Chapter 11
Greenhouse Gas Emissions

Summary Statistics from Tables in this Chapter

Source			
Table 11.1	Carbon dioxide emissions (million metric tonnes)	1990	2004
	United States	*4,989*	*5,923*
	OECD Europe	*4,092*	*4,381*
	China	*2,241*	*4,707*
	Russia	*2,334*	*1,685*
	Japan	*1,015*	*1,262*
	Non-OECD Europe	*1,859*	*1,134*
	India	*578*	*1,111*
Table 11.5	Transportation share of U.S. carbon dioxide emissions from fossil fuel consumption		
	1990		*31.6%*
	1995		*31.7%*
	2000		*32.0%*
	2006		*33.8%*
Table 11.6	Motor gasoline share of transportation carbon dioxide emissions		59.6%
Table 11.9	Average annual carbon footprint (tons of CO_2)		
	Cars		*6.4*
	Light trucks		*8.4*

The U. S. accounted for 23.5% of the World's carbon dioxide emissions in 1990 and 22.0% in 2004. Nearly half (44%) of the U.S. carbon emissions are from oil use.

Table 11.1
World Carbon Dioxide Emissions, 1990 and 2004

	1990		2004	
	Million metric tons	Percent of emissions from oil use	Million metric tons	Percent of emissions from oil use
United States	4,989	44%	5,923	44%
Canada	474	47%	584	50%
Mexico	300	77%	385	66%
OECD[a] Europe	4,092	46%	4,381	49%
OECD[a] Asia	238	61%	497	49%
Japan	1,015	66%	1,262	53%
Australia/New Zealand	291	38%	424	33%
Russia	2,334	34%	1,685	22%
Non-OECD[a] Europe	1,859	31%	1,134	25%
China	2,241	15%	4,707	17%
India	578	28%	1,111	28%
Non-OECD[a] Asia	1,807	57%	1,593	54%
Middle East	705	70%	1,289	60%
Africa	649	46%	919	43%
Central & South America	673	75%	1,027	70%
Total World	21,246	42%	26,922	40%

Source:
U.S. Department of Energy, Energy Information Administration, *International Energy Outlook 2007*, Washington, DC, June 2007, Tables A10 and A11. (Additional resources: www.eia.doe.gov)

[a] OECD is the Organization for Economic Cooperation and Development. See Glossary for included countries.

Global Warming Potentials (GWP) were developed to allow comparison of the ability of each greenhouse gas to trap heat in the atmosphere relative to carbon dioxide. Extensive research has been performed and it has been discovered that the effects of various gases on global warming are too complex to be precisely summarized by a single number. Further understanding of the subject also causes frequent changes to estimates. Despite that, the scientific community has developed approximations, which are shown below. Most analysts use the 100-year time horizon.

Table 11.2
Numerical Estimates of Global Warming Potentials Compared with Carbon Dioxide
(kilogram of gas per kilogram of carbon dioxide)

Gas	Lifetime (years)	Global warming potential direct effect for time horizons of 20 years	100 years	500 years
Carbon Dioxide (CO_2)	5-200[a]	1	1	1
Methane (CH_4)	12	62	23	7
Nitrous Oxide (N_2O)	114	275	296	156
HFCs[b], PFCs[c], and Sulfur Hexafluoride				
HFC-23	260	9,400	12,000	10,000
HFC-125	29	5,900	3,400	1,100
HFC-134a	14	3,300	1,300	400
HFC-152a	1	410	120	37
HFC-227ea	33	5,600	3,500	1,100
Perfluoromethane (CF_4)	50,000	3,900	5,700	8,900
Perfluoroethane (C_2F_6)	10,000	8,000	11,900	18,000
Sulfur hexafluoride (SF_6)	3,200	15,100	22,200	32,400

Source:
U.S. Department of Energy, Energy Information Administration, *Emissions of Greenhouse Gases in the United States 2005*, Washington, DC, November 2006, Table 4. Original source: Intergovernmental Panel on Climate Change; *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2000), pp. 38 and 388-389. (Additional resources: www.eia.doe.gov, www.ipcc.ch)

Note: The typical uncertainty for global warming potentials is estimated by the Intergovernmental Panel on Climate Change ± 35 percent.

