

Greenhouse Gas Emissions from the U.S. Transportation Sector *1990–2003*



Greenhouse Gas Emissions from the U.S. Transportation Sector, 1990-2003

March 2006

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U.S. Environmental Protection Agency
Office of Transportation and Air Quality

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Released for printing: March 2006

Acknowledgements

ICF Consulting contributed significantly to this effort.

The Environmental Protection Agency would like to acknowledge the many individual and organizational reviewers whose work has significantly improved this document. These include: Leif Hockstad, EPA Office of Atmospheric Programs; Mark Schipper, EIA Office of Energy Markets and End Use, Energy Information Administration; Michael Wang, Argonne National Laboratory; Mark DeLucchi, Institute of Transportation Studies, University of California at Davis; Clare Sierawski, USDOT Office of Safety, Energy and Environment; Maryalice Locke, FAA Office of Environment and Energy; Lourdes Maurice, Federal Aviation Administration, Office of Environment and Energy; and John Maples, EIA Office of Integrated Analysis and Forecasting, Energy Information Administration.

Preface

The United States Environmental Protection Agency (EPA) prepares the Greenhouse Gas Emissions from the U.S. Transportation Sector report to provide researchers, transportation and environmental practitioners, policy makers, and the public with a more complete understanding of greenhouse gas (GHG) emissions from the U.S. transportation sector. GHG emissions estimates in this report are based on the official U.S. Inventory of Greenhouse Gas Emissions and Sinks. In addition, this report highlights factors affecting emissions trends, projections, and emerging issues that may affect emissions in the future. It also includes information on the full life-cycle GHG emissions associated with transportation, GHG emissions from other mobile sources, and uncertainties associated with emissions estimates.

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1 Introduction

1.1 Background

Although transportation is a vital part of the economy and is essential for everyday activities, it is also a significant source of greenhouse gas (GHG) emissions. In 2003, the transportation sector accounted for about 27 percent of total U.S. GHG emissions, up from 24.8 percent in 1990. Transportation GHG emissions increased by a larger amount than any other economic sector¹ over this period, growing from 1509.3 Tg CO₂ Eq. in 1990 to 1,866.7 Tg CO₂ Eq. in 2003, an increase of 24 percent.² GHGs from all other sectors increased by a total of 9.5 percent over the same timeframe. Looking forward, transportation GHGs are forecast to continue increasing rapidly, reflecting the anticipated impact of factors such as economic growth, increased movement of freight by trucks and aircraft, and continued growth in personal travel. According to the U.S. Department of Energy (DOE), transportation energy use is expected to increase 48 percent between 2003 and 2025, despite modest improvements in the efficiency of vehicle engines. This projected rise in energy consumption closely mirrors the expected growth in transportation GHG emissions.³

This report was developed by the U.S. Environmental Protection Agency's (EPA) Office of Transportation and Air Quality (OTAQ) to help transportation agencies, the transportation industry, researchers, and the public better understand the connection between transportation and GHG emissions in the United States. The GHG emissions estimates presented in this report are taken from the official GHG Inventory produced by EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2003* (“U.S. GHG Inventory”). As a complement to the U.S. GHG Inventory, this report includes additional detail on GHG emissions from transportation and non-transportation mobile sources. It also analyzes factors affecting emissions, uncertainty in the data, and emerging issues.

1.2 Report Organization

The remainder of this report is organized in the following sections:

Section 2. Overview of Greenhouse Gas Emissions and Transportation—This section provides a brief introduction to specific GHGs and their measurement. It also compares the

¹ The “economic sectors” referred to in this report do not represent official Intergovernmental Panel on Climate Change (IPCC) categories. EPA has found it useful to estimate emissions by sectoral categories that are commonly used for policy analysis. One method allocates emissions to seven different “economic sectors,” which include Electricity Generation, and the *non-electricity component* of all six other sectors (Transportation, Industry, Agriculture, Commercial, Residential and U.S. Territories). The second method distributes the emissions from Electricity Generation to the remaining “end use” sectors. For purposes of simplicity, this report uses the second categorization when referring to sectoral estimates.

² U.S. Environmental Protection Agency, 2005. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2003*. Washington, DC. The total transportation sector GHGs cited in this report are slightly lower than the transportation sector totals reported in the published *Inventory* (approximately 0.7 to 0.9 Tg lower from 1990 to 2003). This small increment represents “other” non-transportation mobile sources, such as lawn mowers and leaf blowers, which are counted as transportation in the published *Inventory* but not this report. GHG emissions are typically reported in terms of CO₂ equivalent (CO₂ Eq.) in order to provide a common unit of measure, and because CO₂ is the most prevalent of all GHGs.

³ U.S. Energy Information Administration, *Annual Energy Outlook 2005 with Projections to 2025*, Table A2. U.S. Department of Energy, Energy Information Administration, Washington, DC.

nation's transportation emissions to other sectors, and discusses variables contributing to the rise transportation GHGs.

Section 3. Light-Duty Vehicles – Passenger Cars, SUVs, Minivans, Pickup Trucks, and Motorcycles—This section describes GHG emissions from light-duty motor vehicles, currently the largest sources of transportation GHGs.

Section 4. Heavy-Duty Vehicles—Freight Trucks and Buses—This section addresses emissions and trends for heavy-duty vehicles.

Section 5. Aircraft—This section discusses emissions from aircraft, which are the largest source of non-road transportation GHG emissions.

Section 6. Other Non-Road Transportation Sources—This section characterizes emissions from boats and ships, rail, and pipelines.

Section 7. HFCs from Mobile Air Conditioners and Refrigerated Transport—This section describes HFC emissions from transportation sources, which include mobile air conditioners and refrigerated transportation units.

Section 8. Non-Transportation Mobile Sources—This section discusses GHG emissions from non-transportation mobile sources, such as agricultural equipment, construction equipment, and other utility equipment.

Section 9. Estimating Transportation GHG Emissions—Methodology and Uncertainty — This section briefly describes methods that are used to estimate transportation GHG emissions and explores uncertainties in the calculations.

Section 10. Lifecycle Transportation Emissions—This section examines GHG emissions from a broader lifecycle perspective, including activities such as fuel processing and distribution, vehicle manufacture and vehicle maintenance.

Section 11. GHG Emissions Projections and Emerging Issues—This section provides forecasts of GHG emissions from transportation sources through 2025 and highlights some of the issues affecting trends in GHG emissions from transportation during this time period.

2 Overview of Greenhouse Gas Emissions and Transportation

2.1 Background on Greenhouse Gases

Greenhouse gases (GHGs) occur naturally in the Earth’s atmosphere and help to keep the planet hospitable to life by trapping some of the sun’s natural heat. Without this “greenhouse effect,” the Earth’s average surface temperature would be about 33 degrees Celsius cooler than it is currently.⁴ The most important naturally occurring GHGs associated with this phenomenon are water vapor (H₂O), carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O).

Human activities release GHG emissions and contribute to increasing concentrations of GHGs in the atmosphere. CO₂ is the predominant GHG emitted by human sources. Like most GHGs, CO₂ is produced both by natural and human activities and can be removed from the atmosphere through natural processes.⁵ However, increased production of CO₂ by human sources has caused total GHG emissions to exceed natural absorption rates, resulting in increased atmospheric concentrations. Since the beginning of the industrial revolution, atmospheric concentrations of CO₂ have increased by nearly 30 percent, CH₄ concentrations have more than doubled, and N₂O concentrations have risen by approximately 15 percent. Human activities over the past 70 years have also produced synthetic chemicals that are greenhouse gases, including chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF₆).⁶

Greenhouse Gas	GWP
CO ₂	1
N ₂ O	296
CH ₄	23
HFC-125	3,400
HFC-134a	1,300
HFC-143a	4,300
HFC-152a	120

Source: International Panel on Climate Change, 2000. *Third Assessment Report: Climate Change 2001*. Geneva, Switzerland.

GHG emissions are typically reported in terms of CO₂ equivalent (CO₂ Eq.) to provide a common unit of measure, and because CO₂ is the most prevalent of all GHGs. Other GHGs are converted into CO₂ equivalent on the basis of their global warming potential (GWP), which is defined as the cumulative radiative forcing⁷ effects of a gas over a specified time horizon in comparison to CO₂ (see sidebar). For example, one kilogram of CH₄ is estimated to have the same radiative forcing effect as 21 kilograms of CO₂.⁸

CO₂ accounted for 85 percent of the radiative forcing effect of all human-produced GHGs in the United States in 2003. This proportion is higher for transportation sources, with CO₂ representing about 96 percent of the sector’s GWP-weighted emissions. The transportation sector is the largest

⁴ International Panel on Climate Change (IPCC), 2001. *Third Assessment Report, Climate Change 2001: A Scientific Basis*. Cambridge, UK.

⁵ International Panel on Climate Change (IPCC), 2001. *Third Assessment Report, Climate Change 2001: A Scientific Basis*. Cambridge, UK.

⁶ International Panel on Climate Change (IPCC), 2001. *Third Assessment Report, Climate Change 2001: A Scientific Basis*. Cambridge, UK.

⁷ Radiative forcing is the change in balance between radiation entering the Earth’s atmosphere and radiation being emitted back into space. A “positive radiative forcing effect” means that the ratio of incoming to outgoing radiation increases, generally resulting in a warming of the Earth. Conversely, a “negative radiative forcing effect” generally results in cooler Earth temperatures.

⁸ Note that the GWPs used in this report are those reported in IPCC’s *Second Assessment Report*, which is consistent with international inventory guidelines. The IPCC has published a *Third Assessment Report* with revised GWPs, which are currently being considered for international inventory guidelines. This report presents estimates of CO₂, N₂O, CH₄, and HFC emissions in teragrams or trillion grams of carbon dioxide equivalent (Tg CO₂ Eq.) unless noted otherwise.

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source of domestic CO₂ emissions, producing over 30 percent of the nation's total in 2003. The vast majority of anthropogenic CO₂ emissions come from the combustion of fossil fuels.⁹ CO₂ production is related to the amount of fuel combusted and the fuel's carbon content.¹⁰ The U.S. transportation sector derived all but 1 percent of its energy from fossil fuels in 2003, 97 percent of which was petroleum.¹¹

CH₄ and N₂O collectively represented 13 percent of all United States GHGs in 2003, but only accounted for 2 percent of the transportation total. These gases are released during fossil fuel consumption, although in much smaller quantities than CO₂. They are also unlike CO₂ in that their emissions rates are affected by vehicle emissions control technologies.

A final category of GHGs comprises various families of synthetic chemicals. These include compounds such as CFCs and hydrochlorofluorocarbons (HCFC) that result in stratospheric ozone depletion and are controlled under the Montreal Protocol. Because of their required phase out, ozone depleting substances are not included in official estimates of national GHGs.¹² Compounds such as HFCs, perfluorocarbons (PFC), and SF₆ have been identified as acceptable alternatives to ozone depleting substances. Nonetheless, the replacement chemicals are also potent greenhouse gases with very high global warming potential. While small quantities of these chemicals are released, they accounted for approximately 2 percent of GWP-weighted GHGs from all U.S. sectors in 2003. HFCs are the primary replacement chemicals associated with transportation sources, replacing CFCs and HCFCs in vehicle air conditioning and refrigeration systems. Leakage of HFCs was responsible for 2 percent of transportation GHGs in 2003.

Transportation sources emit several other compounds that are believed to have an indirect effect on global warming but are not considered greenhouse gases. These substances include ozone, carbon monoxide, (CO) and aerosols. Scientists have not yet been able to quantify their impact with certainty, and these compounds are not included in the transportation GHG emissions estimates.¹³

⁹ Approximately 95 percent in the U.S.

¹⁰ A lesser consideration is the fraction of the carbon oxidized, which is assumed to be 100 percent for emissions from transportation. The formula for CO₂ emissions from fossil fuels is Fuel Combusted X Carbon Content Coefficient X Fraction Oxidized X (44/12).

¹¹ Approximately 2.5 percent is in the form of natural gas, with less than 1 percent renewables (alcohol fuels blended with gasoline to make gasohol) and electricity. Source: Oakridge National Laboratory, *Transportation Energy Data Book*, Table 2.2. Citing, U.S. Department of Energy, Energy Information Administration, *Monthly Energy Review*.

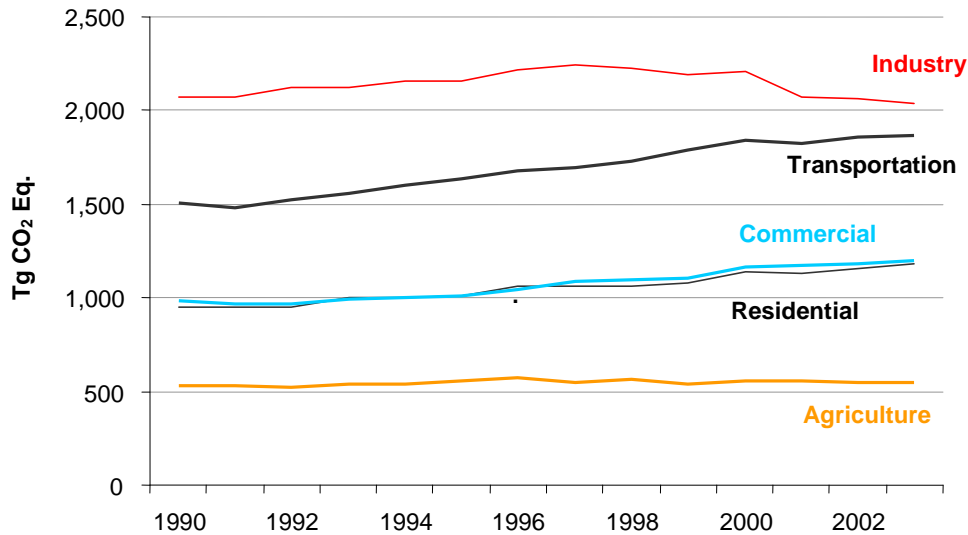
¹² Transportation GHG estimates reflect an accounting issue related to the phase-in of HFCs, primarily as a replacement for CFCs in vehicle air conditioners. Transportation HFCs increased from virtually zero in 1990 to over 40 Tg CO₂ Eq. in 2003, at which point they represented about 2 percent of total transportation GHGs. CFCs emissions have declined over the same period, but they are not reported in official GHG inventories because of their required phase-out under the Montreal Protocol. As a result, the official transportation GHG estimates do not reflect the net impact of increasing HFCs and declining CFCs. On balance, the introduction of HFCs has reduced GWP-weighted GHG emissions because these substances have lower global warming potential than CFCs.

¹³ Ozone traps heat in the atmosphere and prevents a breakdown of CH₄, but its lifetime in the atmosphere varies from weeks to months, making it difficult to estimate net radiative forcing effects. CO indirectly affects global warming by reacting with atmospheric constituents that would otherwise destroy CH₄ and ozone. Aerosols are small airborne particles or liquid droplets that have both direct and indirect effects on global warming. The most prominent aerosols are sulfates and black carbon, or soot. Sulfate aerosols also have some cooling effect by reflecting light back into space.

2.2 Transportation in the Context of U.S. Greenhouse Gas Emissions

Although the United States accounts for approximately 5 percent of the world’s population, it produces an estimated 21 percent¹⁴ of the world’s GHG emissions, amounting to 6,900 Tg CO₂ Eq. in 2003.¹⁵ Transportation sources were responsible for about 27 percent of total U.S. GHG emissions in 2003 (1,866.7 Tg CO₂ Eq.).¹⁶ Non-transportation mobile sources, such as equipment used for construction and agriculture, accounted for an additional 2.1 percent of the total U.S. GHG emissions (144.8 Tg CO₂ Eq.). These estimates are primarily representative of “tailpipe” GHGs that result from the use of energy to power vehicles.¹⁷ They do not include “lifecycle” emissions from processes such as the extraction of crude oil and manufacture of vehicles. (Lifecycle issues are discussed in Chapter 10.)

Figure 2-1. U.S. Greenhouse Gas Emissions by End-Use Economic Sector, 1990–2003



Source: Derived from U.S. Environmental Protection Agency, 2005. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2003*. Washington, DC, Table 2-16.

Note: GHG emissions from electricity generation are distributed to economic sectors. Also, territories are excluded even though they are reported in the U.S. inventory. Territories comprise less than 1 percent of national emissions.

Total U.S. production of greenhouse gases in 2003 was 13 percent greater than in 1990. By comparison, transportation GHGs grew almost 24 percent over the same period. GHG emissions

¹⁴ Based on 2000 data reported by the Climate Analysis Indicators Tool (CAIT), World Resources Institute, <http://cait.wri.org/cait.php>. Does not adjust for land-use and forestry change.

¹⁵ U.S. Environmental Protection Agency, 2005. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2003*. Washington, DC, Table 2-16.

¹⁶ Based on global warming potential of all gases emitted.

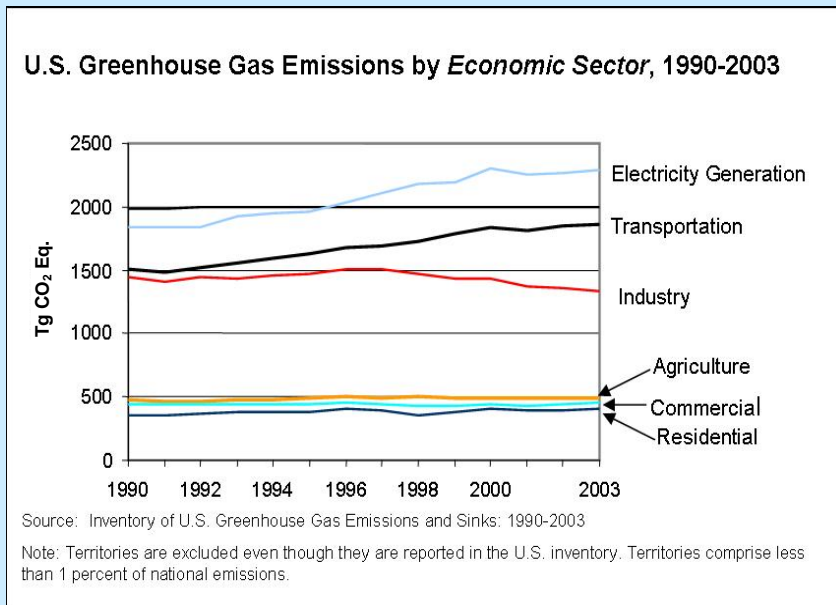
¹⁷ There are two notable exceptions. Included in the transportation estimates are pipelines, which are used as a means of transporting petroleum and natural gas. Pipeline GHGs include emissions from natural gas used to operate pumps, motors, engines, and compressors, but not electricity used in the operation of pipelines. This is consistent with the energy accounting procedures used by the U.S. Energy Information Administration. Second, the transportation sector includes the emission of HFCs from vehicle air conditioning and refrigerated transport. This process occurs as a result of leakage during equipment operation, servicing, and disposal. Pipeline and HFC emissions collectively accounted for slightly less than 3.5 percent of total transportation GHGs.

from the transportation sector increased more in absolute terms than any other sector,¹⁸ growing by 357.4 Tg CO₂ Eq. from 1990 to 2003 (Figure 2-1). The growth rate of transportation GHGs was equal to the residential sector (also 24 percent), slightly above the commercial sector (22 percent), and considerably greater than agriculture (3 percent) and industry (which decreased by 2 percent).

The overall rise in U.S. GHGs primarily reflects increased emissions of CO₂ as a result of increasing fossil fuel combustion. Transportation petroleum use grew by 23 percent from 1990 to 2003 and accounted for 93 percent of the increase in total U.S. petroleum consumption over this period. Considering only CO₂, transportation sources emitted 1780.7 Tg CO₂ in 2003, an increase of 319.0 Tg (or 22 percent) from 1990. The combined emissions of CH₄ and N₂O decreased by 4.0 Tg CO₂ Eq. over the same period, due largely to the introduction of control technologies designed to reduce criteria pollutant emissions.¹⁹ Meanwhile, HFC emissions from mobile air conditioners and refrigerated transport increased from virtually no emissions in 1990 to 42.7 Tg CO₂ Eq. in 2003 as these chemicals were phased in as substitutes for ozone depleting substances.

Categorizing U.S. Greenhouse Gas Emissions: The Difference Between “Economic Sector” and “End Use Economic Sector” Estimates

The “economic” sectors referred to in this report do not represent official Intergovernmental Panel on Climate Change (IPCC) categories. IPCC guidelines allocate emissions into the following sectors: Energy, Industrial Processes, Solvent and Other Product Use, Agriculture, Land Use Change and Forestry, and Waste. However, EPA has also found it useful to allocate emissions into “economic sector” categories that are commonly used for policy analysis.



The *Inventory of U.S. Greenhouse Gas Emissions and Sinks* classifies “economic sector” estimates in two different ways. The first categorization identifies the emissions from Electricity Generation, as well as the non-electricity components of Transportation, Industry, Agriculture, Commercial, Residential, and U.S. Territories (note the adjacent chart). The second categorization distributes the emissions from Electricity Generation to the remaining “end use economic sectors” in which electricity is consumed.

