions associated with petroleum use, (8.4 tons per capita) Washington ranks 26th and equals the national average.

Figure 15 State per capita CO_2 emissions for 2004.



Summary

Our evaluation of the trends in Washington State GHG and CO_2 emissions reveal the following.

- Greenhouse gas emissions for Washington have increased from 78.5 MMT in 1990 to 88.2 MTT in 2004: an average annual increase of 0.8 percent. Emissions of non-CO2 GHGs have actually fallen over the last several years.
- Of the total GHG emissions in 2004 energy related emissions were 85 percent, industrial emissions were 9 percent, and agriculture emissions were 7 percent.
- Carbon dioxide emissions for Washington have increased from 28.9 MMT in 1960 to 72.4 MMT in 2004: an average annual increase of 3.3 percent. Since 1990 the average annual increase has been 1.3 percent.
- Over the last twenty years most of the increase in CO_2 emissions has been in the transportation and electric power generation sectors.
- Growth in GHG and CO_2 emissions are highly correlated with population growth.

[8] The emerging convention in the GHG Inventory process is to attribute emissions to the state where the fuel or energy is consumed.

- In 2004 Washington per capita CO_2 emissions were 12.2 metric tons per year and have remained at this level for past 20 years. Our per capita emissions are 63 percent of the national average of 19.4 metric tons per year.

Appendix

Data from Figure 1: Greenhouse Emissions by Sector and Gas Type. (Million metric tons CO2 equivalent)

	1990	1995	2000	2004
Energy	61.2	68.3	77.8	74.6
Industry	10.8	8.9	10.6	7.5
Agriculture	6.6	7.0	6.5	6.1
Total	78.5	84.2	94.9	88.2
CO2	61.5	68.2	78.1	73.3
CH4	7.1	6.9	7.6	7.9
N2O	4.8	5.4	4.9	4.5
PFC	4.2	2.5	2.2	0.1
Other	0.9	1.1	2.0	2.3
Total	78.5	84.2	94.9	88.2

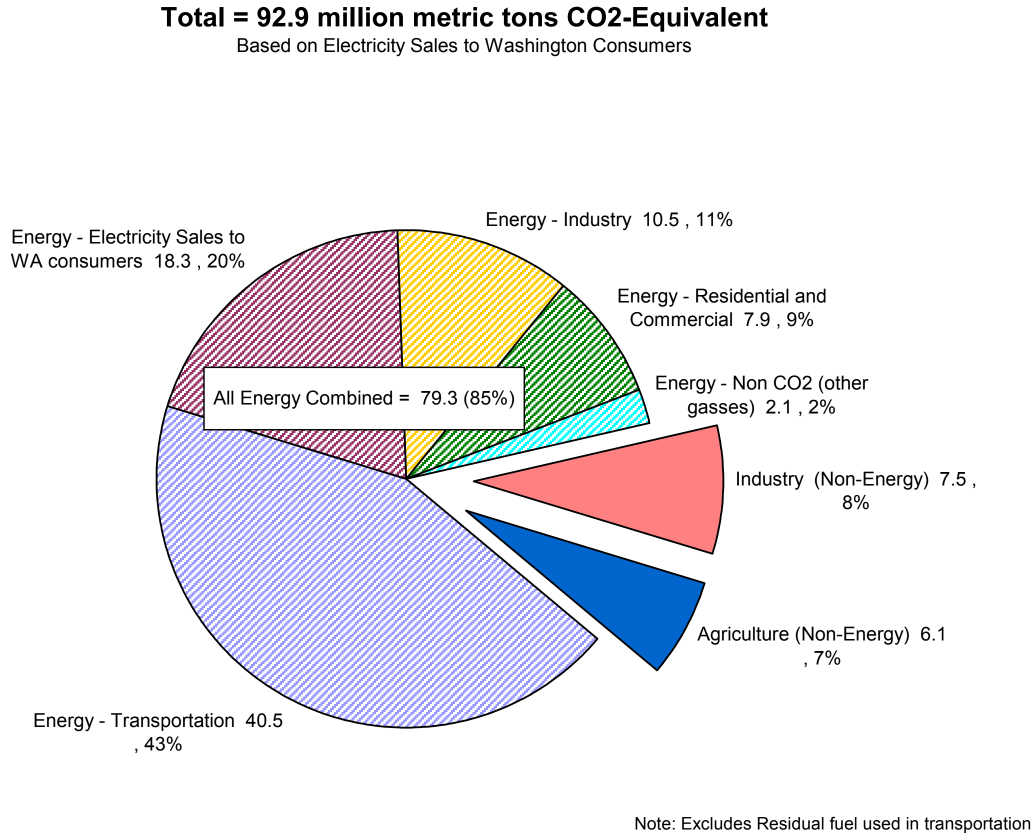
	1990	1995	2000	2004
Energy	78%	81%	82%	85%
Industry	14%	11%	11%	9%
Agriculture	8%	8%	7%	7%
Total	100%	100%	100%	100%
CO2	78%	81%	82%	83%
CH4	9%	8%	8%	9%
N2O	6%	6%	5%	5%
PFC	5%	3%	2%	0%
Other	1%	1%	2%	3%
Total	100%	100%	100%	100%

Data from Figure 11: Emissions from Electric Power Generation by Fuel Type. (Million metric tons CO2)

	Coal	Petroleum	Natural Gas	Total
1990	7.41	0.01	0.01	7.43
1991	7.79	0.01	0.06	7.86
1992	9.45	0.01	0.61	10.07
1993	8.61	0.03	1.52	10.15
1994	9.48	0.01	2.32	11.81
1995	5.99	0.10	2.18	8.27
1996	8.20	0.15	2.26	10.62
1997	7.20	0.21	1.50	8.90
1998	9.42	0.04	2.20	11.66
1999	8.84	0.01	1.79	10.64
2000	9.66	0.33	4.02	14.01
2001	9.01	0.22	4.67	13.90
2002	9.20	0.02	2.14	11.35
2003	10.84	0.01	3.12	13.97
2004	10.20	0.04	3.61	13.84

Figure 16 below shows the same data from Figure 2 but emissions from electricity sales to Washington consumers were used instead of emissions from in-state generation.

Figure 16 All Greenhouse Gas Emissions in Washington for 2004 (preliminary estimate)



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