[a] No single lifetime can be defined for carbon dioxide due to different rates of uptake by different removal processes.
[b] Hydrofluorocarbons
[c] Perfluorocarbons

Carbon dioxide emissions in 2006 were 18% higher than in 1990. Carbon dioxide accounts for the majority of greenhouse gases.

Table 11.3
U.S. Emissions of Greenhouse Gases, based on Global Warming Potential, 1990–2006
(million metric tons carbon dioxide equivalent[a])

	Carbon Dioxide	Methane	Nitrous Oxide	High GWP Gases[b]	Total
1990	5,017.5	708.4	333.7	87.1	6,146.7
1991	4,969.4	707.7	342.9	79.0	6,098.9
1992	5,078.7	709.7	350.0	83.7	6,222.1
1993	5,203.0	684.8	349.5	82.9	6,320.2
1994	5,288.3	685.6	374.9	85.3	6,434.0
1995	5,343.4	675.9	357.1	94.9	6,471.2
1996	5,531.0	656.0	357.6	110.6	6,655.2
1997	5,606.7	654.6	350.5	118.0	6,729.8
1998	5,632.5	631.3	347.9	134.4	6,746.1
1999	5,703.1	615.8	346.3	133.9	6,799.1
2000	5,890.5	608.0	341.9	138.0	6,978.4
2001	5,806.3	593.9	336.6	128.6	6,865.4
2002	5,875.9	598.6	332.5	137.8	6,944.9
2003	5,940.4	603.7	331.7	136.6	7,012.4
2004	6,019.9	605.9	358.3	149.4	7,133.5
2005	6,045.0	607.3	368.0	161.2	7,181.4
2006	5,934.4	605.1	378.6	157.6	7,075.6

Source:
U.S. Department of Energy, Energy Information Administration, *Emissions of Greenhouse Gases in the United States, 2006*, Washington, DC, November 2007, Table 1. (Additional resources: www.eia.doe.gov)

Note: This greenhouse gas emissions inventory includes two "adjustments to energy consumption" which make the data different from Table 11.5. The adjustments are as follows:
1) Emissions from U.S. Territories are included.
2) International bunker fuels and military bunker fuels are excluded from the U.S. total.

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[a] Carbon dioxide equivalents are computed by multiplying the weight of the gas being measured by its estimated Global Warming Potential (See Table 11.2).

[b] GWP = Global warming potential. Includes HFC-hydrofluorocarbons; PFC-perfluorocarbons; and SF_6-sulfur hexaflouride.

Though the transportation sector accounts for the largest share of carbon dioxide emissions, the industrial sector accounts for the largest share of total greenhouse gas emissions.

Table 11.4
Total U.S. Greenhouse Emissions by End-Use Sector, 2006
(million metric tons carbon dioxide equivalent[a])

Greenhouse gas and source	Residential	Commercial	Industrial	Transportation	Total
Carbon dioxide	1,216.8	1,056.1	1,775.8	1,884.7	5,934.4
Methane	8.2	162.9	429.2	4.8	605.1
Nitrous oxide	4.3	9.6	309.9	54.8	378.6
Hydrofluorocarbons	0.0	48.4	14.5	66.1	129.0
Perfluorocarbons	0.0	0.0	6.9	0.0	6.9
Other hydrofluorocarbons, perfluorocarbons/perfluoropolyether	0.0	6.1	0.0	0.0	6.1
Sulfur hexafluoride	4.5	4.3	6.7	0.0	15.5
Total greenhouse gas emissions	1,233.8	1,287.4	2,544.0	2,010.3	7,075.6

Source:
U.S. Department of Energy, Energy Information Administration, *Emissions of Greenhouse Gases in the United States, 2006*, Washington, DC, November 2007, and annual. (Additional resources: www.eia.doe.gov)

Note: This greenhouse gas emissions inventory includes two "adjustments to energy consumption" which make the data different from Table 11.5. The adjustments are as follows:
1) Emissions from U.S. Territories are included.
2) International bunker fuels and military bunker fuels are excluded from the U.S. total.