The sectoral estimates in this report are based on the second categorization. However, if electrical generation is considered a separate sector, it accounts for 33 percent of all GHG emissions, and is larger than any of the five sectors discussed in this report. Also, emissions from Electricity grew by 24.7 percent from 1990 to 2003, representing the largest percentage increase of any economic sector. See the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2003* Section 2.2 for additional discussion of the two approaches.

¹⁸ Based on “end use economic sector” estimates, in which emissions from Electricity Generation are allocated to economic sectors in which electricity is consumed.

¹⁹ The decline in CFC emissions is not captured in the official transportation estimates. See footnote 9 above.

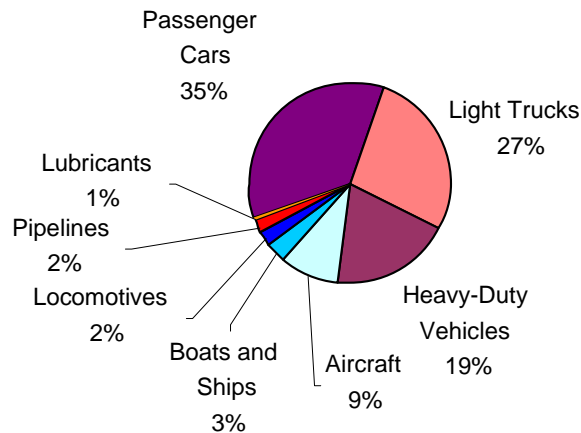
2.3 Transportation Sources

In 2003, about 81 percent of transportation GHG emissions in the United States came from “on-road” vehicles, including passenger cars, sport-utility vehicles (SUVs), vans, motorcycles, and medium- and heavy-duty trucks and buses (Figure 2-2). “Light-duty” vehicles, which are used primarily for personal transport, accounted for 62 percent of total transportation emissions. This category consists of passenger cars, (35 percent of the transportation total), “light-duty trucks,” including SUVs, minivans and pickup trucks (27 percent), and motorcycles (less than 1 percent). Heavy-duty vehicles, which include trucks and buses, were responsible for 19 percent of total transportation emissions.

Non-road transportation sources produced 16 percent of all transportation GHG emissions in 2003. Aircraft were the largest non-road source, producing 9 percent of total transportation GHGs. Other non-road sources include boats and ships (3 percent), rail (2 percent), and pipelines (2 percent).²⁰

Finally, the transportation sector estimates include emissions from sources that are classified as neither on-road nor non-road. Approximately 2 percent of total transportation emissions in 2003 consisted of HFCs from vehicle air conditioning and refrigerated transport. Another 1 percent came from lubricants, consisting mainly of oil used in motor vehicle engine combustion.

Figure 2-2. 2003 Transportation Greenhouse Gas Emissions, by Source



Source: U.S. Environmental Protection Agency, 2005. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2003*. Washington, DC, Table 2-9.

2.4 GHG Emissions Trends for Major Transportation Sources

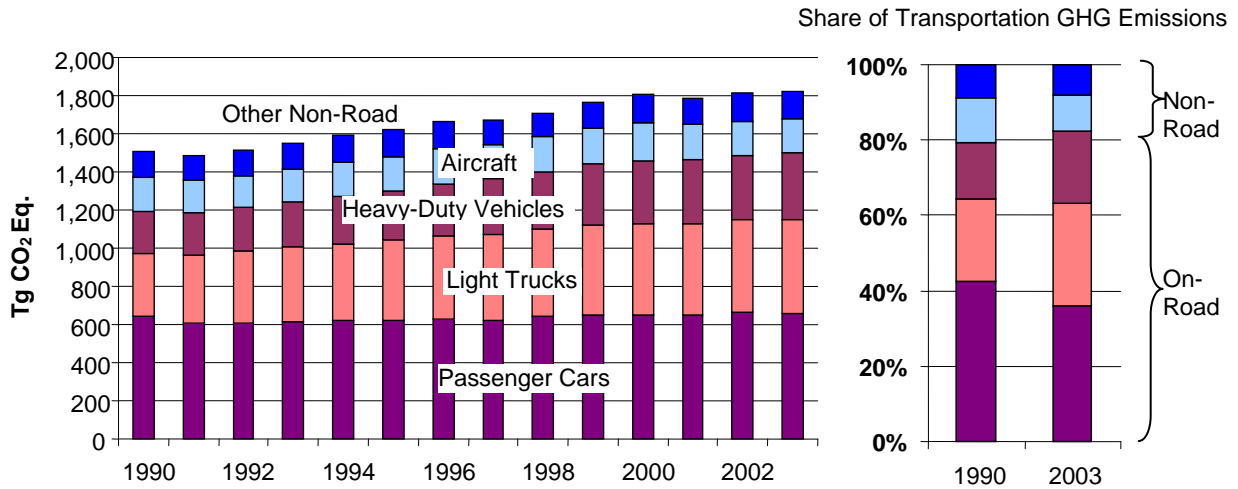
The increase in transportation emissions from 1990 to 2003 reflects continued growth in passenger and freight travel, which has substantially exceeded improvements in the energy efficiency of most major transport modes. GHG emissions from on-road vehicles increased by

²⁰ Estimated pipeline GHGs include emissions from natural gas used to operate pumps, motors, engines, and compressors, but not electricity used in the operation of pipelines. This is consistent with the energy accounting procedures used by the U.S. Energy Information Administration.

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308.6 Tg CO₂ Eq., or 26 percent, from 1990 to 2003. Meanwhile, GHG emissions from non-road transportation sources increased by 7.8 Tg CO₂ Eq., or 3 percent (Figure 2-3).²¹

Figure 2-3. GHG Emissions by Modes of Transportation,^a 1990–2003



Source: U.S. Environmental Protection Agency, 2005. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2003*. Washington, DC, Table 2-9.

Note: “Other Non-Road” includes boats and ships, rail, pipelines, and lubricants.

^a Emissions of HFCs from refrigerated transport and mobile air conditioners are not included in this chart. To view HFC emission trends, please refer to Table 13-5.

GHG emissions from light-duty vehicles (passenger cars and light-duty trucks) grew 19 percent from 1990 to 2003. The overall rise can be broadly explained by a 34 percent increase in light-duty vehicle miles traveled (VMT) over the period, which outweighed a small improvement in overall light-duty fuel economy. However, it is worth noting that the improvement in vehicle energy efficiency was due primarily to the replacement of less fuel-efficient vehicles from the 1970s and early-1980s. Since 1988, the average fuel economy of new light-duty vehicles sold has declined as a result of increasing light-duty truck sales. In 2002, sales of new light-duty trucks overtook passenger cars. As one primary result, GHGs from light-duty trucks increased by 51 percent from 1990 to 2003, compared with a 2 percent increase from passenger cars.

GHG emissions from heavy-duty vehicles (predominantly freight trucks) grew by 57 percent from 1990 to 2003—more than twice the rate of light-duty vehicles. An increase in truck freight haulage²² caused heavy-duty truck VMT to rise 48 percent over the same period.²³ Meanwhile,

²¹ This does not include lubricants, which are used for all modes. Lubricant GHG emissions decreased by 1.6 Tg CO₂ Eq. from 1990 to 2003.

²² According to data from the Commodity Flow Survey and additional estimates compiled by the Bureau of Transportation Statistics, the value of goods transported by truck domestically increased by 42 percent, and ton-miles increased 56 percent between 1993 and 2002 (survey data are not available for 1990 or 2003). These figures do not include “multimodal combinations.” Source: U.S. Department of Transportation, Bureau of Transportation Statistics. *Freight Shipments in America: Preliminary Highlights from the 2002 Commodity Flow Survey Plus Additional Data*. Table 1.

²³ Refers to combination trucks and single-unit trucks, excluding two-axle, four-tire trucks. Federal Highway Administration, 2004. *Highway Statistics 2003*. Washington, DC.

overall heavy-duty truck fuel economy declined from 6.0 to 5.7 miles per gallon,²⁴ although the average vehicle size has increased slightly and data for this mode is less certain.

In contrast to on-road vehicles, aircraft GHG emissions decreased by 3 percent from 1990 to 2003. GHGs from military aircraft declined significantly over the period, while other sources of aviation GHGs increased moderately. The largest source of aviation GHGs are commercial aircraft, which produced 4.7 percent more greenhouse gases in 2003 than 1990. However, the rise in commercial aircraft GHG emissions was significantly less than the growth in air travel, with aircraft passenger miles increasing 48 percent over the same timeframe. Emissions per passenger mile decreased by 24 percent from 1990 to 2003, representing the most significant improvement in emissions intensity of any major mode. Most of the improvement reflected the increasing fuel efficiency of aircraft and increased numbers of occupied seats.

Among other non-road sources, GHG emissions from rail increased 18 percent from 1990 to 2003. Water-based transportation GHGs appear to have increased similarly (17 percent), although the data show much more fluctuation and have a higher degree of uncertainty. (See Section 9.1.2 for a discussion of uncertainty in GHG emissions estimates.) Pipeline emissions were virtually unchanged between 1990 and 2003.

Impact of Freight Transportation

Freight GHG emissions²⁵ increased by 46 percent between 1990 to 2003, while GHGs from passenger modes increased by 20 percent.²⁶ Collectively, freight sources emitted 13 percent more GHGs per ton-mile in 2003 than in 1990. Most of the increase in GHG intensity resulted from a shift to energy-intensive freight modes. Rail is typically the least energy-intensive freight mode. Measured in BTUs per ton-mile, rail used 90 percent less energy than trucks and 80 percent less than ships.²⁷ While the share of freight carried by rail has remained roughly constant, trucks' share of freight ton-miles increased from 26 percent in 1993 to 32 percent in 2002,²⁸ accounting for most of the overall increase in freight GHG output and intensity.²⁹

²⁴ According to FHWA's estimates of average fuel economy, based on estimates of fuel consumption and VMT by vehicle type. Federal Highway Administration, 1997. *Highway Statistics: Summary to 1995*. Washington, DC, Table VM-201A, and *Highway Statistics 2003*, Table VM-1.

²⁵ Freight modes are those used to ship materials and goods, and include heavy-duty trucks, freight rail, freight vessels, and pipelines. Emissions from refrigerated transport are also freight-related and so are allocated to freight transportation.

²⁶ The U.S. GHG Inventory does not explicitly calculate aircraft emissions resulting from shipping materials and goods. These emissions are generally included in overall estimates for "commercial aircraft," which are categorized as passenger transport.

²⁷ U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, 2004. *Transportation Sector Trend Data*. Available at <http://intensityindicators.pnl.gov/data.html>.

²⁸ Data not available for 1990 or 2002. U.S. Department of Transportation, Bureau of Transportation Statistics, and U.S. Department of Commerce, U.S. Census Bureau, *2002 Economic Census, Transportation 2002 Commodity Flow Survey*. Washington, DC.

²⁹ Air shipments required approximately 82 times more energy per ton-mile than rail in 2001, according to the DOE estimates referenced above. While air was the fastest-growing mode of freight transport, its share of total shipments remained below 1 percent.

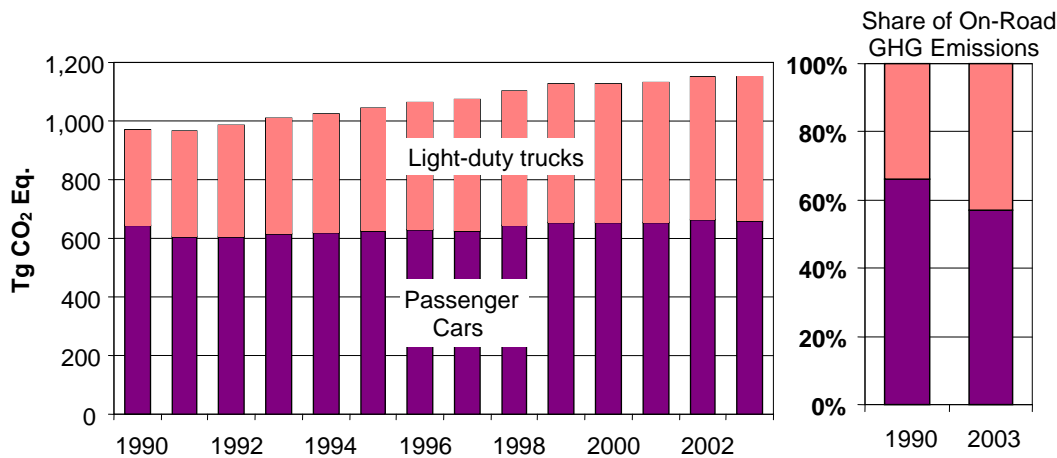
3 Light-Duty Vehicles – Passenger Cars, SUVs, Minivans, Pickup Trucks, and Motorcycles

3.1 Overview

Light-duty vehicles³⁰ in the U.S. produced 1152.6 Tg CO₂ Eq. in 2003, representing 77 percent of on-road vehicle GHG emissions and 62 percent of total transportation emissions.³¹ GHG emissions from light-duty vehicles increased 19 percent between 1990 and 2003. CO₂ emissions increased 20 percent, or 187.8 Tg, mirroring the growth in light-duty vehicle fuel consumption. Meanwhile, emissions of CH₄ and N₂O from light-duty fleet vehicles decreased by 2.1 and 2.9 Tg CO₂ Eq., due to the introduction of vehicle emissions control technologies in newer vehicles.

A growing portion of new vehicle sales from 1990 to 2003 consisted of light-duty trucks, which include pickup trucks, SUVs, and vans. GHG emissions from light-duty trucks increased 51 percent from 1990 to 2003, while emissions from passenger cars increased about 2 percent (Figure 3-1). In 2003, light-duty trucks produced 43 percent of light-duty vehicle GHG emissions, up from 34 percent in 1990. Motorcycles make up a very small proportion of light-duty GHG emissions (less than 0.1 percent in 2003), and this share has remained relatively constant.

Figure 3-1. GHG Emissions from Passenger Cars and Light-Duty Trucks, 1990–2003 (CO₂ Eq.)



Source: Derived from U.S. Environmental Protection Agency, 2005. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2003*. Washington, DC, Table 2-9, with adjustments.

Light-duty vehicles are primarily used for personal transportation, although some are used for business purposes, or are maintained as part of public sector or private sector fleets.³² Among vehicles owned by households, light-duty trucks account for an even higher share of light-duty GHG emissions. Nearly half of household vehicle fuel consumption was by light-duty trucks in 2001, including vans (22 percent), SUVs (17 percent), and pickup trucks (11 percent).³³ Passenger cars consumed about 49 percent of the

³⁰ Light-duty vehicles are defined as vehicles with a gross vehicle weight rating (GVWR) of less than 8,500 lbs.

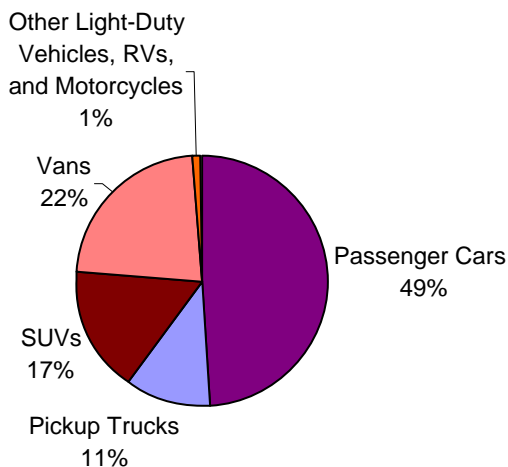
³¹ This figure does not include motorcycle emissions.

³² Such uses include rental cars, taxis, police vehicles, and government vehicles.

³³ National Household Travel Survey, 2001.

motor vehicle fuel used by households, and the remaining 1 percent was used by other light-duty trucks, recreational vehicles (RVs), and motorcycles.³⁴

Figure 3-2. Household Vehicle Fuel Consumption by Mode, 2001



Source: Energy Information Administration, 2005. *Household Vehicles Energy Use: Latest Data & Trends*. Washington, DC. Table A1, p. 54. Available online at http://www.eia.doe.gov/emeu/rtecs/nhts_survey/2001/tablefiles/table-a01.pdf.

3.2 Factors Affecting Light-Duty Vehicle Emissions

The increase in GHG emissions from light-duty vehicles reflects 1.) growth in vehicle travel and 2.) limited improvement in vehicle fuel economy, largely associated with the increased sales and use of light-duty trucks. Light-duty vehicle fuel consumption increased 22 percent between 1990 and 2003,³⁵ resulting in a 20 percent increase in CO₂ emissions. CH₄ and N₂O emissions also have been influenced by the increase in travel, although their potential growth has been mitigated by technologies in newer vehicles that have reduced GHG emissions.

3.2.1 *Increasing VMT*

Nationally, travel by light-duty vehicles rose 34 percent between 1990 and 2003. VMT has grown more than twice as fast as population, with economic, social, and land use factors spurring increased vehicle trip making and VMT per person. According to data from the National Household Travel Survey (NHTS),³⁶ VMT by households (which are a subset of all vehicle users) increased by 35 percent between 1990 and 2001, while the total number of households in the United States increased by only 15 percent (Figure 3-3).³⁷

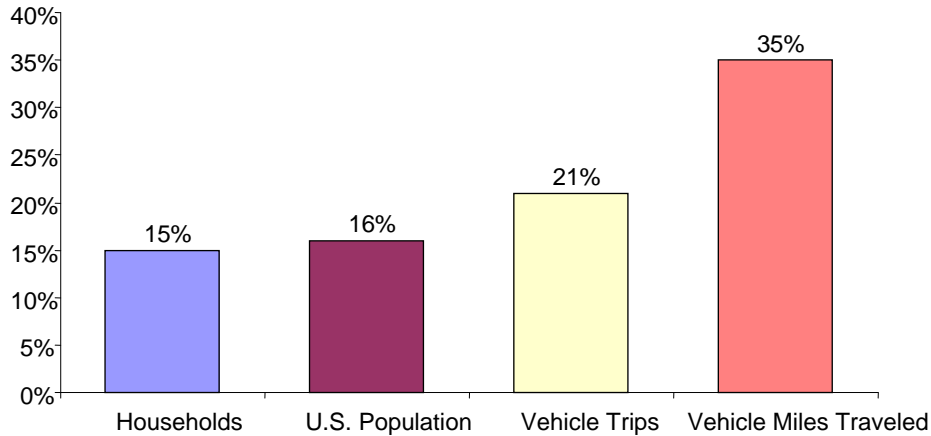
³⁴ Energy Information Administration, 2005. *Household Vehicles Energy Use: Latest Data & Trends*. Washington, DC. Table A1, p. 54. Available online at http://www.eia.doe.gov/emeu/rtecs/nhts_survey/2001/tablefiles/table-a01.pdf.

³⁵ U.S. Department of Energy, 2004, *Transportation Energy Data Book, Edition 24*. Washington, DC.

³⁶ The predecessor survey of the NHTS is the Nationwide Personal Travel Survey (NPTS).

³⁷ Federal Highway Administration, *2001 National Household Travel Survey*. Washington, DC. “Summary Statistics on Demographic Characteristics and Total Travel 1969, 1977, 1983, 1990, and 1995 NPTS, and 2001 NHTS” and “Americans and Their Vehicles,” presentation by Pat Hu, Director, Center for Transportation Analysis, Oak Ridge National Laboratory. Available online at http://nhts.ornl.gov/2001/html_files/trends_ver6.shtml and <http://nhts.ornl.gov/2001/presentations/americanVehicles/index.shtml>.

Figure 3-3. Comparison of Percent Growth of U.S. Population, Households, Vehicle Trips, and Vehicle Miles Traveled by Households, 1990–2001



Source: Federal Highway Administration, 2001 National Household Travel Survey. Washington, DC. “Summary Statistics on Demographic Characteristics and Total Travel 1969, 1977, 1983, 1990, and 1995 NPTS.”