[a] Carbon dioxide equivalents are computed by multiplying the weight of the gas being measured by its estimated Global Warming Potential (See Table 11.2).

Gases which contain carbon can be measured in terms of the full molecular weight of the gas or just in terms of their carbon content. This table presents carbon dioxide gas. The ratio of the weight of carbon to carbon dioxide is 0.2727. The transportation sector accounts for approximately one-third of carbon emissions.

Table 11.5
U.S. Carbon Emissions from Fossil Energy Consumption by End-Use Sector, 1990–2006[a]
(million metric tons of carbon dioxide)

	End Use Sector				Transportation Percentage	Total Energy
	Residential	Commercial	Industrial	Transportation		
1990	961.8	787.5	1,679.9	1,582.6	31.6%	5,011.8
1995	1,039.2	848.4	1,730.9	1,682.2	31.7%	5,300.7
1999	1,120.0	955.5	1,764.8	1,828.3	32.3%	5,668.6
2000	1,181.5	1,015.1	1,778.1	1,872.6	32.0%	5,847.3
2001	1,171.1	1,023.3	1,703.8	1,851.0	32.2%	5,749.2
2002	1,196.2	1,018.1	1,707.8	1,890.9	32.5%	5,813.0
2003	1,124.1	1,027.1	1,712.8	1,901.4	33.0%	5,765.4
2004	1,121.5	1,041.6	1,735.7	1,958.6	33.4%	5,857.4
2005	1,253.0	1,065.4	1,677.1	1,986.2	33.2%	5,981.7
2006	1,204.2	1,045.2	1,650.8	1,990.1	33.8%	5,890.3
	Average annual percentage change					
1990–2006	1.4%	1.8%	-0.1%	1.4%		1.0%
2000–2006	0.3%	0.5%	-1.2%	1.0%		0.1%

Source:
U.S. Department of Energy, Energy Information Administration, *Emissions of Greenhouse Gases in the United States, 2006*, Washington, DC, November 2007, Tables 5 through 8 and annual. (Additional resources: www.eia.doe.gov)

Note: Emissions from U.S. Territories are not included. International bunker fuels and military bunker fuels are included in these data.

[a] Includes energy from petroleum, coal, and natural gas. Electric utility emissions are distributed across consumption sectors.

Most U.S. transportation sector carbon dioxide emissions come from petroleum fuels (98%). Motor gasoline has been responsible for about 60% of U.S. carbon dioxide emissions over the last twenty years.

Table 11.6
U.S. Carbon Emissions from Energy Use in the Transportation Sector, 1990–2006
(million metric tons of carbon dioxide)

	1990		2000		2006	
Fuel	Emissions	Percentage	Emissions	Percentage	Emissions	Percentage
			Petroleum			
Motor gasoline	961.7	60.7%	1,121.9	59.9%	1,186.2	59.6%
LPG[a]	1.3	0.1%	0.7	0.0%	1.1	0.1%
Jet fuel	222.6	14.0%	253.8	13.6%	239.5	12.0%
Distillate fuel	267.8	16.9%	377.8	20.2%	452.2	22.7%
Residual fuel	80.1	5.1%	69.9	3.7%	65.6	3.3%
Lubricants	6.5	0.4%	6.7	0.4%	5.5	0.3%
Aviation gas	3.1	0.2%	2.5	0.1%	2.3	0.1%
Subtotal	**1,544.1**	97.5%	**1,833.3**	97.9%	**1,952.4**	98.1%
			Other energy			
Natural gas	36.2	2.3%	35.6	1.9%	32.5	1.6%
Electricity[b]	3.2	0.2%	3.6	0.2%	5.2	0.3%
Total	**1,584.5**	100.0%	**1,872.6**	100.0%	**1,990.1**	100.0%