The rapid increase in VMT by households has been influenced in part by the increasing ownership of personal vehicles. The proportion of households without a motor vehicle dropped from 9.2 percent in 1990 to 7.9 percent in 2001, continuing a longer term pattern of increasing vehicle ownership. In 1969, about 20.6 percent of households owned no vehicles. By 2001, more households owned four or more vehicles (8.5 percent) than owned no vehicles.³⁸ The most substantial changes in vehicle ownership occurred during the late 1960s through 1990, a period when a significant number of women entered the workforce, the number of licensed drivers increased rapidly, and disposable income grew. The average household in 1969 had 3.16 persons and 1.16 vehicles. Average household size in 1990 dropped to 2.56 persons, while the number of vehicles increased to 1.77 per household, exceeding the number of licensed drivers per household. In 2001, there were about 203.9 million household vehicles serving 190.3 million licensed drivers.³⁹

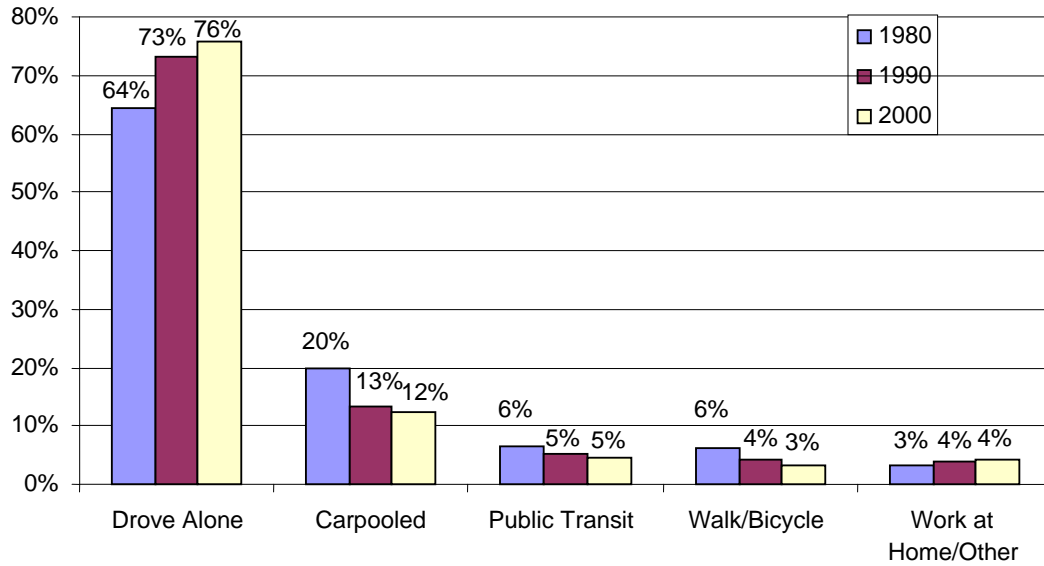
As vehicle ownership has increased, average vehicle occupancy has declined and the number of vehicle trips has grown. According to the Census Bureau’s Journey to Work Survey, the proportion of commute trips taken by single-occupant vehicle increased from 73.2 percent in 1990 to 75.7 percent in 2000, while carpooling, transit, and walking mode shares declined. These trends reflect longer-term changes in commuting patterns. In 1980, 64.4 percent of commuters drove to work alone, while nearly 20 percent carpoolled, about 6 percent used public transit, and nearly 6 percent walked. By 2000, the proportion using carpools had fallen to 12 percent, transit to about 5 percent, and walking to 3 percent (Figure 3-4).⁴⁰ Shared use of vehicles also has declined for other forms of personal travel, due in part to smaller household sizes and increased vehicle availability. Across all trip purposes, the average number of occupants per vehicle in 2000 was 1.6 persons, down from 1.9 in 1977.

³⁸ Federal Highway Administration, 1999. *Summary of Travel Trends: 1995 Nationwide Personal Transportation Survey*. Washington, DC, Table 16, p. 28; and Federal Highway Administration. 2001 National Household Travel Survey online tool. Available online at <http://nhts.ornl.gov/2001/index.shtml>.

³⁹ Household vehicles are a subset of all light-duty vehicles and do not include business fleets or vehicles maintained by persons living in institutions, such as colleges and military bases. Federal Highway Administration, 2001 *National Household Travel Survey*. Washington, DC. “Summary Statistics on Demographic Characteristics and Total Travel 1969, 1977, 1983, 1990, and 1995 NPTS, and 2001 NHTS.” Available online at http://nhts.ornl.gov/2001/html_files/trends_ver6.shtml.

⁴⁰ Although work trips make up only about one-quarter of total vehicle trips, they are important because work trips tend to involve longer distances than trips for other purposes and often are conducted as part of a chain of trips.

Figure 3-4. Journey to Work Mode Choice, 1980, 1990, 2000



Source: U.S. Decennial Census, Supplemental Survey: Journey-to-Work, various census years, 1960 to 2000, as tabulated by Alan Pisarski and reported in A. Pisarski, *Commuting in America III*. Washington, DC: Eno Transportation Foundation, 2003.

The average household in 2001 took more than 100 additional vehicle trips per year compared to 1990.⁴¹ In addition to the increase in trip-making, the average household trip length also increased from 8.7 miles in 1990 to 9.7 miles in 2001.⁴² Consequently, the average household traveled over 3,000 more vehicle miles in 2001 (21,253 vehicle miles) compared to 1990 (18,161 vehicle miles).

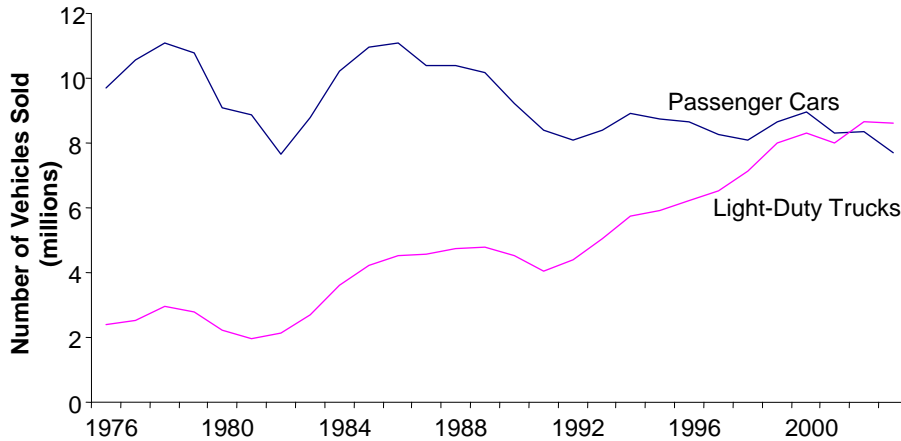
3.2.2 Changes in Vehicle Fleet Composition and Limited Improvements in Fuel Economy

Over the past 25 years, consumer preferences for new vehicles have shifted notably, with an increasing share of buyers opting to purchase light-duty trucks instead of passenger cars (Figure 3-5). In 1976, approximately four new passenger cars were sold for each new light-duty truck. By 1990, the ratio had shifted to two-to-one (67.1 percent passenger cars and 32.9 percent light-duty trucks), and in 2002, sales of light-duty trucks surpassed those of passenger cars.

⁴¹ Federal Highway Administration, 2004. *Summary of Travel Trends: 2001 National Household Travel Survey*. Table 6.

⁴² However, the trend before 1990 is inconsistent. Calculated using Federal Highway Administration, 2001. *2001 National Household Travel Survey*. Washington, DC. Summary Statistics on Demographic Characteristics and Total Travel 1969, 1977, 1983, 1990, and 1995 NPTS, and 2001 NHTS. Available online at http://nhts.ornl.gov/2001/html_files/trends_ver6.shtml.

Figure 3-5. Number of New Light-Duty Vehicles Sold, 1976-2003



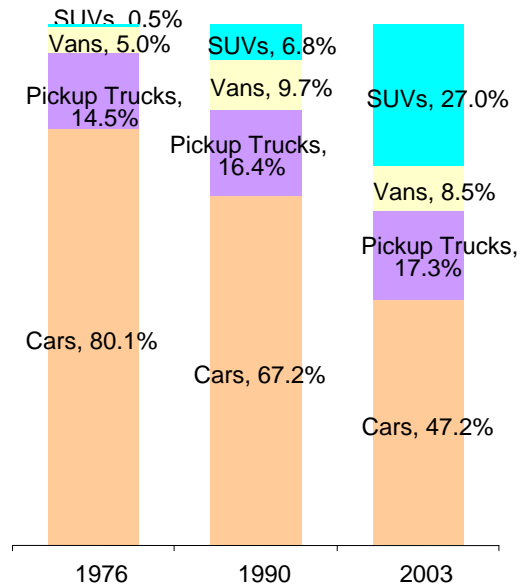
Source: U.S. Department of Energy, 2004. *Transportation Energy Data Book, Edition 24*. Washington, DC. Tables 4.7 and 4.8.

Most of the growth in the light-truck market has been led by rapidly increasing sales of SUVs. As a result, the SUV market share has increased from less than one percent of new light-duty vehicles in 1976 to more than 25 percent of the market by 2003. Other light-duty trucks categories also gained market share over the same period, with minivans growing from 5 percent to 8 percent of new vehicles, and pickup trucks increasing from about 15 percent to 17 percent⁴³ (Figure 3-6). Meanwhile, the share of new light-duty vehicle sales that are passenger cars has fallen from over 80 percent of the new vehicle market in 1976 to just over 47 percent in 2003. The total number of passenger cars on the road has declined from 137.6 million in 2001 to 135.7 million in 2003, while the number of registered light-duty trucks increased from 84.2 million to 87.0 million.⁴⁴

⁴³ U.S. Environmental Protection Agency, 2004. *Light-Duty Automotive Technology and Fuel Economy Trends, 1975 through 2004*. Washington, DC.

⁴⁴ Federal Highway Administration, *Highway Statistics 2003* and *Highway Statistics 2001*. Table VM-1.

Figure 3-6. New Light-Duty Vehicle Sales (Market Share) by Size Class, 1976, 1990, and 2003

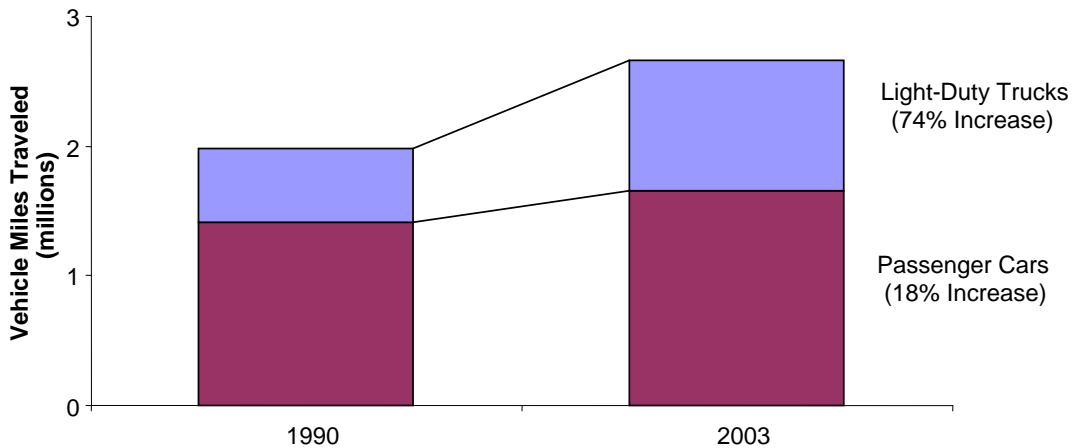


Source: U.S. Department of Energy, 2004. *Transportation Energy Data Book*, Edition 24. Washington, DC, Table 4.9. Note: Original source percentage shares do not equal exactly 100%.

The growing number of light-duty trucks on the road has corresponded with an increase in light-duty truck travel. Light-duty truck VMT increased by 74 percent from 1990 to 2003, while passenger car VMT increased by 18 percent (

Figure 3-7). In 2003, light-duty trucks comprised about 37 percent of all VMT by light-duty vehicles, up from 29 percent in 1990.⁴⁵ The increasing share of VMT by light-duty trucks is significant because those vehicles tend to be less fuel efficient than their passenger car counterparts.

Figure 3-7. VMT by Passenger Cars and Light-Duty Trucks, 1990-2003



Source: Federal Highway Administration, U.S. Department of Transportation, 2004. *Highway Statistics 2003*. Washington, DC, Table VM-1, and *Highway Statistics Summary to 1995*. Table VM-201.

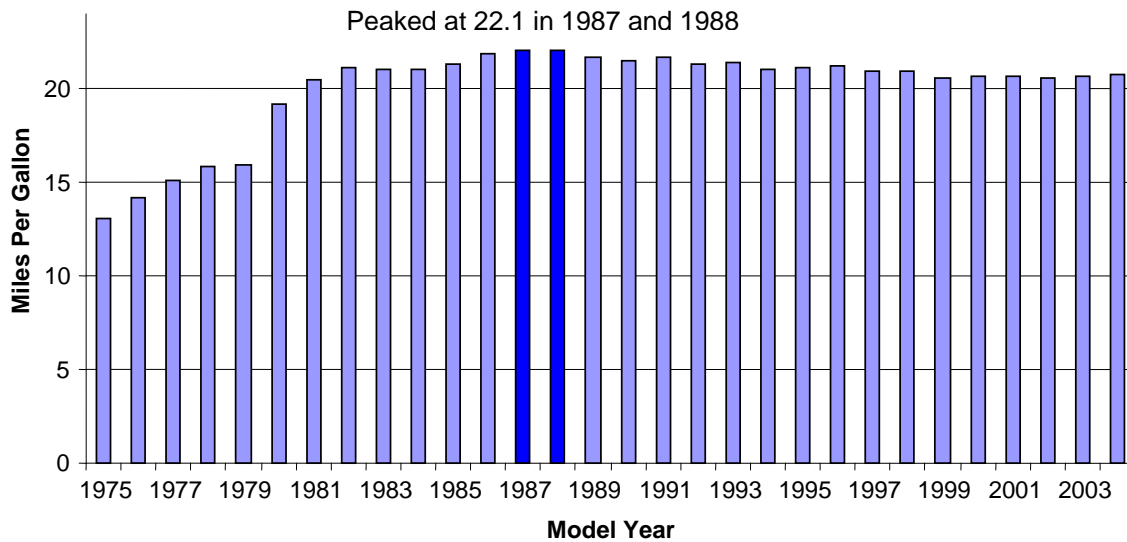
⁴⁵ Oak Ridge National Laboratory, Light-Vehicle MPG and Market Shares System, 2002, as cited in U.S. Department of Energy, 2003. *Transportation Energy Data Book*, Edition 23. Washington, DC, and U.S. Environmental Protection Agency, 2004. *Light-Duty Automotive Technology and Fuel Economy Trends, 1975 through 2004*. Washington, DC.

The Impact of Corporate Average Fuel Economy Standards

Since 1978, Congress has set standards for the average fleet fuel economy of new cars through the Corporate Average Fuel Economy (CAFE) program. These standards initially required a fleet average of at least 18 miles per gallon (mpg) for new passenger cars. The required average was subsequently increased nearly every year until 1990, when it reached 27.5 mpg. The passenger car requirement does not cover light-duty trucks, which must meet their own CAFE standards. The light-duty truck fuel economy requirement is lower than the passenger car standard and has been increased more slowly, from 17.5 mpg in 1982 to 20.7 mpg in 1996.⁴⁶ The reported fuel economy of both passenger cars and light-duty trucks has closely mirrored CAFE standards. The most significant improvements in passenger car fuel economy were reported between 1978 and 1985, and there were moderate increases in new light-duty truck fuel economy through the late 1980s. Since then, the fuel economy of both new passenger cars and new light-duty trucks has been relatively flat.

As a result of the increasing market share of light-duty trucks, the sales-weighted fuel economy of new light-duty vehicles has steadily declined from its peak of 22.1 mpg in 1987 and 1988 (Figure 3-8). By model year 2004, the new light-duty vehicle average had declined to 20.8 mpg.

Figure 3-8. Sales-Weighted Fuel Economy of New Light-Duty Vehicles (Combined Car and Light-Truck Fleet) by Model Year, 1975-2004



Source: U.S. Environmental Protection Agency, 2005. *Light-Duty Automotive Technology and Fuel Economy Trends, 1975 through 2004*. Washington, DC.

Note: This graph represents the estimated sales-weighted fuel economy of new vehicles, based on EPA's adjusted estimates for 55/45 combined city/highway driving.

⁴⁶ Standards for light trucks were initially set in 1978, with separate standards for two-wheel drive and four-wheel drive vehicles.

While EPA-rated new light-duty vehicle fuel economy has declined since the late 1980s, average fuel economy for the in-use fleet of *all* light-duty vehicles has increased. Most of the gain occurred in the early 1990s, reflecting the retirement of a large number of less fuel efficient vehicles built in the late 1970s and early 1980s. Overall fuel economy of the in-use fleet fuel increased from 18.9 mpg in 1990 to 19.6 mpg in 1991, then fluctuated and rose slowly to 20.3 mpg in 2003, representing a 7 percent improvement from 1990 levels.^{47,48} However, the increase in vehicle energy efficiency was offset by a 34 percent increase in light-duty VMT from 1990 to 2003, accounting for the overall growth in light-duty CO₂ emissions.

Effect of Light-duty Vehicle Technologies on Criteria Air Pollutants

Criteria pollutants are not included in transportation GHG totals but are considered to be indirect greenhouse gases and are reported to the United Nations Framework Convention on Climate Change (UNFCCC). Increasingly stringent vehicle emissions controls have dramatically reduced criteria pollutants from light-duty motor vehicles. Between 1970 and 2002, during a time when light-duty VMT increased by 32 percent, light-duty vehicle emissions of CO dropped by 38 percent, volatile organic compounds (VOCs) dropped by 48 percent, and oxides of nitrogen (NO_x) fell by 33 percent.

Source: U.S. Environmental Protection Agency, Emission Factors and Inventory Group, Office of Air Quality Planning and Standards, National Emission Inventory (NEI) Air Pollutant Emission Trends web site.
<www.epa.gov/ttn/chieftrends/index.html>

3.2.3 Improvements in Vehicle Technologies and Emission Controls

Changes in light-duty vehicle technologies have not significantly impacted CO₂ emissions. For the most part, these technologies have been used to improve vehicle power, safety, and driving performance, rather than to increase vehicle fuel economy.⁴⁹ By contrast, vehicle emissions control technologies have reduced emissions of CH₄ and N₂O between 1990 and 2003, although the two gasses have been affected differently by various generations of these technologies.

Emissions control technologies were primarily designed to reduce emissions of criteria air pollutants under EPA emissions standards. Beginning in the 1970s, auto manufacturers switched from non-catalyst control systems to early oxidation catalysts and then to Tier 0-compliant technologies in the mid-1980s. Tier 0 technologies were intended to control emissions of the hydrocarbons CO and NO_x, but had the co-benefit of reducing CH₄ (which is also a hydrocarbon). However, they also increased the amount of N₂O emitted per mile, and caused overall N₂O emissions from light-duty vehicles to grow 27 percent between 1990 and 1998.

Newer generation technologies have lowered N₂O emission rates. These include Tier 1-compliant technologies, introduced in 1994, and low emissions vehicles (LEVs), which entered the fleet in 1996. Nonetheless, these emissions rates are still higher than with the non-catalyst control systems. Since these newer vehicles entered the fleet, light-duty emissions of N₂O have declined to nearly 8 percent below their 1990 level. These new vehicle technologies have had a larger impact on CH₄ emissions rates from light-duty vehicles, which decreased by 52.5 percent from 1990 to 2003 despite a significant increase in VMT.

⁴⁷ Federal Highway Administration, 1997. *Highway Statistics: Summary to 1995*. Washington, DC, Table VM-201A, and *Highway Statistics* (annual editions), Table VM-1. FHWA estimates average fuel economy for the in-use fleet from fuel consumption data (based on state fuel tax receipts) and estimates of VMT (based on travel monitoring data from states).

⁴⁸ For instance, studies of 1984 model vehicles found maximum fuel efficiency achieved at steady-state speeds of 35 to 40 mph, while newer studies of 1997 model vehicles showed peak fuel efficiency at steady-state speeds of 50 to 55 mph, and less fuel economy loss above 55 mph (U.S. Department of Energy, *Transportation Energy Data Book*. Edition 23, Table 4.24).

⁴⁹ The introduction and growing market share of gas-electric hybrid vehicles is increasing the number of fuel-efficient vehicles on the road. A hybrid vehicle uses an electric motor in combination with a traditional combustion engine to power the vehicle using less fuel. For instance, according to EPA fuel economy estimates, a 2003 Honda Civic Hybrid gets 47 combined mpg, compared to 34 combined mpg with the traditional Honda Civic. The 2005 Ford Escape SUV hybrid gets 33 MPG, while the traditional gasoline engine Escape achieves 23 mpg.

4 Heavy-Duty Vehicles—Freight Trucks and Buses

Heavy-duty vehicles are the second-largest source of U.S. transportation GHGs,⁵⁰ accounting for 19 percent of the transportation total in 2003, or 343 Tg CO₂ Eq. Heavy-duty vehicles consist of medium- and heavy-duty trucks used primarily for freight haulage (97 percent of heavy-duty emissions) and buses (3 percent). Emissions from heavy-duty sources grew by 57 percent between 1990 and 2003, the largest increase of any major transportation source. By comparison, emissions from passenger “light-duty” vehicles increased 19 percent. Heavy-duty vehicles accounted for 23 percent of the on-road total GHG emissions in 2003, up from 18 percent in 1990.

The majority of heavy-duty trucks run on diesel, while a smaller percentage run on motor gasoline.⁵¹ (Light-duty vehicles generally use motor gasoline.) It should be noted that the U.S. GHG Inventory’s CO₂ calculations for heavy-duty sources are based on diesel estimates from the Energy Information Administration, which are lower than estimates compiled from Federal Highway Administration (FHWA) and industry sources. As a result, the U.S. GHG Inventory may underestimate the CO₂ emissions from heavy-duty vehicles. (See Section 9 for discussion of uncertainty.)

4.1 Heavy-Duty “Freight” Trucks

Data for heavy-duty trucks are less certain than that of light-duty vehicles, but generally indicate a significant increase in activity and constant or slightly declining fleetwide fuel economy. Heavy-duty truck ton-miles increased 55.5 percent between 1993 and 2002 to 1.45 trillion ton-miles.⁵² VMT grew by a more modest 48 percent between 1990 and 2003,⁵³ most likely reflecting improvements in distributional efficiency. Nevertheless, overall GHG intensity of truck shipments increased 1 percent from 1990 to 2003 as total fleet fuel economy edged downward over the period. In 2001, trucks required 11 times more energy to carry a ton-mile than rail, and 2.2 times more than ships.⁵⁴ The relative GHG intensity of truck haulage has significantly impacted total freight GHG emissions, especially as trucks’ share of total ton-miles increased from 19 percent in 1980 to 26 percent in 1993 and 32 percent in 2002.⁵⁵

⁵⁰ Heavy-duty vehicles are defined by EPA as vehicles weighted over 8,500 pounds. Vehicles weighing between 8,500 and 10,000 pounds are sometimes considered to be medium-duty trucks, but for simplicity, this category is referred to simply as “heavy-duty vehicles.” In addition, to freight trucks, heavy-duty trucks encompass larger commercial vehicles that are not used to transport goods, such as some utility, service, and construction vehicles in addition to those used by some households.

⁵¹ A very small portion, consisting mainly urban delivery vehicles, run on alternative fuels.

⁵² U.S. Department of Transportation, Bureau of Transportation Statistics, and U.S. Department of Commerce, U.S. Census Bureau, *2002 Economic Census, Transportation 2002 Commodity Flow Survey*. Washington, DC.

⁵³ Refers to combination trucks and single-unit trucks, excluding two-axle, four-tire trucks. Federal Highway Administration, 2004. Highway Statistics 2003. Washington, DC.

⁵⁴ U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, 2004. *Transportation Sector Trend Data* Available online at <http://intensityindicators.pnl.gov/data.html>.

⁵⁵ U.S. Department of Transportation, Bureau of Transportation Statistics, and U.S. Department of Commerce, U.S. Census Bureau, *2002 Economic Census, Transportation 2002 Commodity Flow Survey*. Washington, DC.

4.1.1 Factors Underlying Increase in Trucking Activity

A number of factors contributed to increased freight movement, including the growth in domestic consumption and global trade, as well as declining oil costs. Trucks carried a larger share of the increasing domestic freight load for several reasons:⁵⁶

Changing composition of shipments. The United States and world economies shifted toward more high-value, low-weight products, such as electronic, electrical, office equipment, pharmaceuticals, and food products, which are more conducive to haulage by trucks than by rail or ships.

Just-in-time inventory practices. Manufacturers that employ just-in-time systems strive to minimize on-site inventory by coordinating their supply deliveries with production schedules. This requires smaller, more frequent, and more reliable inbound shipments—characteristics that typically favor trucking over rail and also may diminish the loads of smaller trucks.

Declining labor costs. The costs of truck freight transport have decreased relative to other shipping modes, in part because of stiff price competition that followed trucking deregulation with the 1980 Motor Carrier Act.

Manufacturing and warehouse location patterns. Manufacturing and warehousing have migrated from urban areas to suburban or rural locations that often provide greater highway access and cheaper land and labor. Longer hauls by truck carriers are required to connect more distant supply, production, and consumption facilities. At the same time, these facilities are increasingly inaccessible by rail.

4.1.2 Fuels, Energy Efficiency, and GHG Emissions

Overall fuel economy for heavy-duty trucks fell from 6.0 mpg in 1990 to 5.7 mpg in 2003.⁵⁷ These calculations are somewhat uncertain and may reflect changes in the average size and weight of trucks or other factors. According to the 1992 Truck Inventory and Use Survey (TIUS) and 1997 Vehicle Inventory and Use Survey (VIUS), there was a small increase in mean fuel economy for most sizes of heavy-duty trucks between 1992 and 1997.

Although single-unit trucks outnumber combination trucks by more than two-to-one, combination trucks account for 64 percent of heavy-duty truck VMT and 72 percent of truck fuel use (Table 4-1). Combination trucks are typically much larger than single-unit models. They are also used for much longer hauls and require more fuel per mile. Diesel fuel is generally used in combination trucks, while both gasoline and diesel are commonly used by single-unit vehicles.

Table 4-1. 2003 Vehicle Registrations, Vehicle Miles Traveled, and Fuel Use for Heavy-Duty Trucks

Type of Truck	# of Vehicles	%	VMT (millions)	%	Fuel Use (million gallons)	%
Single-Unit	5,666,933	72%	77,562	35%	10,690	28%
Combination	2,245,085	28%	138,322	64%	26,895	72%

Source: Federal Highway Administration, U.S. Department of Transportation, 2004. *Highway Statistics 2003*. Washington, DC. Table VM-1.

Overall, the share of heavy-duty vehicles using diesel has increased over the period 1990 to 2003. During this time period, VMT by diesel-powered heavy-duty trucks increased 60 percent, while VMT by gasoline-powered heavy-duty vehicles increased 7 percent.⁵⁸

⁵⁶ For a discussion of these issues, see *A Guidebook for Forecasting Freight Transportation Demand*, NCHRP Report 388, Transportation Research Board, 1997.

⁵⁷ Federal Highway Administration, U.S. Department of Transportation, 2004. *Highway Statistics 2003*. Washington, DC. Based on estimates of fuel consumption and VMT by vehicle type

⁵⁸ Vehicle miles of travel by alternative fuel heavy-duty vehicles increased by 82 percent for trucks but still comprise a very small portion (about 1 percent) of total VMT.

4.2 Buses

Buses produced approximately 0.5 percent of total transportation GHGs and 0.6 percent of on-road emissions in 2003. Bus GHGs increased about 15 percent from 1990. Best estimates suggest that transit buses produced about 46 percent of total bus GHGs, followed by schoolbuses at 38 percent, and intercity buses at 16 percent.⁵⁹

Transit bus VMT⁶⁰ increased 45 percent between 1990 and 2002, growing from 1.67 billion to 2.43 billion vehicle miles.⁶¹ The number of schoolbuses in service is estimated to have risen by 21 percent over the same timeframe, increasing from approximately 508,000 to 617,067.⁶² Intercity buses passenger-miles and energy use also increased over this period.⁶³

Most buses run on diesel, while a small portion run on gasoline and alternative fuels. Alternative fuels are playing an increasingly significant role in bus travel. Between 1990 and 2003, VMT for buses running on alternative fuels increased by 273 percent. Alternative fuels include biodiesel, ethanol, methanol, compressed natural gas, and liquefied natural gas.

⁵⁹ Total GHG estimates for buses and the breakdown of emissions into these subcategories are somewhat uncertain, given different estimates of bus fuel consumption from different sources and limited data on fuel consumption by schoolbuses. For instance, estimates of fuel consumption by transit buses from the American Public Transportation Association (APTA) and fuel consumption from schoolbuses and intercity buses from the Eno Transportation Foundation systematically exceed the estimates of total bus fuel consumption reported by FHWA for the years 1990 to 2003. The estimates in this report and the U.S. GHG inventory rely on the FHWA data, and thus the GHG estimates reported here are lower than estimates that would result using the APTA and Eno data directly.

⁶⁰ Includes trolley buses.

⁶¹ No data available for 2003 at time of publication. U.S. Department of Transportation, Bureau of Transportation Statistics, 2005. *National Transportation Statistics 2004*. Washington, DC, Table 1-32.

⁶² Federal Highway Administration, 2004. *Highway Statistics 2003*. Washington, DC, Table MV-10.

⁶³ U.S. Department of Energy, 2004. *Transportation Energy Data Book, Edition 24*. Table 5.13.

5 Aircraft

5.1 Overview

Aircraft produced about 9 percent of U.S. transportation greenhouse gas emissions in 2003 (173.1 Tg CO₂ Eq.) and were the largest source of non-road transportation GHGs. In total, aircraft GHG emissions decreased approximately 3 percent from 1990 to 2003. GHGs from military aircraft declined by 40 percent over the period, and commercial aircraft GHGs increased moderately.

Commercial aircraft⁶⁴ produced 72 percent of U.S. aircraft GHGs in 2003 (124.0 Tg CO₂ Eq.), which was 4.7 percent greater than in 1990. The moderate increase reflected a 20 percent rise in GHGs from 1990 to 2001, followed by a substantial decline following the terrorist attacks of September 11, 2001, and a small increase in 2003. Passenger travel rose much more rapidly than the level of GHG emissions, due to a higher number of occupied seats per plane and improved aircraft fuel efficiency. Consequently, GHG emissions per passenger-mile decreased 24 percent from 1990 to 2003, the largest improvement of any transportation mode.

The remainder of aircraft GHG emissions in 2003 came from military aircraft (12 percent), general aviation⁶⁵ aircraft (7 percent), and “other”⁶⁶ aircraft (10 percent). In the U.S. GHG Inventory, aircraft emissions are based on domestic travel only, and exclude international travel to and from U.S. cities.⁶⁷ Commercial and military aircraft rely almost exclusively on jet fuel, while about one-quarter of the fuel used for general aviation is aviation gasoline.⁶⁸ GHG emissions from aircraft in 2003 were 99 percent CO₂, about 1 percent N₂O, and less than 1 percent CH₄.

5.2 Factors Affecting Aircraft Emissions

Aircraft emissions have risen due to increased air travel activity by both passengers and freight, but this has been offset to a large degree by the increased efficiency of aircraft and their operations. Between 1990 and 2003, passenger-miles traveled on certificated domestic services increased by 48 percent, from 345.9 billion to 505.2 billion passenger-miles. (In comparison, light-duty vehicle passenger-miles increased 31 percent over the same timeframe.) The increase in air travel would likely have been greater if not for the terrorist attacks of September 11, 2001. From 1990 to 2000, commercial aircraft passenger-miles increased by an average of 4.1 percent annually; passenger miles dropped by 6.6 percent between 2000 and 2002, and then increased by 4.7 percent in 2003.⁶⁹

Although air cargo accounted for less than 1 percent of total United States freight ton-miles in 2002, aviation was the fastest growing mode of freight transportation. Air ton-miles increased 63 percent from 1993 to 2002. The value of air freight shipments nearly doubled over the same period, increasing from \$395 billion in 1993 to more than \$770 billion in 2002, at which point it represented 7 percent of the total

⁶⁴ Represents any aircraft used in “common carriage.” These are generally certificated air carriers (aircraft holding a certificate issued by the Federal Aviation Administration to conduct scheduled and/or non-scheduled (charter) services) and may carry passengers and/or freight.

⁶⁵ These are non-certificated civil aviation operations, typically operated for personal or business use. The types of aircraft used in general aviation range from corporate multiengine jet aircraft piloted by professional crews to amateur-built single-engine acrobatic planes to balloons and dirigibles.

⁶⁶ The balance of aircraft emissions are from “other” aircraft, which may include other uses of jet fuel such as heating oil.

⁶⁷ GHGs associated with international travel are reported in the Inventory under bunker fuel estimates.

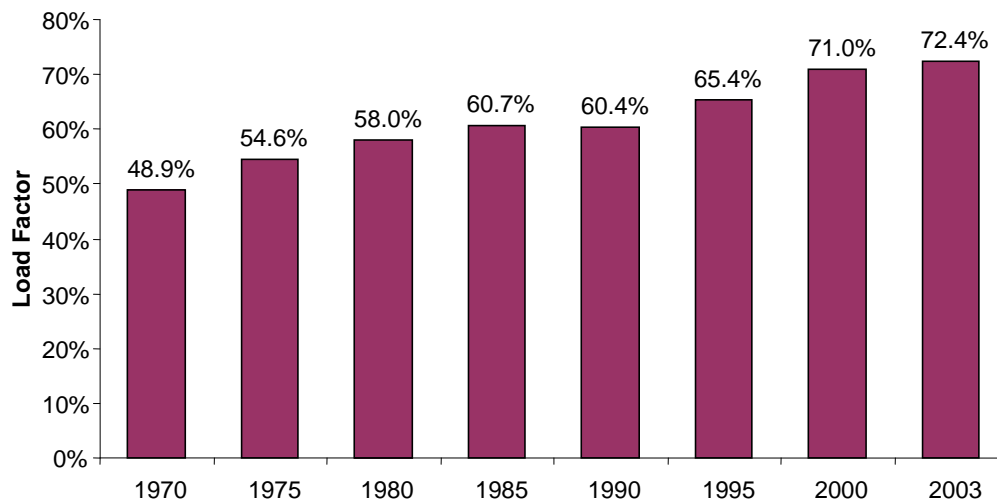
⁶⁸ In total, aviation gasoline makes up about 1 percent of total aircraft fuel use.

⁶⁹ U.S. Department of Transportation, Bureau of Transportation Statistics, 2005. *National Transportation Statistics 2004*. Washington, DC, Table 1-11.

goods transported domestically. (Freight truck ton-miles increased 24 percent from 1993 to 2002, with the value of their cargo increasing 45 percent.) Based on the energy used per ton-mile, aviation is the most energy intensive mode of freight haulage. In 2001, the energy required to move a ton-mile of air cargo was 7.5 times greater than heavy-duty trucks, over 17 times that of ships, and 83 times greater than rail.⁷⁰ Using an energy intensity metric based on the monetary value of goods moved (such as Btu per dollar value shipped), air cargo is closer to other modes. However, it is also important to note that almost all air cargo shipments begin and end their journey by truck, meaning that the growth in air freight has increased demand for truck and intermodal services.⁷¹

The energy intensity of passenger air travel has declined substantially, in part because of increased occupancy of aircraft. The average passenger load factor (percent of available seats that are occupied) on certificated air carriers' domestic operations increased from 60.4 percent in 1990 to 72.4 percent in 2002, continuing a longer term pattern of increasing passenger loads (Figure 5-1). As a result, aircraft passenger miles grew faster than aircraft miles traveled between 1990 and 2000 (49 percent versus 43 percent).⁷²

Figure 5-1. Aircraft Passenger Load Factor, 1970–2003



Source: U.S. Department of Transportation, Bureau of Transportation Statistics, 2005. *National Transportation Statistics 2004*. Washington, DC. Table 4-21.

The reduced energy intensity of commercial aviation also reflects improvements in aircraft fuel efficiency.⁷³ For new production aircraft, the fuel economy improvements have averaged 1 to 2 percent per year since the 1950s.⁷⁴ These developments have been market-driven, as airlines have improved airframe and propulsion technology in order to reduce fuel costs.

⁷⁰U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, 2004. *Transportation Sector Trend Data* <http://intensityindicators.pnl.gov/data.html> .

⁷¹ For more discussion, see: Bureau of Transportation Statistics, 2004. *Freight Shipments in America: Preliminary Highlights from the Commodity Flow Survey Plus Additional Data*.

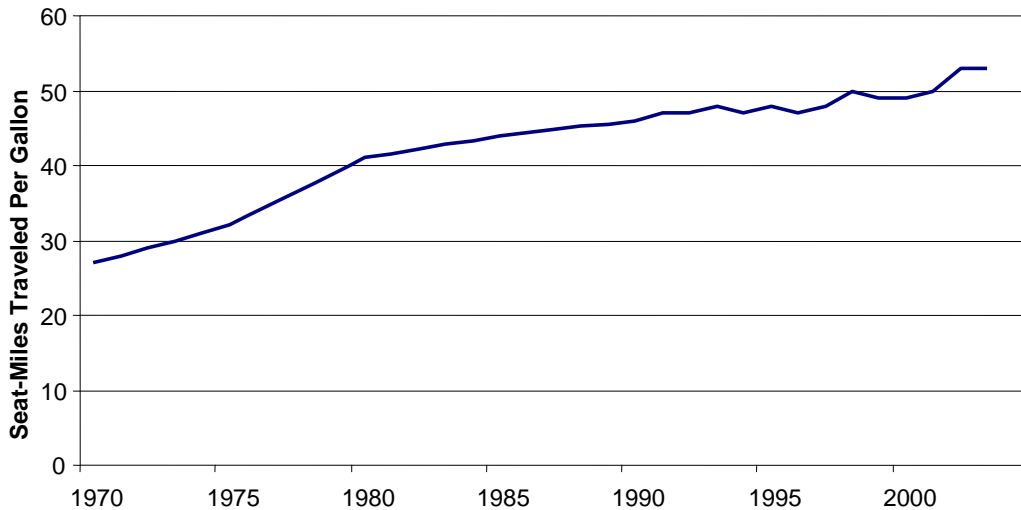
⁷² Aircraft miles traveled increased from 3.96 billion to 5.66 billion by certified carriers. Source: Bureau of Transportation Statistics, 2005. *National Transportation Statistics 2004*. Table 1-32.

⁷³ Measured in fuel consumed per aircraft-mile traveled.

⁷⁴ Intergovernmental Panel on Climate Change, September 1999. *Aviation and the Global Atmosphere*.

One measure of fuel efficiency is the number of aircraft seat-miles per gallon of fuel consumed. The measure, aircraft seat-miles, is calculated by multiplying the total air mileage traveled by the total number of seats available.⁷⁵ Available aircraft seat-miles per gallon increased by about 15 percent between 1990 and 2003 (from 46 to 53 seat-miles per gallon), although about half of this gain occurred since 2001 as airlines reduced the number of flights. Nevertheless, the overall increases indicate the impact of longer-term improvements in aircraft fuel efficiency, as well as the retirement of older, less fuel-efficient aircraft (Figure 5-2).⁷⁶

Figure 5-2. Average Seat-Miles Traveled Per Gallon of Fuel Consumed, 1970–2003



Source: For years 1970, 1975, 1980, 1985, and 1990 and beyond, U.S. Department of Transportation, Bureau of Transportation Statistics, 2005. *National Transportation Statistics 2005*. Washington, DC, Table 4-21. All other years estimated using linear regression.

5.3 Other Considerations in Estimating Global Warming Impact

The total effect of aircraft GHGs on global warming is difficult to discern and may not be entirely accounted for by examining the GWP of CO₂, N₂O, and CH₄. In addition to the primary GHGs, jet engines produce NO_x, which has two contrary effects. In the upper atmosphere, NO_x leads to the production of ozone, which traps heat, but also indirectly destroys CH₄. Aircraft also create condensation trails (contrails) under certain atmospheric conditions, which might have a greenhouse effect by allowing most of the solar radiation to pass and by absorbing infrared radiation from the Earth. These considerations lead to greater uncertainty in estimating the impact of air travel on global warming.

⁷⁵ Vacant and occupied seats are considered equal.

⁷⁶ Between 1990 and 2003, the amount of energy consumed per passenger-mile on commercial aircraft dropped by 30 percent, from 4,900 Btu's per passenger-mile to about 3,500 Btu's per passenger-mile.

6 Other Non-Road Transportation Sources

6.1 Boats/Ships

Boats and other marine vessels produced 3 percent of U.S. transportation GHG emissions in 2003 (58.0 Tg CO₂ Eq.), a 17 percent increase from 1990. However, these figures reflect wide fluctuations in year-to-year estimates of residual fuel consumption and are subject to a high degree of uncertainty. Much of this uncertainty results from the challenge of separating the domestic and international components of fuel consumption estimates. According to the UNFCCC reporting guidelines, national totals of GHG emissions should reflect only domestic transport, including the domestic leg of shipments bound for foreign markets. (The international component is represented by bunker fuel estimates). However, differentiating domestic and international fuel consumption is often difficult, resulting in significant year-to-year variations in the official estimates.

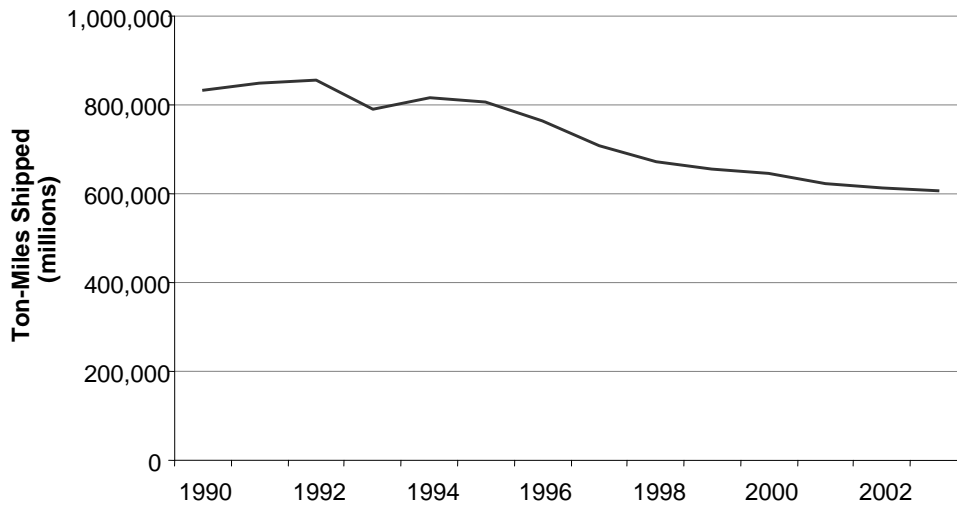
Domestic water shipments⁷⁷ declined by 27.3 percent from 1990 to 2003 (Figure 6-1). As a share of total freight movement, waterborne haulage declined from 24 percent of domestic ton-miles in 1993 to 16 percent in 2002.⁷⁸ Part of the decrease reflected shifts to trucks for goods movement, especially in the transport of lighter weight, time-sensitive commodities. Water shipments were also impacted by maintenance needs on the lock-and-dam systems, environmental constraints for river channel dredging and dam-controlled water levels, and a reduction in crude oil shipment from Alaska.⁷⁹ In contrast to domestic water shipments, tons of waterborne imports and exports increased between 1990 and 2003, as the nation's international trade grew.