Source:
U.S. Department of Energy, Energy Information Administration, *Emissions of Greenhouse Gases in the United States, 2006*, Washington, DC, November 2007, Table 8, and annual. (Additional resources: www.eia.doe.gov)

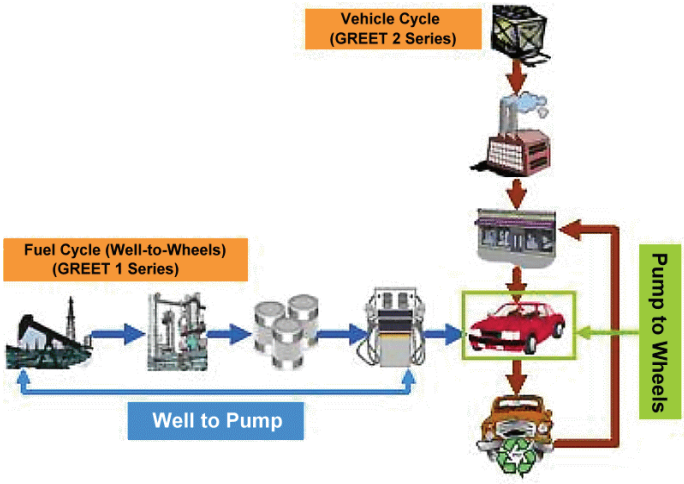
[a] Liquified petroleum gas.
[b] Share of total electric utility carbon dioxide emissions weighted by sales to the transportation sector.

The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model

http://www.transportation.anl.gov/software/GREET/

Sponsored by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE), Argonne has developed a full life-cycle model called GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation). It allows researchers and analysts to evaluate energy and emission impacts of various vehicle and fuel combinations on a full fuel-cycle/vehicle-cycle basis. The first version of GREET was released in 1996. Since then, Argonne has continued to update and expand the model. The most recent GREET versions are GREET 1.7 version for fuel-cycle analysis and GREET 2.7 version for vehicle-cycle analysis.

Figure 11.1. GREET Model



For a given vehicle and fuel system, GREET separately calculates the following:

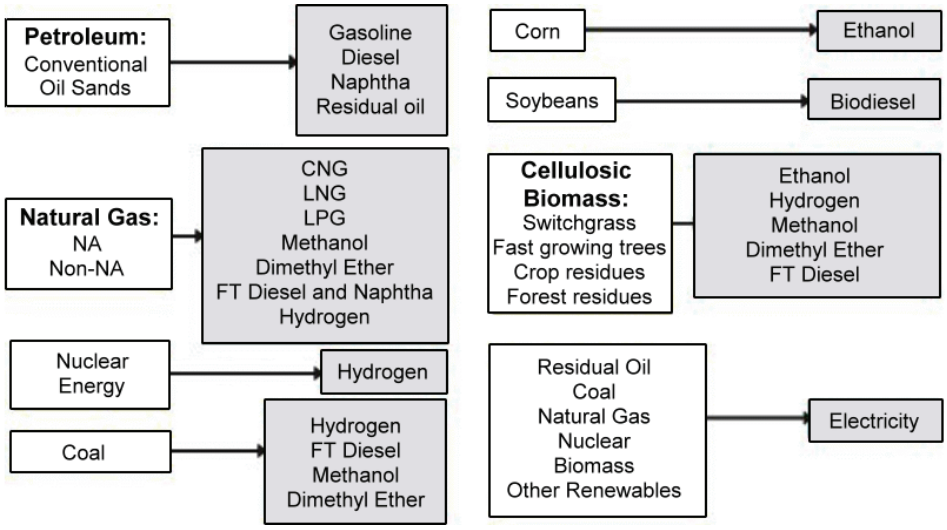
- Consumption of total energy (energy in non-renewable and renewable sources), fossil fuels (petroleum, natural gas, and coal together), petroleum, coal and natural gas.
- Emissions of CO_2-equivalent greenhouse gases - primarily carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).
- Emissions of six criteria pollutants: volatile organic compounds (VOCs), carbon monoxide (CO), nitrogen oxide (NOx), particulate matter with size smaller than 10 micron (PM_{10}), particulate matter with size smaller than 2.5 micron ($PM_{2.5}$),and sulfur oxides (SOx).