⁷⁷ Measured in ton-miles. Waterborne commerce is comprised of several major elements: tugs and barges on the major rivers and inland waterways, oil tankers carrying Alaskan crude to California, ocean-going ships carrying various cargo between the continental United States, Hawaii, Alaska, and Puerto Rico, and large bulk vessels carrying coal, grain, and iron ore on the Great Lakes.

⁷⁸ U.S. Department of Commerce, U.S. Census Bureau, 2002 Economic Census, Transportation 2002 Commodity Flow Survey. Washington, DC.

⁷⁹ U.S. Department of Transportation, Bureau of Transportation Statistics, 2005. *National Transportation Statistics 2004*. Washington, DC, Table 1-52.

Figure 6-1. Ton-Miles Shipped by Domestic Water Transportation, 1990–2003



Source: U.S. Department of Transportation, Bureau of Transportation Statistics, 2005. *National Transportation Statistics 2005*. Washington, DC, Table 1-46.

Recreational boats make up about one-fifth of boat and ship GHG emissions. Recreational boat GHGs have increased steadily, growing from about 9.5 Tg CO₂ Eq. in 1990 to 11.2 Tg CO₂ Eq. in 2003, most likely the result of increased activity and a growing number of crafts. Between 1990 and 2002, the number of recreational boats registered in the United States increased by 17 percent from nearly 11.0 million to 12.9 million.⁸⁰

6.2 Rail

Rail produced 2 percent of total transportation GHG emissions in 2003, or 43.2 Tg CO₂ Eq. This was an increase of 18 percent from 1990. About 89 percent of rail GHGs were from freight haulage, with the remainder coming from passenger sources such as urban transit rail,⁸¹ commuter rail, and intercity rail (Amtrak).⁸² GHG emissions from both freight and passenger rail increased. The majority of rail GHG emissions are from the combustion of diesel fuel (92 percent), with electricity use comprising the balance.

6.2.1 Freight Rail

Between 1990 and 2003, total ton-miles shipped via rail increased by 50 percent, an average annual growth rate of about 3.2 percent.⁸³ Several factors contributed to the growth in ton-miles of rail shipments, including the economic expansion through much of the 1990s and steady growth in coal shipments. Demand also has grown for other bulk commodities that rely heavily on rail transport, including chemicals, lumber and wood products, and farm products.

⁸⁰ U.S. Department of Energy, 2004. *Transportation Energy Data Book, Edition 24*. Table 9.7.

⁸¹ Especially the electricity used for heavy- and light-rail systems.

⁸² The Energy Information Administration's estimates of transportation electricity consumption, which are used to calculate CO₂ emissions for the U.S. GHG inventory, only account for electricity used by urban transit rail, not for intercity rail (Amtrak). As a result, the GHG electricity figures for rail are likely underestimated. Moreover, industry estimates of diesel fuel consumption by railroads exceeds the estimate calculated for the U.S. GHG Inventory, based on the apportionment of diesel fuel consumption to individual transportation sources (see Chapter 9 for a discussion of uncertainty).

⁸³ U.S. Department of Transportation, Bureau of Transportation Statistics, 2005. *National Transportation Statistics 2003*. Washington, DC, Table 1-46.

Rail fuel economy has improved steadily from 1990 to 2003.⁸⁴ Calculations by the Association of American Railroads (AAR) show that revenue ton-miles per gallon for Class I railroads⁸⁵ has been increasing at a rate of about 1.6 percent annually over the last 12 years. In 2003, this measure was 405 revenue ton-miles per gallon, up from 332 in 1990.⁸⁶ This increase can be attributed to a number of factors, including the introduction of more efficient locomotives and lighter weight railcars. Railroads have also taken steps to improve the efficiency of their operations, by minimizing the movement of empty railcars and short trains. For example, railroads in the Great Plains states have closed many of their smaller spur lines and now carry grain shipments on 100-car “unit trains” that operate only on the railroads’ major trunk lines.

6.2.2 Passenger Rail

The increase in GHG emissions from passenger rail reflects a significant growth in passenger rail services, with a number of light-rail and commuter rail lines coming into service or expanding operations. Between 1990 to 2003, the number of vehicle miles of rail transit operations⁸⁷ increased by 21.6 percent, from 560.9 million to 682 million vehicle miles. Meanwhile, commuter rail operations increased by 33 percent, from 212.7 to 284 million vehicle miles. Amtrak train-miles and energy use also increased, although overall ridership declined from 1990 to 2003. Meanwhile, passenger-miles traveled on urban transit and commuter rail increased at an even higher rate than vehicle miles and fuel consumption.

6.3 Pipelines

While pipelines are not technically “mobile,” they are generally classified as part of the transportation sector because they serve an important purpose in transporting energy products domestically. (The U.S. GHG Inventory includes pipelines in its transportation sector estimates, but excludes them from the mobile source section.) More than 1.4 million miles of pipelines are used to transport natural gas, and almost 177,000 miles are used to transport crude oil and petroleum products in the United States. While there are far fewer miles of pipelines dedicated to transporting petroleum products, they account for two-thirds of domestic petroleum transport. Pipelines also are used to transport coal slurry and water. According to the Commodity Flow Survey, pipelines accounted for about 17 percent of total ton-miles of all raw and finished products transported in 2002, similar to their share in 1993.⁸⁸

The two primary “fuels” used to operate pipelines are natural gas and electricity, which are used in pumps, motors, engines, and compressors. Natural gas used to power pipelines produced an estimated 35 Tg CO₂ in 2003, or about 2 percent of total GHG emissions from transportation, a figure that has stayed fairly constant since 1990.⁸⁹

⁸⁴ Locomotive fuel efficiency is generally reported in ton-miles per gallon. Gross ton-miles are based on the movement of the entire train, including locomotives, railcars, and freight. Revenue ton-miles are based on the movement of freight for which the railroad collects revenue—roughly half of gross ton-miles.

⁸⁵ Class I railroads have operating revenues of more than \$50 million.

⁸⁶ Association of American Railroads, 2004. *Railroad Facts*. Washington, DC, p. 40.

⁸⁷ Includes heavy and light rail.

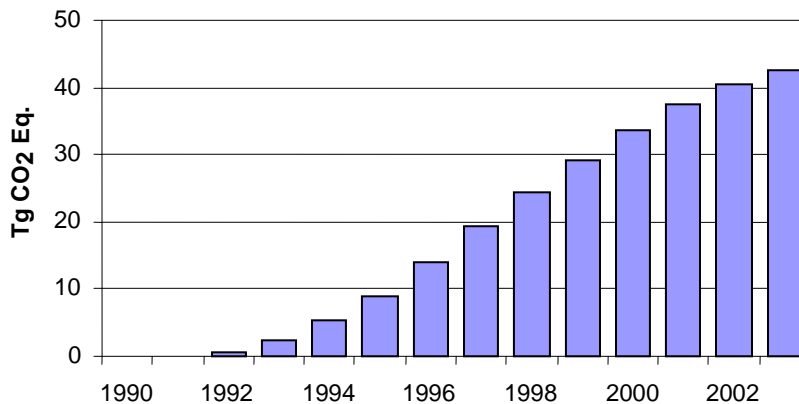
⁸⁸ U.S. Department of Transportation, Bureau of Transportation Statistics, 2004. *Freight Shipments in America: Preliminary Highlights from the Commodity Flow Survey Plus Additional Data*.

⁸⁹ The reported estimates do not include CO₂ emissions associated with electricity use, although electricity is a major power source for pipelines. According to estimates in the Transportation Energy Data Book, electricity used to power pipelines consumed about 3.0 billion kilowatt-hours (kWh) in 2002 (most recent year available). At the average rate of CO₂ emitted per kWh, based on fuel mix in the United States, this level of electricity use equates to approximately 1.8 Tg CO₂.

7 HFCs from Mobile Air Conditioners and Refrigerated Transport

Hydrofluorocarbon (HFC) emissions from mobile air conditioners and transport refrigeration produced about 2 percent of total transportation GHG emissions in 2003. HFCs are used as a replacement for chlorofluorocarbons (CFC) and hydrochlorofluorocarbons (HCFCs), which deplete ozone and are required to be phased out through international agreement under the Montreal Protocol. (Official GHG Inventory estimates do not include CFC and HCFC estimates in national totals because of their mandated retirement.) As HFCs have replaced CFCs and HCFCs, their emissions have risen steadily from nearly zero emissions in 1990 to approximately 42.7 Tg CO₂ Eq. in 2003 (Figure 7-1). While estimating the net effect of this transition is difficult, the introduction of HFCs has lowered GWP-weighted emissions because the replacement gases generally have lower GWPs than their predecessors. For instance, the standard automobile air conditioner refrigerant, HFC-134a, has a GWP of 1,300, compared with its predecessor's net effect of between 7,300 and 9,900.⁹⁰

Figure 7-1. HFC Emissions from Mobile Air Conditioners and Refrigerated Transport, 1990-2003



Source: U.S. Environmental Protection Agency, 2005. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003. Washington, DC.

Approximately 71 percent of HFC emissions in 2003 were associated with mobile air conditioners, which are used to cool the passenger compartments of on-road vehicles. The remaining HFC emissions came from refrigerated transport. HFCs are commonly used to refrigerate perishable food and temperature-sensitive items during transport on reefer ships, refrigerated freight trains, and insulated trucks and trailers with self-contained refrigeration units.

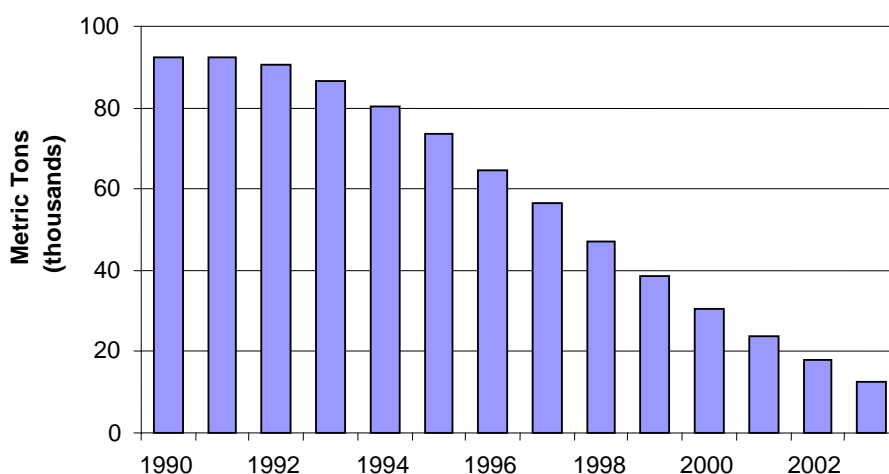
HFC-134a was introduced in some automobiles beginning in 1992 and became the standard automobile refrigerant in 1994. Some vehicles with CFC air conditioners were retrofitted with HFC-134a or a refrigerant blend. Regulations and industry practices established during the CFC phase-out, such as better training of technicians, certification requirements to purchase CFC refrigerant, and requirements to use recovery equipment and not vent refrigerant during equipment service, have reduced leakage and other “unnecessary” emissions. Some of these practices and requirements have also been implemented with newer HFC-equipped vehicles, which has helped limit the growth of HFC emissions. Manufacturers have also become increasingly sensitive to the environmental effects of refrigerants. Many have responded by reducing refrigerant charge sizes and leak rates, increasing reliability of their equipment, and investigating refrigerants with even lower GWPs.

⁹⁰ CFC-12 was the predecessor to HFC-134a. Although CFC-12 has an estimated direct GWP of 10,600, it also destroys stratospheric ozone, thus lowering its net effect.

Other vehicle air conditioning systems also are transitioning away from ozone depleting chemicals.⁹¹ Most buses and many passenger trains currently use HCFC-22, which is an ozone depleting chemical that will be phased out under the Montreal Protocol. HCFC-22 has an ozone depleting impact estimated to be 5.5 percent that of CFC-12. While production is currently allowed under the Montreal Protocol in all countries, many nations have accelerated phase-out through regulations and other measures. Some new buses and trains have utilized alternatives to HCFC-22, most notably HFC-134a, R-407C (a blend of HFC-32, HFC-125, and HFC-134a), and R-410A (a blend of HFC-32 and HFC-125).

CFC and HCFC emissions are *not* included in official U.S. GHG inventory estimates. Due to the required phase-out of these gases, their emissions have been steadily declining (Figure 7-2). The use of HFCs as a replacement to CFCs and HCFCs has resulted in lower GWP-weighted emissions, although there is no official estimate of the net change in GWP-weighted emissions.

Figure 7-2. CFC and HCFC Emissions from Mobile Air Conditioners and Refrigerated Transport, 1990–2003



NOTE: CFC and HCFC emissions are *not* included in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*.

Source: U.S. Environmental Protection Agency, 2004. U.S. EPA Vintaging Model. Version VM IO file_11-08-04.

⁹¹ In the past, transportation-related air conditioning and refrigeration systems have used a wide variety of CFCs and HCFCs. Most notable have been CFC-12, HCFC-22, and R-502 (a blend of CFC-115 and HCFC-22). These are being replaced primarily by HFCs, although some non-fluorocarbon alternatives such as ammonia, hydrocarbons, and water also are used. CFC-12 and R-502 have been replaced by HFC-134a, R-404A (a blend of HFC-125, HFC-143a, and HFC-134a) and R-507A (a blend of HFC-125 and HFC-143a). HCFC-22 is still used but also is being replaced by these refrigerants as well as R-407C (a blend of HFC-32, HFC-125 and HFC-134a) and R-410A (a blend of HFC-32 and HFC-125).

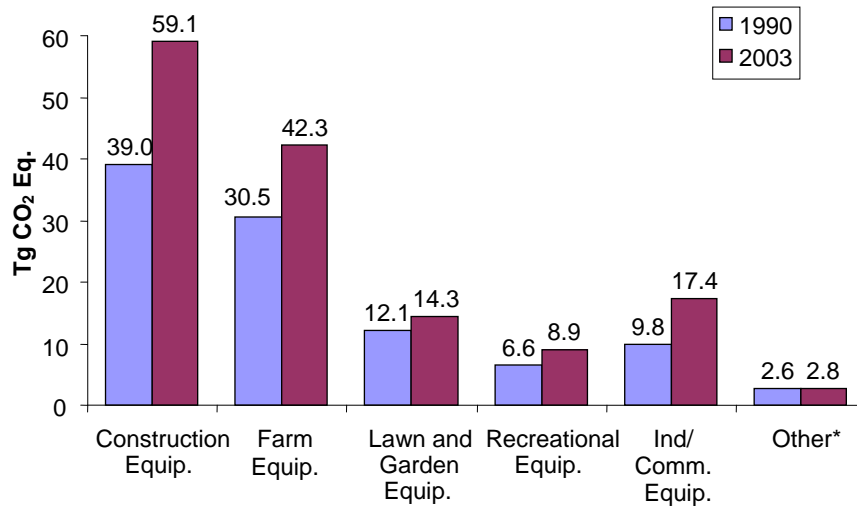
8 Non-Transportation Mobile Sources—Agricultural and Construction Equipment, Recreational Vehicles, and Other

This report focuses on GHG emissions from the transportation sector. For the most part, transportation sources are associated with the movement of people and goods. There are several other mobile sources that serve functions other than transportation, such as construction or shelter. These “non-transportation mobile” sources were estimated to have produced 144.8 Tg CO₂ Eq. in 2003.⁹²

Non-transportation mobile sources include:

- *Agricultural equipment*—This category predominantly consists of tractors, mowers, combines, balers, and other farm-related equipment that perform functions while moving. There are twice as many diesel vehicles as gasoline vehicles in this category.
- *Construction equipment*—Construction equipment includes cement and mortar mixers, excavators, forklifts, loaders, bore drill rigs, and other equipment.
- *Recreational vehicles*—These vehicles include snowmobiles, off-road motorcycles, all-terrain vehicles, and golf carts.
- *Lawn and garden equipment*—This equipment type includes lawnmowers, lawn and garden tractors, snowblowers, leaf blowers, and other equipment used for residential and commercial purposes.
- *Other commercial and industrial equipment*—This source includes equipment such as airport ground service equipment, aerial lifts, sweepers/scrubbers, and other utility equipment.

Figure 8-1. Greenhouse Gas Emissions from Non-Transportation Mobile Sources, 1990 and 2003



Source: Calculated by summing estimates of N₂O, CH₄, and CO₂. N₂O and CH₄ estimates were taken from U.S. Environmental Protection Agency. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2003*. Washington, DC, Tables 3-20 and 3-21. CO₂ estimates were developed based

⁹² The U.S. GHG Inventory presents estimates of CH₄ and N₂O from non-transportation mobile sources but does not provide estimates of CO₂ emissions, since fuel consumption from these sources is not broken out as a separate data element in the Energy Information Administration’s fuel data. In the U.S. GHG Inventory, CO₂ from these sources is encompassed in other sectors (e.g., industrial) and is not included among transportation sources. As a result, this report includes CO₂ estimates calculated for these non-transportation mobile sources based on fuel consumption estimates from EPA’s NONROAD Model, which are used in the CH₄ and N₂O inventory calculations for mobile sources.

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on fuel consumption data contained in U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2003*. Washington, DC, Annex 3, Table 3-13.

Although there is considerable uncertainty⁹³ associated with these estimates, it appears likely that GHG emissions from non-transportation mobile sources were nearly equal to the combined GHGs of boats and ships, rail, and pipelines in 2003. Collectively, GHG emissions from non-transportation mobile sources increased by 44 percent from 1990 (Figure 8-1). CO₂ accounted for more than 99 percent of GHG emissions, and N₂O and CH₄ each produced less than 1 percent.

⁹³ Activity and fuel consumption data for these sources are limited in comparison to transportation sources. There is no one data source that currently has information on all the non-transportation mobile sources, and different publications report significantly different estimates, complicating the estimation process. For instance, estimates derived from a 2004 analysis of various data sources, including FHWA, EPA, and EIA by Oak Ridge National Laboratory (ORNL), were considerably higher than estimates currently used in developing the U.S. GHG Inventory. Moreover, it is likely that the transportation and mobile sources estimates of GHG emissions in the U.S. GHG Inventory are missing emissions associated with off-road use of trucks, and these emissions may be captured under other sectors, especially the industrial sector.

9 Estimating Transportation GHG Emissions—Methodology and Uncertainty

All GHG emissions estimates presented in this report are from the official *Inventory of U.S. Greenhouse Gas Emissions and Sinks*, published annually by EPA.⁹⁴ These estimates are calculated using data such as vehicle miles traveled, fuel consumption, and emissions factors. The quality and reliability of these data sources significantly determine the reliability of GHG emissions estimates. This chapter briefly describes the methods used to calculate transportation GHG emissions, and then discusses the uncertainty associated with these methods and the supporting data sources.

9.1 Carbon Dioxide Emissions

9.1.1 **Methodology**

Carbon dioxide emissions are a direct product of fossil fuel combustion. They are calculated for each fuel type as a simple product of the following factors:

- Fuel consumption (in Btus) – These estimates are based on data provided by EIA.
- The carbon coefficient of a particular fuel – These values represent the total amount of carbon released when the fuel is burned (expressed in Tg carbon per Btu). The carbon coefficient depends on the density, carbon content, and gross heat combustion of the fuel.
- The percent of fuel that is combusted – The 1996 IPCC assumes that oxidation is 99 percent complete and that 1 percent of the carbon remains sequestered.⁹⁵

In the U.S. GHG Inventory, CO₂ emissions from the transportation sector are estimated using a multistage process. First, total national CO₂ emissions from fossil fuel combustion are calculated by accounting for the factors described above. National-level estimates of fuel consumption by fuel type are multiplied by the carbon content of each fuel and the percent of fuel that is oxidized, producing fuel-specific CO₂ estimates. These fuel-specific CO₂ estimates then are apportioned to economic sectors based on each sector's contribution to total fuel consumption. Within each sector, emissions then are allocated to individual sources (such as particular transportation modes) based on fuel consumption data.

9.1.2 **Uncertainty**

Since the vast majority of transportation GHG emissions are in the form of CO₂, uncertainty in the CO₂ estimates has a much greater effect on the transportation sector estimates than uncertainty associated with N₂O, CH₄, or HFC emissions. EPA believes that the uncertainty in CO₂ estimates for the United States as a whole is relatively small.

As described in Chapter 3 of the U.S. GHG Inventory, the uncertainty associated with total CO₂ emissions from fossil fuel combustion is a function of the uncertainty in primary input data: fuel consumption, carbon content, and oxidation factors. Fuel-specific consumption data are obtained from EIA, primarily from its *Monthly Energy Review*, as well as unpublished sources within the agency. EIA also provides the carbon contents. Oxidation fractions are published by the IPCC.