GREET includes more than 100 fuel production pathways and more than 70 vehicle/fuel systems.

These vehicle/fuel systems cover all major vehicle technologies in the market and R&D arena:

- Conventional spark-ignition engines
- Direct-injection, spark-ignition engines
- Direct injection, compression-ignition engines
- Grid-independent hybrid electric vehicles
- Grid-connected (or plug-in) hybrid electric vehicles
- Battery-powered electric vehicles
- Fuel-cell vehicles

Figure 11.2. GREET Model Feedstocks and Fuels



To address technology improvements over time, GREET simulates vehicle/fuel systems over the period from 1990 to 2020, in five-year intervals.

For additional information about the GREET model, see the GREET website, or contact:

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Carbon Footprint

The carbon footprint measures a vehicle's impact on climate change in tons of carbon dioxide (CO_2) emitted annually. The following three tables show the carbon footprint for various vehicle classes. The sales-weighted average fuel economy rating for each vehicle class, based on 45% highway and 55% city driving, is used to determine the average annual carbon footprint for vehicles in the class. An estimate of 15,000 annual miles is used for each vehicle class and for each year in the series. The equation to calculate carbon footprint uses results of the GREET model version 1.8.

$$CarbonFootprint = \left(CO_2 \times LHV \times \frac{AnnualMiles}{CombinedMPG} \right) + \left(CH_4 + N_2O \right) \times AnnualMiles$$

where:

CO_2 = (Tailpipe CO_2 = Upstream Greenhouse Gases) in grams per million Btu

LHV = Lower (or net) Heating Value in million Btu per gallon

CH_4 = Tailpipe CO_2 equivalent methane in grams per mile

N_2O = Tailpipe CO_2 equivalent nitrous oxide in grams per mile

The carbon footprint for all classifications of cars has declined significantly between 1975 and 2007 though midsize cars have experienced the greatest reduction in carbon footprint with a drop of 55.6%.

Table 11.7
Sales-Weighted Annual Carbon Footprint of New Domestic and Import Cars by Size Class, Model Years 1975–2007[a]
(tons of CO_2)

	Cars			Wagons		
Sales period	Small	Midsize	Large	Small	Midsize	Large
1975	10.2	13.6	14.2	8.3	14.1	15.6
1976	9.3	11.8	13.1	7.8	11.6	13.7
1977	9.0	11.3	11.7	7.3	11.4	12.0
1978	8.0	10.0	11.1	7.7	10.0	11.7
1979	8.0	9.7	10.7	7.3	9.7	11.5
1980	7.1	8.6	9.7	6.5	8.8	9.7
1981	6.5	8.1	9.1	6.2	8.1	9.3
1982	6.4	7.8	9.0	6.1	7.9	9.7
1983	6.3	7.8	9.2	5.8	7.6	9.5
1984	6.3	7.7	9.1	5.9	7.5	9.3
1985	6.3	7.5	8.3	5.7	7.4	8.9
1986	6.2	7.2	7.8	6.0	7.2	8.5
1987	6.2	7.2	7.8	6.1	7.3	8.4
1988	6.1	7.0	7.7	6.0	7.1	8.2
1989	6.2	7.0	7.8	5.9	7.3	8.3
1990	6.3	7.1	7.9	6.3	7.4	8.2
1991	6.2	7.2	7.9	6.1	7.2	8.1
1992	6.2	7.2	7.8	6.2	7.1	8.2
1993	6.1	7.1	7.7	5.7	7.1	8.3
1994	6.1	7.2	7.7	5.7	7.2	8.1
1995	6.1	7.1	7.6	5.6	7.0	8.2
1996	6.1	7.0	7.7	5.9	7.1	8.0
1997	6.0	7.0	7.6	5.8	7.1	*b*
1998	6.0	6.9	7.6	5.8	7.1	*b*
1999	6.2	6.9	7.5	5.9	7.1	*b*
2000	6.2	6.9	7.3	6.4	6.8	*b*
2001	6.1	6.9	7.3	6.8	7.0	*b*
2002	6.1	6.7	7.2	7.1	6.8	*b*
2003	6.1	6.6	7.2	6.2	6.9	*b*
2004	6.1	6.5	7.2	5.9	7.1	8.5
2005	6.0	6.3	7.1	5.7	7.2	8.4
2006	6.0	6.3	7.2	5.9	6.7	8.6
2007	6.2	6.1	7.4	5.6	7.0	8.3
			Average annual percentage change			
1975–2007	-1.5%	-2.5%	-2.0%	-1.2%	-2.2%	-2.0%
1997–2007	0.3%	-1.4%	-0.3%	-0.4%	-0.1%	*c*

Source:
Calculated using fuel economy from the U.S. Environmental Protection Agency, *Light-Duty Automotive Technology and Fuel Economy Trends: 1975 Through 2007*, July 2007. See page 11-10 for details.

[a] Annual carbon footprint is based on 15,000 miles of annual driving.
[b] No vehicles in this category were sold in this model year.
[c] Data are not available.

The annual carbon footprint of light trucks decreased significantly for all classes of light trucks between 1975 and 2007. In the last ten years, midsize and large SUVs experienced the greatest decrease with about 16% for each while midsize pickups and small SUVs experienced a slight gain in carbon emissions.

Table 11.8
Sales-Weighted Annual Carbon Footprint of New Domestic and Import Light Trucks by Size Class, Model Years 1975–2007[a]
(liters)

	Pickups			Vans			SUVs		
Sales Period	Small	Midsize	Large	Small	Midsize	Large	Small	Midsize	Large
1975	8.3	8.8	14.2	9.0	14.0	14.7	11.5	15.3	15.2
1976	7.8	8.1	13.4	9.3	13.2	13.8	11.7	14.0	14.6
1977	7.3	6.3	12.5	8.4	13.0	12.0	10.9	12.7	13.6
1978	7.3	6.4	12.6	9.3	13.4	12.4	11.0	13.4	14.1
1979	8.2	7.2	13.0	9.9	13.0	15.3	11.1	15.6	16.7
1980	7.7	7.2	10.8	9.8	11.0	11.6	9.9	13.0	13.0
1981	6.6	7.1	10.0	10.0	10.4	11.1	9.1	11.9	12.1
1982	6.8	7.0	10.0	8.6	10.4	11.5	9.1	11.3	9.8
1983	6.9	7.0	10.3	9.4	9.9	11.5	8.7	9.9	10.6
1984	7.1	7.3	10.4	7.3	9.7	11.3	8.6	9.8	11.0
1985	7.0	7.3	10.5	7.3	9.4	11.5	8.4	9.4	11.0
1986	7.2	7.1	10.2	7.3	8.9	10.6	7.9	9.4	11.1
1987	7.2	7.3	10.5	7.7	8.8	10.9	7.7	9.4	10.9
1988	7.5	7.4	10.3	7.6	8.5	11.0	7.7	9.5	11.2
1989	7.8	7.5	10.3	7.5	8.5	11.1	8.2	9.5	11.1
1990	7.5	7.5	10.3	7.8	8.5	11.3	8.0	9.7	11.1
1991	7.5	7.6	10.2	7.8	8.5	11.1	7.9	9.2	11.5
1992	7.6	7.8	10.2	6.9	8.5	11.0	8.0	9.3	11.8
1993	7.1	7.9	9.9	6.6	8.3	10.9	8.0	9.3	11.4
1994	7.5	7.8	10.1	6.9	8.5	10.9	7.7	9.4	11.3
1995	7.6	7.5	10.3	7.0	8.4	10.9	7.7	9.5	11.2
1996	7.6	7.5	10.2	7.1	8.2	10.9	6.5	9.3	10.7
1997	7.5	7.7	9.8	*b*	8.2	10.0	8.2	9.1	10.6
1998	7.6	7.8	10.0	*b*	8.0	10.2	7.8	8.9	10.7
1999	8.0	8.3	10.0	*b*	8.1	10.4	7.7	8.9	10.8
2000	7.1	8.2	9.6	*b*	7.9	10.3	8.3	8.9	10.6
2001	7.0	8.5	9.8	*b*	7.8	10.5	7.5	8.6	10.0
2002	8.0	8.8	9.9	*b*	7.9	10.4	7.5	8.5	9.7
2003	8.0	8.2	9.8	*b*	7.7	9.9	7.4	8.3	9.9
2004	8.2	8.5	9.8	*b*	7.7	9.6	7.5	8.3	9.8
2005	7.2	7.9	9.6	*b*	7.7	9.6	7.7	8.1	9.3
2006	7.1	7.8	9.4	*b*	7.5	9.6	8.4	7.9	9.1
2007	*b*	7.8	9.4	*b*	7.5	9.4	8.2	7.6	8.9
			Average annual percentage change						
1975-2007	*c*	-0.4%	-1.3%	*c*	-1.9%	-1.4%	-1.0%	-2.2%	-1.7%
1997-2007	*c*	0.2%	-0.4%	*c*	-0.8%	-0.6%	0.0%	-1.8%	-1.7%