⁹⁴ Non-transportation mobile estimates for CO₂ are not provided in the body of the Inventory report but are calculated in the Inventory Annex. For this report, a minor correction was made to the diesel CO₂ figures for non-transportation mobile sources, so the figures reported differ slightly from those in the Inventory Annex. Some emissions from sources considered “non-transportation mobile sources” in this report are counted as part of transportation sector emissions in the Inventory.

⁹⁵ Note that the 2006 IPCC guidelines specify a 100 percent oxidation fraction.

Fuel sales are tracked for many reasons, such as taxation and economic analyses. On an aggregate level, fuel consumption data are believed to be relatively accurate. The carbon content of fuels and oxidation fraction values are also relatively certain. As a result, the total estimate of CO₂ emissions from fossil fuel combustion reflects a small degree of presumed uncertainty, estimated to range from 1 percent below the U.S. GHG Inventory's actual estimate to 6 percent above it, based on a 95 percent confidence interval.⁹⁶

However, additional uncertainty is introduced when the national totals are allocated to individual sectors (such as transportation) and sources within sectors (such as modes and vehicle types). The allocation process is based on the relative consumption of fuel by each individual source. For example, if transportation is estimated by EIA to comprise X percent of national gasoline consumption, then the transportation sector is allocated X percent of CO₂ emissions from gasoline. The CO₂ emissions then are allocated to individual modes and vehicle types by EPA based on fuel consumption data from a variety of sources, including FHWA, American Public Transportation Association, AAR, and DOE.

The apportionment methodology used to develop CO₂ estimates for the GHG Inventory represents a "top-down" calculation approach. These values are somewhat different than estimates that would be calculated "bottom-up" starting with primary data sources, such as FHWA's *Highway Statistics*. These differences are a source of uncertainty in the transportation GHG estimates.

Differences in fuel consumption reported by EIA and other sources largely stem from different survey methodologies, data collection processes, and allocations of fuel use. EIA's estimates of transportation diesel fuel consumption, which are used in the official GHG inventory, are systematically 2.5 to 10.0 percent lower than estimates from various bottom-up sources for 1990 to 2003.⁹⁷ EIA's estimates of transportation motor gasoline fuel consumption for 1990 to 2003 also are systematically lower by a small amount (ranging from 0.6 to 2.4 percent) than estimates compiled by EPA using FHWA's *Highway Statistics* for on-road vehicles and EPA's NONROAD Model for recreational boats. On the other hand, EIA's estimates of transportation jet fuel use are consistently higher (9.1 to 12.3 percent) than estimates compiled by EPA for 1990 to 2003.

Using the "bottom-up" method described above, VMT were apportioned by fuel type and then allocated to individual model years using temporal profiles of both the vehicle fleet by age and vehicle usage by model year in the United States provided by EPA (2004b) and EPA (2000). Although the uncertainty associated with total U.S. VMT is believed to be low, the uncertainty within individual source categories was assumed to be higher, given uncertainties associated with apportioning total VMT into individual vehicle categories, by technology type, and equipment age. The uncertainty of individual estimates was assumed to relate to the magnitude of estimated VMT (i.e., it was assumed smaller sources had a greater percentage of uncertainty). A further source of uncertainty occurs because FHWA and EPA use different definitions of vehicle type, and estimates of VMT by vehicle type (provided by FHWA) are broken down by fuel type using EPA vehicle categories. The bottom-up estimates are also subject to several possible sources of error, such as unregistered vehicles, unreported fuel sales to avoid fuel taxes, differences in achieved versus estimated fuel economy, and measurement and estimation errors.

Despite these issues, EPA believes that the uncertainty associated with CO₂ from the transportation sector is still relatively small. Depending on the fuel type, these values range from 6 percent below to 7 percent above actual estimates based on a 95 percent confidence interval. However, it is likely that the uncertainty for individual modes is higher. For instance, FHWA is recognized as being the preeminent data source for

⁹⁶ Based on Monte Carlo simulations, which randomly generate values for uncertain variables repeatedly. These randomly generated numbers are used by the simulation to estimate results. For a 95 percent confidence interval, estimated values fell within the specified range for 19 out of 20 simulations.

⁹⁷ These include FHWA's *Highway Statistics* for highway vehicles, EIA's Fuel Oil and Kerosene Sales Report for ships and boats, and individual data sources for locomotives (AAR for Class I railroads, the Upper Great Plains Transportation Institute for Class II and III railroads, and the Transportation Energy Data Book for commuter rail and Amtrak).

on-road vehicle fuel use, and EIA’s transportation sector totals are estimated using FHWA data for on-road vehicles and other survey data for non-road transportation sources. As a result, uncertainties in non-road fuel use are believed to be largely responsible for discrepancies in consumption of motor gasoline and diesel fuel between EIA and other sources. Nonetheless, if CO₂ estimates from EIA are lower than estimates that would be developed using bottom-up data sources, CO₂ emissions for *all* modes are reduced proportionately using the current allocation method.

Table 9-1 provides a summary comparison of estimates of transportation CO₂ emissions reported in the U.S. GHG Inventory for 1990 and 2003 compared with estimates developed based on a bottom-up approach.

Table 9-1. Comparison of U.S. GHG Inventory Estimates and Bottom-Up Estimates of CO₂ for Selected Transportation Fuels and Sources

Fuel Type/Vehicle Type	1990			2003		
	Inventory Est.	Bottom-Up Est.	Difference	Inventory Est.	Bottom-Up Est.	Difference
Gasoline	955.2	973.5	18.3	1,143.7	1,153.9	10.2
Automobiles	605.1	616.7	11.6	630.2	635.8	5.6
Light-Duty Trucks	301.0	306.7	5.7	460.9	465.0	4.1
Heavy-Duty Trucks	37.7	38.5	0.8	39.6	39.9	0.3
Buses	0.3	0.3	0.0	0.3	0.3	0.0
Motorcycles	1.7	1.7	0.0	1.6	1.6	0.0
Boats (Recreational)	9.4	9.6	0.2	11.0	11.1	0.1
Diesel Fuel	253.7	264.1	10.4	386.6	417.0	30.4
Automobiles	7.4	7.7	0.3	3.4	3.7	0.3
Light-Duty Trucks	10.7	11.2	0.5	17.6	19.0	1.4
Heavy-Duty Trucks	178.4	186.4	8.0	301.1	325.5	24.4
Buses	7.5	7.8	0.3	8.0	8.6	0.6
Locomotives	33.3	34.8	1.5	39.6	42.8	3.2
Ships and Boats	16.3	16.2	-0.1	17.0	17.4	0.4
Electricity	3.0	3.2	0.2	3.2	3.9	0.7
Jet Fuel	174.2	158.2	-16.0	169.0	152.7	-16.3
Commercial Aircraft	117.2	117.2	0.0	122.8	122.8	0.0
Military Aircraft	34.8	34.8	0.0	20.5	20.5	0.0
General Aviation Aircraft	6.3	6.3	0.0	9.4	9.4	0.0
Other Aircraft	15.9	-		16.3	-	

As shown in this table, bottom-up estimates suggest that GHG emissions from transportation diesel fuel use may be higher than reported in the U.S. GHG Inventory, particularly from diesel fuel used by heavy-duty trucks. GHG emissions from motor gasoline also may be higher, although the percentage difference in these estimates is smaller than those of diesel. Electricity fuel consumption in transportation also appears higher using a bottom-up methodology and shows a higher rate of growth; much of this difference is likely attributable to increased electrification of Amtrak service in the Northeast Corridor, which is not reflected in the EIA estimates. The total GHG estimates presented in the U.S. GHG Inventory are believed to account for all these emissions, but the transportation sector estimate may not.

Finally, a recent EPA study suggested that the fraction of fuel combusted for light-duty gasoline motor vehicles is 100 percent. The revised estimate has been peer reviewed and may be incorporated into future IPCC guidance. It also is possible that diesel and gasoline vehicles burn virtually 100 percent of their fuel, and EPA will be conducting further research to examine these estimates for transportation and non-transportation sources.

9.2 Methane and Nitrous Oxide Emissions

9.2.1 **Highway Vehicles**

Unlike CO₂ emissions, which are directly proportional to fuel consumption, CH₄ and N₂O emissions from highway vehicles are affected by vehicle emissions control technologies. Emissions are calculated based on VMT and per-mile emissions factors, which vary by type of emissions control technology system. The total VMT driven within each class of vehicles is distributed among various emissions control systems, based on distributions of vehicles by model year, VMT by vehicle age, and control technologies in place by model year.

Uncertainty in CH₄ and N₂O emissions from highway vehicles is a product of uncertainty in VMT estimates, the distribution of VMT to control technology types, and emissions factors.

VMT estimates by vehicle type are taken from FHWA. These estimates are believed to be relatively accurate at the national level but are subject to several possible sources of error. The VMT are apportioned by fuel type and then allocated to individual model years using EPA temporal profiles of both the vehicle fleet by age and vehicle usage by model year in the United States. Although the uncertainty associated with total U.S. VMT is believed to be low, the uncertainty within individual vehicle categories is assumed to be higher, given uncertainties associated with apportioning total VMT into individual vehicle categories, by technology type, and equipment age.

The emissions factors for highway vehicles used in the U.S. GHG Inventory are based on laboratory testing of vehicles. Although the controlled testing environment simulates actual driving conditions, the results from such testing can only *approximate* real world conditions and emissions. For some vehicle and control technology types the testing did not yield statistically significant results within the 95 percent confidence interval, requiring reliance on expert judgment when developing the emissions factors. In those cases, the emissions factors were developed based on comparisons of fuel consumption between similar vehicle and control technology categories.

The U.S. GHG Inventory reports that the uncertainty range of CH₄ and N₂O emissions is greater than that of CO₂ emissions. CH₄ is estimated to be somewhere between 9 percent below and 4 percent above the actual U.S. GHG Inventory total, based on a 95 percent confidence interval. The calculated value of N₂O emissions has even greater uncertainty, with uncertainty estimates ranging from 16 percent below to 26 percent above the U.S. GHG Inventory total, based on a 95 percent interval. However, the overall significance of uncertainty in CH₄ and N₂O estimates is presumed to be relatively minor because these emissions comprise a small portion of total highway vehicle GHG emissions.

9.2.2 **Other Mobile Sources**

The U.S. GHG Inventory calculates CH₄ and N₂O emissions for other mobile sources by applying an emissions factor to the quantity of fuel consumed. The uncertainty of these calculations is a direct product of uncertainties in these two inputs, which often are considered to be highly uncertain. For example, the *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* reports that CH₄ emissions from aviation and marine sources may be uncertain by a factor of two, while N₂O emissions may be uncertain by an order of magnitude for marine sources and several orders of magnitude for aviation. No information is provided on the uncertainty of emissions factors for other non-road sources.

Fuel consumption data are drawn from a variety of sources. Consumption tracking for some modes, particularly for the less significant modes, is not highly accurate. Fuel consumption for some modes is estimated using EPA's NONROAD model and is not based on actual sales records for each year. Sales data often cannot accurately reflect the actual end use of a given fuel. For instance, some gasoline purchased by the marine sector may be used for operating heavy equipment or even generators, instead of

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being used entirely by ships and boats. This distinction between mobile and stationary fuel users is not made by EIA.

An even greater level of uncertainty is associated with the emissions factors themselves. The U.S. GHG Inventory relies on emissions factors provided by the IPCC. In some cases these factors cover very broad categories. For example, the same emissions factors are used for tractors, snowmobiles, riding lawnmowers, and construction vehicles. It is likely that these various modes emit differing amounts of non-CO₂ gases per gallon of fuel consumed. As another example, a single emissions factor is applied to all jet fuel consumed, even though emissions amounts vary depending on whether the aircraft is in the landing/take-off cycle or the cruise portion of flight.

Despite the large degree of uncertainty associated with non-road modes, the significance of this uncertainty is low given the relatively small quantity of GHGs released by these sources.

10 Lifecycle Transportation Emissions

This report primarily addresses GHG emissions from energy that is used for powering vehicles. Transportation depends on array of additional processes, such as the manufacture of vehicles and extraction of crude oil. Within the U.S. GHG Inventory, these activities are accounted for in other economic sectors—most notably the industrial sector. Nevertheless, they are still a part of the transportation lifecycle and can offer a broader perspective on the GHG impact of transportation.⁹⁸

A full lifecycle assessment (LCA) of transportation takes into account all emissions associated with the vehicles, fuel, infrastructure, and associated activities that make up the nation’s transportation system. Emissions occur during three lifecycle *stages*:

1. **Upstream Emissions**—Upstream emissions are those that occur before a product is used, including extraction of raw materials, processing, manufacturing, and assembly. Sources of upstream emissions include any fuel combustion associated with these processes, as well as “fugitive” emissions, such as venting and/or flaring of natural gas from oil wells or natural gas plants.
2. **Direct Emissions**—Direct emissions occur during the operation and maintenance of vehicles.
3. **Downstream Emissions**—Downstream emissions occur at the end of the lifecycle and are associated primarily with disposal. Sources of downstream emissions include fuel combustion used during disposal, collection of municipal solid waste, and landfills.

An LCA of transportation also should take into account emissions from three key *components* of transportation systems: fuels, vehicles, and infrastructure.

Table 10-1 provides examples of sources of emissions at each stage of life for each component. Transportation fuel use is the focus of traditional analysis of transportation emissions. An LCA of transportation fuels, often referred to as a fuel cycle analysis, includes upstream emissions associated with drilling, exploration and production, crude oil transport, refining, fuel transport, storage, and product retail, as well as downstream disposal or recycling of oil products.

An analysis of vehicle lifecycle emissions includes each stage of vehicle manufacturing (raw material extraction, processing, and transport; manufacture of finished materials; assembly of parts and vehicles; and distribution to retail locations), vehicle operation and maintenance, and vehicle disposal.

Finally, an LCA of infrastructure includes emissions associated with construction, operation and maintenance, and disposal of all transportation-related infrastructure, such as roads, parking lots, pipelines, railroad tracks, bridges, tolls, airports, train and bus stations, and fuel stations.

A lifecycle assessment can be useful in evaluating certain policy questions. This approach is increasingly used in the transportation sector to compare emissions from different fuel types, especially when the emissions generated in fuel production may vary significantly from the tailpipe emissions during combustion.

⁹⁸ Although official estimates of national GHG emissions do not usually take a lifecycle approach, there are some exceptions. Fuel ethanol derived from biomass is assumed to have net CO₂ emissions of zero, as crops sequester carbon from the atmosphere while they grow. Similarly, in some places in the U.S. Inventory, electricity emissions are accounted for in the transportation sector, although they are all upstream emissions.

Table 10-1. Elements of the Transportation Lifecycle

	Vehicle Cycle	Fuel Cycle	Infrastructure Cycle
Upstream Emissions	Upstream Vehicle Cycle Raw material (e.g., ore for steel or aluminum; petroleum for plastics) extraction, processing, production, and transport; manufacture of finished materials and components; intermediate parts transportation; assembly of parts and vehicles; distribution to retail locations	Upstream Fuel Cycle Exploration, drilling, production, and pumping; agricultural activities for biomass; production activities for other energy sources; crude oil/gas/material transport; refining and processing into motor fuel; product transport, intermediate, wholesale, and retail storage; retail product sales and dispensing	Upstream Infrastructure Cycle Raw material production and transport (e.g., asphalt, cement, and steel); desequestration (clear-cutting) of land; construction activities
Direct (Operating) Emissions	Direct Vehicle Cycle Tire wear; engine oil and other lubricant and fluid use; parts replacement; other operations and maintenance activities	Direct Fuel Cycle Fuel combustion; fuel evaporation [This element is the only one covered under traditional transportation emissions analyses.]	Direct Infrastructure Cycle Resurfacing; repainting and striping; pothole repair; plowing, street cleaning, other operations and maintenance activities
Downstream Emissions	Downstream Vehicle Cycle Disposal of vehicles, including possible recycling of parts; tire disposal and possible incineration	Downstream Fuel Cycle Disposal and possible recycling of oil products	Downstream Infrastructure Cycle Disposal and possible recycling of certain infrastructure raw materials; potential reclamation of land (e.g., rails-to-trails)

10.1 Estimates of Transportation-Related CO₂ Emissions

A lifecycle analysis of CO₂ emissions from the nation’s transportation system was developed for this report, examining upstream fuel cycle and vehicle cycle emissions. This analysis did not account for emissions from the infrastructure cycle, although their potential impact is recognized to be potentially significant. Nevertheless, the estimates in this section offer an initial perspective on some of the additional GHG impacts associated with various vehicle types and modes, as well as the transportation sector as a whole.

Special consideration needs to be given to potential areas of double-counting. For example, a comprehensive LCA of the GHG impacts of passenger vehicles includes emissions from the transport of crude oil and motor gasoline used by these vehicles, as well the original shipment of these vehicles from the automotive manufacturing plant to the dealer. However, upstream transport-related emissions are already represented in the direct emissions from other vehicle types, such as heavy-duty vehicles used to transport new passenger cars. While attributing these transport-related emissions to passenger cars is acceptable when examining the lifecycle impacts of these vehicles, it is not appropriate to include these when considering the sector as a whole. Therefore, all upstream and downstream transport-related emissions should be excluded when examining the entire sector.

Two leading transportation lifecycle models were used to assess GHG impacts for this analysis. The Lifecycle Emissions Model (LEM) was developed by Mark A. Delucchi of the Institute of Transportation Studies at the University of California-Irvine. The Greenhouse Gases, Regulated Emissions, and Energy

Use in Transportation (GREET) model was developed by Argonne National Laboratory for DOE's Office of Transportation Technologies. Each of these models is described briefly below.⁹⁹

10.1.1 Lifecycle Emissions Model (LEM)

The Lifecycle Emissions Model¹⁰⁰ examines energy use, GHG emissions (CO₂, CH₄, N₂O, HFCs), and criteria pollutant emissions associated with the full lifecycle of various transportation activities. This model examines the following components:

- Fuel cycle—raw material production (e.g., crude oil), raw material transport, fuel production, fuel distribution and storage, fuel dispensing, and end use;
- Material lifecycle—raw material recovery (e.g., iron ore), vehicle manufacture, and transport of materials to end-users;
- Vehicle lifecycle—assembly, operations and maintenance, secondary fuel cycle; and
- Infrastructure lifecycle—energy use and materials production.

Lifecycle emissions for a number of vehicle types are calculated, including passenger cars, buses, and medium- and heavy-duty trucks. No estimates regarding other vehicle types or any stage of infrastructure lifecycle emissions have been included, as those estimates in LEM are still considered rudimentary.

10.1.2 GHGs, Regulated Emissions, and Energy Use in Transportation (GREET)

GREET 1.6¹⁰¹ estimates energy use, GHG emissions (CO₂, CH₄, N₂O), and criteria pollutant emissions related to the fuel cycle of various vehicle and fuel combinations. The primary purpose of GREET is to evaluate the energy and emissions impacts associated with alternative fueled vehicles and advanced vehicle technologies in light-duty vehicles, for the purpose of assessing near- and long-term transportation options. GREET examines more than 30 fuel-cycle pathways, and examines the following components:

- Feedstock production;
- Feedstock transportation;
- Feedstock storage;
- Fuel production,
- Fuel transportation and distribution;
- Fuel storage; and
- Vehicle operation (refueling, fuel combustion/conversion, fuel evaporation, tire/break wear).

10.1.3 Results

Both GREET and LEM provide estimates of upstream fuel cycle and vehicle cycle emissions for various vehicle and fuel categories. While both models are capable of estimating emissions for alternative fuels, this analysis focused on the upstream and direct emissions from gas and diesel vehicles, since they comprise the majority of transportation emissions. For each lifecycle component, ranges of emissions for

⁹⁹ Although the LEM model does not specifically account for downstream emissions, the GREET model does include emissions resulting from the fuel cycle portion of the transportation lifecycle.

¹⁰⁰ Delucchi, M. 2003a. *Lifecycle Emissions Model (LEM)*, Mark A. Delucchi, Institute of Transportation Studies, University of California, December.

¹⁰¹ U.S. Department of Energy, Center for Transportation Research, 2001. *Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) 1.6 Model*. Argonne National Laboratory, June 2001.

each vehicle/fuel category were developed based on minimum and maximum values from both models. Ranges were used to account for some of the assumptions and uncertainties behind these models.

Upstream Fuel Lifecycle Emissions

Elements of the upstream fuel cycle that were examined include extraction, shipment, refining, and distribution of raw materials and finished products. Although the GREET model uses these categories, the categories in LEM had to be mapped to this configuration. This mapping was performed using information provided by the developer of LEM.¹⁰²

From each model, CO₂ emissions per million Btu (MMBtu) of fuel for each of these components were obtained by mode, vehicle, and fuel type. Ratios of upstream emissions to direct emissions then were determined for each component, as shown in Table 14-1.

Upstream Vehicle Lifecycle Emissions

Emissions from the upstream vehicle lifecycle were estimated only for highway vehicles. (Neither model has been used to evaluate non-highway vehicle cycle emissions.). Ratios of vehicle lifecycle emissions to direct fuel cycle emissions were obtained from LEM as inputs into this analysis.

The LEM model was used to specify the ratio of vehicle cycle emissions to direct fuel cycle emissions for gasoline light-duty vehicles and for diesel heavy-duty. It was assumed that the vehicle cycle for gasoline light-duty vehicles could be used as a proxy for diesel light-duty vehicles and that the vehicle cycle for diesel heavy-duty vehicles could be used as a proxy for gasoline heavy-duty vehicles. This proportion of total upstream vehicle cycle emissions then was disaggregated to transport- and non-transport-related emissions. Ratios of upstream emissions to direct emissions also are shown in Table 14-1.

Total Lifecycle Emissions

To estimate total lifecycle emissions, emissions from the upstream fuel and vehicle cycles were summed for each mode, vehicle type, and fuel type. These total estimates in Table 14-1 represent the ratio of lifecycle emissions to direct emissions for each vehicle/fuel category.

These total estimates are valid when assessing the CO₂ impact over the lifecycle of each vehicle and fuel combination individually. However, it is important to recognize that some of the upstream emissions are currently represented in the transportation totals of the U.S. GHG Inventory. In the upstream fuel cycle, shipment and distribution of fuel fits in this category; in the upstream vehicle cycle, “transport” of vehicles fits in this category. These components were subtracted out of the proportion of total emissions to arrive at “total less transport.” For example, GHG emissions associated with the lifecycle of passenger cars running on conventional gasoline were estimated to be 1.35 to 1.43 times that of direct emissions, when taking out transportation-related emissions that are counted elsewhere in the U.S. GHG Inventory.

The ratios of upstream fuel and vehicle cycle emissions shown in Table 14-1 then were applied to total U.S. CO₂ emissions from direct fuel combustion for each vehicle/fuel type to estimate total lifecycle GHG emissions. These emissions are shown in Table 14-2.

Based on these results, total lifecycle emissions for the nation’s transportation sector are estimated to be 27 to 37 percent higher than direct fuel combustion emissions. These estimates do not include some important components of the transportation lifecycle, such as upstream vehicle cycle emissions for non-highway vehicles, and emissions from the construction and maintenance of infrastructure. However, it should also be noted that these estimates do include upstream emissions that take place outside the United States, such as fuel produced and vehicles manufactured abroad that are used in the nation’s transportation system. As a result, the total GHG emissions presented in Table 14-2 reflect some

¹⁰² Delucchi, M. 2003b. Personal Communication between Mark Delucchi of the University of California and Bill Cowart of ICF Consulting. June 14, 2003.

emissions that are not included in the official U.S. GHG Inventory estimates, but rather are accounted for in the estimates of other nations. While these emissions are not directly attributed to the United States, they are nevertheless sizeable and important on a global scale.

10.2 Other Issues/Next Steps

The results of this analysis are presented to illustrate the potential impact of lifecycle emissions from the transportation sector. A number of impacts still need to be addressed to present a more comprehensive assessment of the transportation lifecycle. Some of these issues include:

- Impacts Not Quantified—While this analysis assesses many of the GHG impacts of the transportation lifecycle, a significant number of impacts were not quantified. These include fuel cycle emissions associated with alternative fuel vehicles (AFVs), and vehicle cycle emissions associated with non-road transport. The analysis also did not assess infrastructure lifecycle emissions or the land use impacts of transportation, such the removal of trees for highway construction, parking lots, airports, and many other types of infrastructure. Measuring the latter impacts is extremely challenging.
- Alternative Fuels and Vehicle Technologies—Resource limitations for this report prevented analysis of these fuels and technologies. There is great variance in the lifecycle emissions from alternative fuels, and substantial work has been done by others to quantify these emissions. Although some of those fuels and vehicle technologies will likely be extremely important in the future, their collective use is presently small enough for their contributions to have a negligible effect on current lifecycle estimates. Future work should incorporate these fuels and technologies because of the critical role they play in forward-looking policy analyses.
- International Boundaries—Accounting for international boundaries could significantly increase total transportations sector estimates. In 2001, approximately 55 percent of the petroleum products consumed in the United States were derived from crude oil produced abroad.¹⁰³ Supplemental tables may be developed in the future to represent upstream emissions occurring outside of the United States.

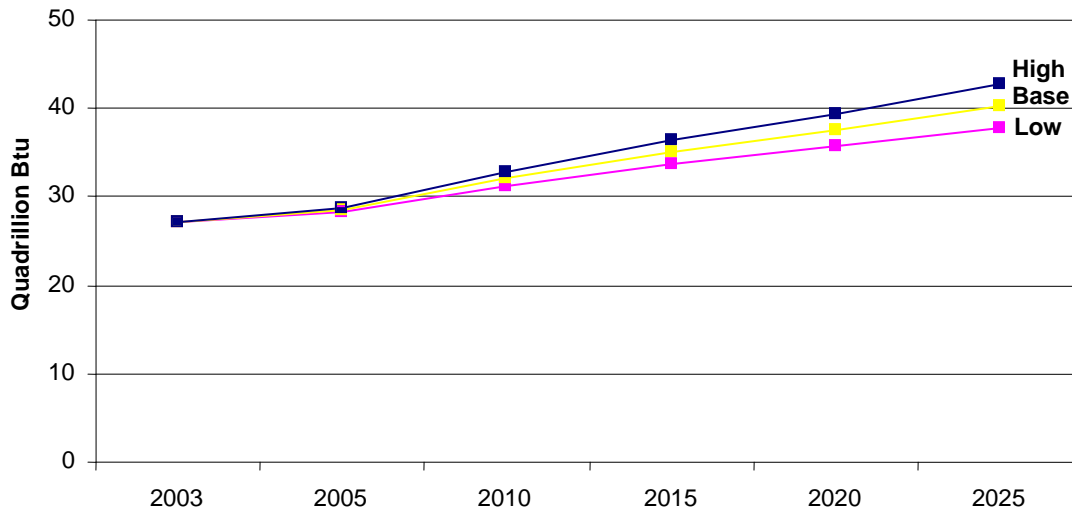
¹⁰³ Energy Information Administration, 2004. *International Energy Annual, 2002*. Washington, DC.

11 GHG Emissions Projections and Emerging Issues

11.1 Projected CO₂ Emissions from Transportation

CO₂ from transportation is expected to remain a major source of total U.S. greenhouse gas emissions. Estimates of transportation energy use are sensitive to factors such as fuel prices, economic growth, and technology adoption. In its *Annual Energy Outlook (AEO)*, EIA has developed various scenarios to forecast the potential impact of these variables on future fuel consumption.¹⁰⁴ In the reference (base) case, transportation-related energy demand is projected to increase by 18 percent between 2003 and 2010, and by 48 percent by 2025 (Figure 11-1).¹⁰⁵ EIA’s high- and low-economic cases show a similar trend (also in Figure 11-1). Since CO₂ emissions are very highly correlated with fuel consumption, transportation-related emissions of GHGs are expected to increase at a similar rate.

Figure 11-1. EIA Projections of Transportation Energy Demand, High, Base, and Low Economic Cases, 2003-2025



Source: Energy Information Administration, U.S. Department of Energy. *Annual Energy Outlook 2005 with Projections to 2025*. Washington, DC, Table B2.

In the AEO reference case, motor gasoline use is projected to increase by 2.0 percent per year between 2003 to 2025, from 16.6 to 24.0 quadrillion Btu. Alternative fuels are projected to displace 2.2 percent of light-duty vehicle fuel consumption by 2025. Gasoline’s share of demand is nevertheless expected to be sustained by low prices relative to the rate of inflation, and a slow increase in the fuel efficiency of conventional cars, vans, pickup trucks, and SUVs. Industrial output is assumed to grow 2.3 percent per year from 2003 to 2025, leading to continued growth in freight truck use and an annual increase of diesel fuel consumption of 2.3 percent. Jet fuel consumption is expected to grow at 1.9 percent annually, reflecting growth in passenger travel of 2.2 percent from 2003 to 2025.

An important assumption underlying the AEO and other forecasts is the continued growth in light-duty travel, albeit at a decreasing rate. From 1980 to 2000, light-duty VMT increased at an average annual rate of 2.99 percent. EIA forecasts that light-duty VMT will increase by 56 percent between 2003 and 2025, or

¹⁰⁴ See Energy Information Administration, 2005, *Annual Energy Outlook (AEO) 2005 with Projections to 2025*.

¹⁰⁵ Energy Information Administration, 2005, *Annual Energy Outlook (AEO) 2005 with Projections to 2025*. Washington, DC, Table A2.

2.0 percent annually. Meanwhile, EIA projects that the fuel economy of light-duty vehicles will improve by about 10 percent over the same period,¹⁰⁶ reflecting the planned increases in fuel economy standards for light-duty trucks.¹⁰⁷ CAFE currently requires that light trucks achieve a manufacturer average of 21.0 mpg in model year 2005, increasing to 22.2 mpg in 2007. The AEO reference forecast also assumes that vehicle technology improvements will marginally improve light-duty fuel economy.

11.2 Emerging Issues Affecting Passenger Transportation

Increasing Vehicle Travel

A number of national-level travel forecasts suggest that the growth in passenger travel will decelerate.¹⁰⁸ There are several reasons to believe that VMT growth could be lower in the future, including an increase in the share of elderly drivers and the impact of highway congestion. These forecasts are nonetheless speculative, and small variations from the projected annual growth rate of 2.0 percent could be significant over time. Annual light-duty VMT growth of 2.5 percent would translate into a 72 percent increase in light-duty VMT between 2003 and 2025, or over 1 trillion vehicle miles more in 2025 than the mileage implied by a 2.0 percent annual growth rate.

Consumers' Vehicle Choice and the Impacts of Light-Duty Trucks

The growing representation of SUVs and other light-duty trucks in the vehicle fleet is expected to have a continuing impact on average in-use vehicle fuel economy. Increased sales of light-duty trucks were largely responsible for the decline in new vehicle fuel economy from its peak in the late 1980s. Although long-term fuel price changes are uncertain, fuel prices historically have had an effect on vehicle purchase decisions and on fuel consumption. Fuel prices have risen significantly since 2003, causing some consumers to consider the purchase of vehicles with higher fuel efficiency. Continued price increases of this magnitude would likely result in the purchase of more fuel-efficient vehicles. There is significant evidence that people respond measurably to changes in fuel prices, with typical reported long-term motor fuel price elasticities of -0.5 to -0.8. However, recent studies also suggest that consumers have become less sensitive to fuel prices than they were in the past, due in large part to higher average incomes and lower real fuel prices as a percentage of household expenses.¹⁰⁹ As a result, the effects of fuel prices in the near term are uncertain, but may likely be at the lower end of the above elasticity range. The long-term sensitivity to fuel costs is even more uncertain, as are projections of consumers' future fuel costs.

Advanced Technology Vehicles

EIA projections show advanced technology vehicles accounting for 19 percent of light-duty sales in 2025. Alcohol flexible-fuel vehicles are expected to comprise about 8 percent of new sales, hybrids about 6 percent, and turbo direct diesel vehicles about 4 percent. Travel in hybrids also is expected to grow significantly from 2003 to 2025 (Figure 11-2), but would still represent less than 5 percent of total light-duty miles in 2025.

¹⁰⁶ Energy Information Administration, 2005. *Annual Energy Outlook 2005 with Projections to 2025*. Washington, DC, Table A7.

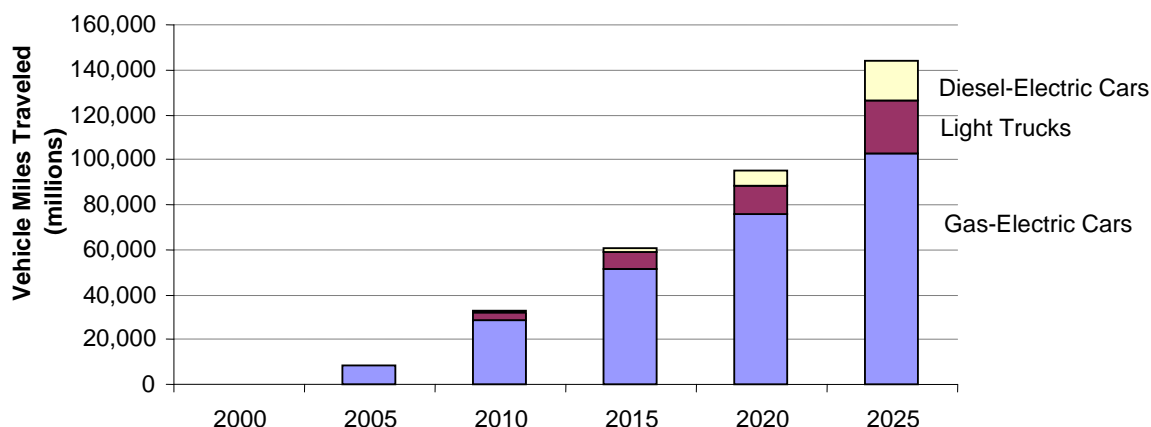
¹⁰⁷ Includes all pickup trucks, vans, and SUVs with gross vehicle weight rating less than 8,500 pounds.

¹⁰⁸ As noted above, EIA forecasts light-duty VMT to increase by 2.0 percent from 2003 to 2025; Highway Performance Monitoring System (HPMS) forecasts are provided by state departments of transportation and forecast an average increase of 2.08 percent per year. See U.S. Department of Transportation, *Status of the Nation's Highways, Bridges, and Transit: 2002 Conditions and Performance Report*, Chapter 9. Available online at <http://www.fhwa.dot.gov/policy/2002cpr/ch9.htm>.

¹⁰⁹ Several studies report on the elasticity of fuel consumption with respect to fuel prices. See, for example: Goodwin, Phil. "Review of New Demand Elasticities," *Journal of Transport Economics*, May 1992. Hagler Bailly, "Potential for Fuel Taxes to Reduce Greenhouse Gas Emissions from Transport," Transportation Table of the Canadian National Climate Change Process, 1999, and DOE's *Policies and Measures for Reducing Energy-Related Greenhouse Gas Emissions*.

Increased sales of hybrid vehicles and other advanced technology vehicles offer the potential to reduce fuel consumption. Nevertheless, manufacturers could also produce a greater number of less fuel-efficient vehicles and remain compliant with current CAFE standards. Another possibility is that hybrid and other advanced technology vehicles will be larger and equipped with more powerful engines, causing their fuel economy to remain largely unchanged. In either case, the net impact on overall fleet fuel economy could be negligible. Hydrogen is a potentially viable alternative to petroleum fuels in the long term. At present, the production and storage costs of hydrogen are the major barriers to increased use of hydrogen in vehicles. The Department of Energy is involved in several initiatives to increase the use of hydrogen in automobiles.¹¹⁰

Figure 11-2. Historical and Projected VMT from Gasoline- and Diesel-Electric Hybrid Vehicles, 2000–2025



Source: Browning, L., 2003. "VMT Projections for Alternative Fueled and Advanced Technology Vehicles through 2025," 13th CRC On-Road Vehicle Emissions Workshop.

Note: "Light Trucks" category includes both Gas-Electric and Diesel-Electric Vehicles

State-Level Regulations and Incentives for Vehicle GHG Emissions Reductions

Although there are currently no national regulations on GHG emissions from motor vehicles, several states' legislatures are beginning to implement or consider controls. Many state and local governments are also implementing policies that are placing more attention on GHG emissions and the role of transportation. Forty states have already developed GHG inventories, and 28 of them have developed detailed climate change action plans. Seven states have set numerical GHG emissions reduction targets, and at least four have considered transportation measures in the portfolio of options that will be used to achieve those targets.

California has promulgated regulations to reduce GHG emissions from new vehicles by 22 percent for the 2012 model year and 30 percent by model year 2016. In 2002, California Assembly Bill 1493 (A.B. 1493) was signed into law, charging the California Air Resources Board (CARB) to develop a maximum feasible CO₂ emissions standard for light-duty vehicles. A second major California GHG initiative was launched in May 2005, when California Governor Arnold Schwarzenegger signed an executive order committing California to reduce greenhouse gas emissions and achieve increasingly stringent targets. The order calls for statewide emissions from all sources in 2010 to meet 2000 levels; emissions in 2020 to achieve 1990 levels; and emissions in 2050 to be reduced 80 percent from current levels.

¹¹⁰ DOE (2005) *The Hydrogen Future*. Energy Efficiency and Renewable Energy. Available online at <http://www.eere.energy.gov/hydrogenandfuelcells/future/barriers.html>.

In May 2005, New York Governor George Pataki proposed regulations similar to the California light-duty standard. Beginning with model year 2009, all passenger vehicles registered in New York will be required to meet fleet average standards for GHG emissions. This standard would become increasingly stringent through 2016. Other states, including Connecticut, Massachusetts, Oregon, and Washington, are considering similar regulations. These measures and other state-level actions have the potential to influence the energy efficiency of vehicles sold throughout the United States.

Increasing Demand for Air Travel

Future GHG emissions from aviation will largely depend on the degree to which improvements in aircraft energy efficiency keep pace with growing passenger travel demand. Passenger seat-miles available on aircraft are expected to grow 46 percent between 2002 and 2015, and by 67 percent between 2002 and 2025. Fuel economy of commercial aircraft is expected to increase at a more modest rate, from 54.8 seat-miles per gallon in 2002 to 63.3 in 2015 (an increase of 15.5 percent) and to 67.0 in 2025 (an increase of 22.3 percent). The result will likely be faster growth in fuel consumption and GHG emissions than observed from 1990 to 2003.¹¹¹

11.3 Emerging Issues Affecting Freight Transportation

Freight Trucks—Future Growth in Activity and Changes in Fuel Economy

GHGs from heavy-duty trucks increased faster than any other major source from 1990 to 2003. Much of the growth resulted from rapid increases in freight haulage and vehicle travel, which overwhelmed a nominal improvement in vehicle fuel efficiency. A number of trends suggest that similar growth in activity is possible in the future. Average shipment sizes have been affected by developments such as the growth in e-commerce and direct delivery to end users, which have tended to decrease vehicle loads and increase VMT. Meanwhile, it is expected that truck fuel economy will improve marginally. According to AEO estimates, the overall fuel efficiency of the freight truck fleet is expected to rise from 6 mpg in 2003 to 6.6 mpg in 2025.¹¹² The AEO notes that freight companies are sensitive to the marginal costs of implementing fuel-efficient strategies and technologies, but anticipates that numerous strategies should still penetrate the industry. EIA forecasts that the penetration of these technologies in the freight industry will increase new freight truck fuel efficiency from 6.1 mpg in 2003 to 6.8 mpg in 2025.¹¹³

Advanced Technology and Hybrid Vehicles

In coming years, gasoline- and diesel-electric hybrids will comprise a greater share of urban delivery vehicles, although they will likely remain a small proportion in the near term. Hydraulic hybrids represent a new technology that may significantly penetrate the heavy-duty vehicle market. Hydraulic hybrid vehicles are similar to gasoline-electric hybrids, except that a hydraulic system replaces the battery and electric motor. In a hydraulic hybrid, energy from regenerative braking is stored by compressing hydraulic fluid in a reservoir. It is used later in a hydraulic pump to provide power to the wheels. Some experts believe that larger vehicles, such as pickup trucks and delivery vans, may be able to incorporate hydraulic hybrid technology at about the same cost as gasoline-electric systems.

¹¹¹ Energy Information Administration, 2004. *Annual Energy Outlook 2004, with Projections to 2025*. Washington, DC, Table 7.

¹¹² Energy Information Administration, 2004. *Annual Energy Outlook 2004, with Projections to 2025*. Washington, DC, Figure 57.

¹¹³ Energy Information Administration, 2004. *Annual Energy Outlook 2004, with Projections to 2025*. Washington, DC, Figure 58.

Programs to Reduce Emissions from Heavy-Duty Vehicles

Many long-haul trucks idle for extended periods of time, using the engine to power cab amenities. This idling is grossly inefficient, and a variety of technologies are available to provide cab heating, cooling, and/or electrical supply while consuming less energy. These include direct-fire heaters, auxiliary power units, and automatic engine idle systems. Truck stop electrification is another option for reducing truck idling that many metropolitan areas are considering as a means to reduce air pollution. These strategies would concurrently reduce vehicle fuel consumption and GHG emissions.

11.4 Implications for the Future

Forecasts indicate that transportation is likely to remain a major source of total U.S. GHGs, and may be a primary contributor to the growth of national greenhouse gas emissions. The AEO 2005 reference case scenario shows transportation accounting for the largest absolute increase in energy consumption of any U.S. economic sector from 2003 to 2025. Transportation energy consumption is expected to be responsible for more than 37 percent of the total increase in U.S. fuel consumption over this period, representing an increase of 13.0 quadrillion Btu. While transportation GHGs will be influenced by factors such as economic expansion and the cost of energy, a variety of measures may reduce the growth and impact of these emissions. Broadly categorized, these measures could include efforts to encourage energy-efficient vehicle technologies, promote efficient patterns of travel and land use, and develop alternatives to petroleum-based fuels. The timing and implementation of such approaches will significantly affect the future volume of greenhouse gases from U.S. transportation sources.

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13 Appendix A: Summary of GHG Emissions for Transportation and Mobile Sources

This appendix contains summary tables with estimates of CO₂, CH₄, N₂O, and HFCs from transportation and non-transportation sources.

Table 13-1. Total GHG Emissions from Transportation Sources (All Gases), 1990-2003 (Tg CO₂ Eq.)