Source:
Calculated using fuel economy from the U.S. Environmental Protection Agency, *Light-Duty Automotive Technology and Fuel Economy Trends: 1975 Through 2007*, July 2007. See page 11-10 for details.

Note: Includes light trucks of 8,500 lbs. or less.

[a] Annual carbon footprint is based on 15,000 miles of annual driving.
[b] No vehicles in this category were sold in this model year.
[c] Data are not available.

Between 1975 and 2007, the carbon footprint for light vehicles sold in the U.S. dropped dramatically. Cars experienced the greatest decrease at 46.6% while the carbon footprint for light trucks decreased by 37.8%.

Table 11.9
Average Annual Carbon Footprint by Vehicle Classification, 1975 and 2007[a]
(tons of carbon dioxide)

	Market Share		Carbon Footprint		Percent Change
Fuel	1975	2007	1975	2007	1975 - 2007
Small	40.0%	17.2%	10.2	6.2	-39.2%
Midsize	16.0%	18.5%	13.6	6.1	-55.1%
Large	15.2%	9.3%	14.2	7.4	-47.9%
Small Wagon	4.7%	4.3%	8.3	5.6	-32.5%
Midsize Wagon	2.8%	1.0%	14.1	7.0	-50.4%
Large Wagon	1.9%	0.6%	15.6	8.3	-46.8%
Total Cars	**80.6%**	**51.0%**	**11.8**	**6.3**	**-46.6%**
			Light Trucks		
Small Van	0.0%	0.0%	9.0	0.0	b
Midsize Van	3.0%	6.2%	14.0	7.5	-46.4%
Large Van	1.5%	0.2%	14.7	9.4	-36.1%
Small SUV	0.5%	1.2%	11.5	8.2	-28.7%
Midsize SUV	1.2%	14.8%	15.3	7.6	-50.3%
Large SUV	0.1%	13.0%	15.2	8.9	-41.4%
Small Pickup	1.6%	0.0%	8.3	7.0	-14.5%
Midsize Pickup	0.5%	1.9%	8.8	7.9	-10.2%
Large Pickup	11.0%	11.8%	14.2	9.4	-33.8%
Total Light Trucks	**19.0%**	**49.0%**	**13.5**	**8.4**	**-37.8%**

Source:
Calculated using fuel economy from the U.S. Environmental Protection Agency, *Light-Duty Automotive Technology and Fuel Economy Trends: 1975 Through 2007*, July 2007. See page 11-10 for details.

[a] Annual carbon footprint is based on 15,000 miles of annual driving.
[b] Data are not available.