Fuel/Vehicle Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	Change 1990-2003
On-Road	1,196.1	1,190.8	1,214.0	1,246.2	1,276.5	1,304.7	1,338.9	1,363.2	1,402.9	1,442.3	1,460.3	1,468.7	1,490.2	1,504.8	+26%
Passenger Cars	640.6	605.1	604.0	613.2	618.7	621.6	627.3	624.1	642.3	650.0	649.7	650.2	662.3	654.6	+2%
Light-Duty Trucks	327.7	359.5	379.8	395.0	404.4	419.9	433.6	446.6	457.1	473.9	476.2	477.7	487.6	496.3	+51%
Medium/Heavy-Duty Trucks	217.9	216.8	220.8	227.9	242.9	252.9	267.1	281.4	292.1	305.9	322.1	329.2	329.3	343.0	+57%
Buses	8.2	7.7	7.8	8.3	8.7	8.6	9.1	9.4	9.6	10.6	10.5	9.9	9.4	9.1	+12%
Motorcycles	1.7	1.7	1.7	1.8	1.8	1.8	1.7	1.8	1.8	1.8	1.8	1.7	1.7	1.7	-4%
Aircraft	179.1	171.2	168.9	169.9	178.0	173.6	182.0	180.9	183.2	188.7	195.2	185.3	176.8	173.1	-3%
General Aviation Aircraft	9.5	8.5	7.6	6.8	7.1	8.1	8.4	8.9	10.3	12.0	11.8	11.6	11.8	11.8	+24%
Commercial Aircraft	118.4	110.5	112.9	114.7	118.6	121.3	126.5	129.8	127.6	137.9	142.1	134.2	123.0	124.0	+5%
Military Aircraft	35.1	34.9	28.5	27.9	25.3	24.4	23.3	21.2	21.7	20.8	21.2	23.1	20.6	20.8	-41%
Other Aircraft	16.1	17.3	19.8	20.5	26.9	19.8	23.8	20.9	23.6	18.0	20.1	16.6	21.4	16.5	+3%
Boats and Ships	49.6	44.2	57.7	54.7	53.9	55.7	53.9	39.1	32.7	42.7	63.7	43.2	57.8	58.0	+17%
Locomotives	36.6	35.0	35.1	35.2	38.0	39.4	41.1	40.4	40.9	42.1	42.2	43.3	41.5	43.2	+18%
Pipelines	35.9	32.7	32.1	33.9	37.3	38.0	38.7	40.9	34.9	35.3	35.0	33.4	36.4	34.8	-3%
Lubricants	11.9	10.6	10.8	11.0	11.5	11.3	11.0	11.6	12.1	12.3	12.1	11.1	10.9	10.2	-14%
Mobile AC	+	+	0.6	2.0	4.3	6.6	10.1	13.8	17.4	20.8	24.0	26.7	28.8	30.3	NA
Refrigerated Transport	+	+	+	0.3	0.9	2.3	3.8	5.5	7.0	8.5	9.8	10.8	11.5	12.3	NA
Total	1,509.3	1,484.5	1,519.3	1,553.2	1,600.4	1,631.8	1,679.5	1,695.4	1,731.1	1,792.5	1,842.3	1,822.4	1,853.9	1,866.7	+24%

+ Less than 0.05 Tg CO₂ Eq.

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Table 13-2. CO₂ Emissions from Transportation Sources, 1990-2003 (Tg)

Mode / Vehicle Type / Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	Change 1990-2003
Highway Vehicles	1,151.3	1,143.5	1,164.0	1,194.3	1,223.1	1,250.4	1,284.0	1,307.8	1,347.4	1,388.0	1,408.0	1,420.7	1,445.8	1,464.2	+27%
Passenger Cars	612.5	577.6	575.8	584.8	589.8	592.5	598.4	595.5	613.8	622.4	623.4	625.7	639.5	633.7	+3%
Light-Duty Trucks	312.2	341.3	359.4	373.0	381.5	396.2	409.3	421.6	432.1	449.2	452.1	456.2	468.1	478.8	+53%
Medium/Heavy-Duty Trucks	217.0	215.6	219.6	226.7	241.7	251.6	265.7	279.9	290.4	304.3	320.4	327.5	327.5	341.2	+57%
Buses	7.8	7.3	7.5	8.0	8.4	8.3	8.8	9.1	9.3	10.4	10.2	9.6	9.1	8.9	+14%
Motorcycles	1.7	1.6	1.7	1.7	1.8	1.7	1.7	1.7	1.8	1.8	1.8	1.6	1.6	1.6	-4%
Aircraft	177.2	169.4	167.1	168.1	176.1	171.8	180.1	179.0	181.3	186.7	193.2	183.4	174.9	171.3	-3%
General Aviation Aircraft	9.4	8.3	7.5	6.7	7.0	8.0	8.3	8.8	10.1	11.8	11.7	11.4	11.6	11.6	+24%
Commercial Aircraft	117.2	109.4	111.8	113.5	117.4	120.1	125.2	128.5	126.3	136.4	140.6	132.8	121.7	122.8	+5%
Military Aircraft	34.8	34.5	28.2	27.6	25.0	24.1	23.1	21.0	21.5	20.6	21.0	22.8	20.4	20.5	-41%
Other Aircraft	15.9	17.1	19.6	20.3	26.7	19.6	23.5	20.6	23.4	17.8	19.9	16.4	21.2	16.3	+3%
Boats and Ships	49.2	43.7	57.2	54.2	53.4	55.2	53.4	38.7	32.4	42.3	63.1	42.7	57.2	57.5	+17%
Locomotives	36.3	34.7	34.8	34.8	37.6	39.1	40.7	40.0	40.5	41.7	41.8	42.8	41.0	42.8	+18%
Pipelines	35.9	32.7	32.1	33.9	37.3	38.0	38.7	40.9	34.9	35.3	35.0	33.4	36.4	34.8	-3%
Lubricants	11.9	10.6	10.8	11.0	11.5	11.3	11.0	11.6	12.1	12.3	12.1	11.1	10.9	10.2	-14%
TOTAL	1,461.7	1,434.7	1,466.0	1,496.4	1,539.1	1,565.8	1,607.9	1,618.0	1,648.7	1,706.2	1,753.1	1,734.2	1,766.4	1,780.7	+22%

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Table 13-3. Methane Emissions from Transportation Sources, 1990-2003 (Tg CO₂ Eq.)

Mode / Vehicle Type / Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	Change 1990-2003
Highway Vehicles	4.3	4.3	4.2	4.1	4.0	3.9	3.7	3.6	3.4	3.1	2.8	2.6	2.4	2.1	-50%
Passenger Cars	2.6	2.4	2.3	2.3	2.2	2.1	2.0	1.9	1.8	1.7	1.5	1.4	1.2	1.1	-58%
Light-Duty Trucks	1.4	1.5	1.5	1.5	1.5	1.4	1.4	1.3	1.3	1.1	1.0	0.9	0.9	0.8	-42%
Medium/Heavy-Duty Trucks	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+497%
Buses	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	-42%
Motorcycles	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-21%
Aircraft	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.2	0.1	0.1	0.1	-11%
General Aviation Aircraft	0.1	0.1	0.1	+	+	0.1	+	0.1	+	0.1	0.1	+	+	+	-23%
Commercial Aircraft	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	+5%
Military Aircraft	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-41%
Other Aircraft	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+3%
Boats and Ships	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	+18%
Locomotives	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	+23%
Total	4.6	4.5	4.5	4.4	4.3	4.2	4.0	3.8	3.7	3.4	3.2	2.9	2.7	2.4	-47%

+ Less than 0.05 Tg CO₂ Eq.

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Table 13-4. Nitrous Oxide Emissions from Transportation Sources, 1990-2003 (Tg CO₂ Eq.)

Mode / Vehicle Type / Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	Change 1990-2003
Highway Vehicles	40.6	43.0	45.8	47.8	49.3	50.4	51.2	51.9	52.1	51.2	49.5	45.4	42.0	38.5	-5%
Passenger Cars	25.5	25.1	25.8	26.1	26.7	26.9	26.9	26.7	26.7	25.9	24.7	23.1	21.6	19.9	-22%
Light-Duty Trucks	14.1	16.7	18.8	20.4	21.4	22.2	22.9	23.7	23.7	23.6	23.0	20.6	18.6	16.8	+19%
Medium/Heavy-Duty Trucks	0.9	1.2	1.1	1.1	1.2	1.3	1.4	1.4	1.6	1.6	1.7	1.7	1.8	1.8	+92%
Buses	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+113%
Motorcycles	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-18%
Aircraft	1.7	1.6	1.6	1.6	1.7	1.7	1.8	1.7	1.8	1.8	1.9	1.8	1.7	1.7	-3%
General Aviation Aircraft	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	+36%
Commercial Aircraft	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.3	1.2	1.3	1.4	1.3	1.2	1.2	+5%
Military Aircraft	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	-41%
Other Aircraft	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	+3%
Boats and Ships	0.4	0.3	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.5	0.3	0.5	0.5	+18%
Locomotives	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	+22%
Total	43.0	45.3	48.1	50.1	51.8	52.9	53.7	54.3	54.4	53.7	52.2	47.9	44.5	40.9	-5%

+ Less than 0.05 Tg CO₂ Eq.

Table 13-5. HFC Emissions from Transportation Sources, 1990-2002 (Tg CO₂ Eq.)

Tg CO ₂ Eq.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	Change 1990-2003
Mobile AC	+	+	0.6	2.0	4.3	6.6	10.1	13.8	17.4	20.8	24.0	26.7	28.8	30.3	NA
Refrigerated Transport	+	+	-	0.3	0.9	2.3	3.8	5.5	7.0	8.5	9.8	10.8	11.5	12.3	NA
Total	+	+	0.6	2.3	5.2	8.9	13.9	19.4	24.4	29.3	33.8	37.4	40.4	42.7	NA

+ Less than 0.05 Tg CO₂ Eq.

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Table 13-6. GHG Emissions from Non-Transportation Mobile Sources (All Gases), 1990-2003 (Tg CO₂ Eq.)

Fuel Type/Vehicle Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	Change 1990-2003
Farm Eq.	30.5	31.1	32.3	42.3	35.0	36.0	36.8	38.3	38.5	37.6	38.0	40.2	41.3	42.3	+39%
Construction Eq.	39.0	40.2	41.4	56.3	44.2	45.6	47.0	48.5	49.3	50.1	51.6	55.8	57.4	59.1	+51%
Industrial and Commercial Eq.	9.8	9.9	10.0	9.8	9.0	9.4	9.5	9.8	10.3	9.3	9.6	16.0	16.6	17.4	+77%
Lawn and Garden Eq.	12.1	12.5	12.9	14.5	13.6	13.9	14.6	13.7	13.7	13.9	14.1	14.2	14.2	14.3	+18%
Recreational Eq.	6.6	6.6	6.6	9.0	6.6	6.6	6.5	6.7	6.9	7.2	7.5	7.9	8.4	8.9	+34%
Other*	2.6	2.6	2.6	2.8	2.7	2.7	2.7	2.7	2.7	2.6	2.7	2.7	2.8	2.8	+7%
Total	100.7	102.9	105.8	134.8	111.0	114.0	117.1	119.6	121.3	120.7	123.6	136.8	140.6	144.8	+44%

* "Other" includes logging equipment, railroad equipment, and airport equipment.

Table 13-7. CO₂ Emissions from Non-Transportation Mobile Sources, 1990-2003 (Tg)

Fuel Type/Vehicle Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	Change 1990-2003
Farm Equipment	30.18	30.75	31.91	41.88	34.61	35.58	36.39	37.86	38.06	37.18	37.64	39.76	40.84	41.85	+39%
Construction Equipment	38.69	39.79	41.03	55.80	43.76	45.17	46.55	48.04	48.82	49.67	51.14	55.27	56.88	58.60	+51%
Industrial and Commercial Eq.	9.71	9.84	9.93	9.76	8.93	9.28	9.46	9.71	10.21	9.22	9.49	15.83	16.42	17.20	+77%
Lawn and Garden Eq.	12.03	12.40	12.77	14.39	13.47	13.75	14.48	13.62	13.56	13.76	14.02	14.07	14.11	14.21	+18%
Recreational Eq.	6.56	6.56	6.57	8.94	6.56	6.52	6.48	6.61	6.81	7.10	7.47	7.84	8.31	8.82	+34%
Other*	2.59	2.60	2.61	2.77	2.63	2.64	2.65	2.66	2.67	2.61	2.69	2.72	2.74	2.77	+7%
Total	99.76	101.94	104.82	133.54	109.96	112.94	116.01	118.49	120.15	119.54	122.43	135.48	139.31	143.44	+44%

* "Other" includes logging equipment, railroad equipment, and airport equipment.

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Table 13-8. Methane Emissions from Non-Transportation Mobile Sources, 1990-2003 (Tg CO₂ Eq.)

Fuel Type/Vehicle Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	Change 1990-2003
Farm Equipment	0.091	0.092	0.096	0.126	0.104	0.107	0.110	0.114	0.115	0.112	0.113	0.120	0.123	0.126	+39%
Construction Equipment	0.046	0.048	0.049	0.067	0.053	0.054	0.056	0.058	0.059	0.060	0.061	0.066	0.068	0.070	+52%
Industrial and Commercial Eq.	0.012	0.012	0.012	0.012	0.011	0.011	0.011	0.012	0.012	0.011	0.011	0.019	0.020	0.021	+79%
Lawn and Garden Eq.	0.014	0.015	0.015	0.017	0.016	0.017	0.017	0.016	0.016	0.017	0.017	0.017	0.017	0.017	+19%
Recreational Eq.	0.008	0.008	0.008	0.011	0.008	0.008	0.008	0.008	0.008	0.009	0.009	0.009	0.010	0.011	+37%
Other*	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	+7%
Total	0.174	0.178	0.183	0.236	0.194	0.200	0.205	0.211	0.213	0.211	0.215	0.235	0.242	0.248	+43%

* "Other" includes logging equipment, railroad equipment, and airport equipment.

Table 13-9. Nitrous Oxide Emissions from Non-Transportation Mobile Sources, 1990-2003 (Tg CO₂ Eq.)

Fuel Type/Vehicle Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	Change 1990-2003
Farm Equipment	0.238	0.242	0.251	0.330	0.273	0.281	0.287	0.299	0.301	0.294	0.297	0.314	0.323	0.331	+39%
Construction Equipment	0.305	0.314	0.323	0.440	0.345	0.356	0.367	0.379	0.385	0.392	0.403	0.436	0.449	0.462	+52%
Industrial and Commercial Eq.	0.077	0.078	0.078	0.077	0.070	0.073	0.075	0.077	0.081	0.073	0.075	0.126	0.131	0.137	+79%
Lawn and Garden Eq.	0.094	0.097	0.100	0.112	0.105	0.108	0.114	0.107	0.107	0.109	0.111	0.111	0.111	0.112	+19%
Recreational Eq.	0.051	0.051	0.051	0.070	0.051	0.051	0.051	0.052	0.054	0.056	0.059	0.062	0.066	0.070	+37%
Other*	0.021	0.021	0.021	0.022	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.022	0.022	0.022	+7%
Total	0.785	0.802	0.825	1.051	0.866	0.892	0.916	0.936	0.949	0.944	0.967	1.071	1.101	1.134	+44%

* "Other" includes snowmobiles and other recreational equipment, logging equipment, lawn and garden equipment, railroad equipment, airport equipment, commercial equipment, and industrial equipment.

14 Appendix B: CO₂ Emissions from Various Components of the Transportation Lifecycle (Proportion Relative to Direct Emissions)

Table 14-1. CO₂ Emissions from Various Components of the Transportation Lifecycle (Proportion Relative to Direct Emissions)

			Direct	Fuel Cycle					Vehicle Manufacture Cycle			Total Lifecycle			
			Direct	Extraction	Shipment	Refining	Distribution	Sub-Total	Non-transport	Transport	Sub-Total	Direct	Indirect	Total	Total, Less Transport
Highway Vehicles	Passenger Cars	Conv Gas ^b	1.00	0.05 - 0.09	0.01 - 0.02	0.18 - 0.19	0.01	0.24 - 0.31	0.12 - 0.15	0.02 - 0.03	0.14 - 0.19	1.00	0.38 - 0.50	1.38 - 1.50	1.35 - 1.43
		US RFG	1.00	0.05 - 0.08	0.01 - 0.02	0.19	0.01	0.25 - 0.30	0.12 - 0.15	0.02 - 0.03	0.14 - 0.18	1.00	0.39 - 0.47	1.39 - 1.47	1.36 - 1.41
		Diesel	1.00	0.04 - 0.08	0.01 - 0.02	0.09 - 0.13	0.01	0.15 - 0.25	0.11 - 0.17	0.03 - 0.04	0.14 - 0.21	1.00	0.29 - 0.46	1.29 - 1.46	1.25 - 1.39
		AFVs	1.00												
	Light-Duty Trucks	Conv Gas	1.00	0.05 - 0.09	0.01 - 0.02	0.18 - 0.19	0.01	0.24 - 0.31	0.12 - 0.15	0.02 - 0.03	0.14 - 0.19	1.00	0.38 - 0.50	1.38 - 1.50	1.35 - 1.43
		US RFG	1.00	0.05 - 0.08	0.01 - 0.02	0.19	0.01	0.25 - 0.30	0.12 - 0.15	0.02 - 0.03	0.14 - 0.18	1.00	0.39 - 0.47	1.39 - 1.47	1.36 - 1.41
		Diesel	1.00	0.04 - 0.08	0.01 - 0.02	0.09 - 0.13	0.01	0.15 - 0.25	0.11 - 0.17	0.03 - 0.04	0.14 - 0.21	1.00	0.29 - 0.46	1.29 - 1.46	1.25 - 1.39
		AFVs	1.00												
	Medium/ Heavy-Duty Trucks	Conv Gas	1.00	0.05 - 0.09	0.01 - 0.02	0.18 - 0.19	0.01	0.24 - 0.31	0.05 - 0.15	0.01 - 0.02	0.06 - 0.17	1.00	0.30 - 0.48	1.30 - 1.48	1.27 - 1.43
		US RFG	1.00	0.05 - 0.08	0.01 - 0.02	0.19	0.01	0.25 - 0.3	0.05 - 0.15	0.01 - 0.02	0.06 - 0.17	1.00	0.31 - 0.46	1.31 - 1.46	1.28 - 1.41
		Diesel	1.00	0.04 - 0.08	0.01 - 0.02	0.09 - 0.13	0.01	0.15 - 0.25	0.04 - 0.17	0.02 - 0.03	0.06 - 0.20	1.00	0.21 - 0.45	1.21 - 1.45	1.18 - 1.39
		AFVs	1.00												
	Buses	Conv Gas	1.00	0.05 - 0.09	0.01 - 0.02	0.18 - 0.19	0.01	0.24 - 0.31	0.12 - 0.15	0.02 - 0.03	0.14 - 0.19	1.00	0.38 - 0.50	1.38 - 1.50	1.35 - 1.43
		US RFG	1.00	0.05 - 0.08	0.01 - 0.02	0.19	0.01	0.25 - 0.3	0.12 - 0.15	0.02 - 0.03	0.14 - 0.18	1.00	0.39 - 0.47	1.39 - 1.47	1.36 - 1.41
		Diesel	1.00	0.04 - 0.08	0.01 - 0.02	0.09 - 0.13	0.01	0.15 - 0.25	0.04 - 0.17	0.02 - 0.03	0.06 - 0.20	1.00	0.21 - 0.45	1.21 - 1.45	1.18 - 1.39
		AFVs	1.00												
Motorcycles	Conv Gas	1.00	0.05 - 0.09	0.01 - 0.02	0.18 - 0.19	0.01	0.24 - 0.31	0.00 - 0.15	0.00 - 0.02	0.00 - 0.17	1.00	0.24 - 0.48	1.24 - 1.48	1.22 - 1.43	
	US RFG	1.00	0.05 - 0.08	0.01 - 0.02	0.19	0.01	0.25 - 0.30	0.00 - 0.15	0.00 - 0.02	0.00 - 0.17	1.00	0.25 - 0.46	1.25 - 1.46	1.23 - 1.41	

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			Direct	Fuel Cycle					Vehicle Manufacture Cycle			Total Lifecycle			
			Direct	Extraction	Shipment	Refining	Distribution	Sub-Total	Non-transport	Transport	Sub-Total	Direct	Indirect	Total	Total, Less Transport
Aircraft	General Aviation Aircraft	Jet Fuel	1.00	0.05 - 0.10	0.01 - 0.02	0.11	0.01	0.17 - 0.24				1.00	0.17 - 0.24	1.17 - 1.24	1.15 - 1.21
		Aviation Gasoline	1.00	0.05 - 0.08	0.01 - 0.02	0.19	0.01	0.25 - 0.30				1.00	0.25 - 0.30	1.25 - 1.3	1.23 - 1.27
	Commercial Aircraft	Jet Fuel	1.00	0.05 - 0.10	0.01 - 0.02	0.11	0.01	0.17 - 0.24				1.00	0.17 - 0.24	1.17 - 1.24	1.15 - 1.21
	Military Aircraft	Jet Fuel	1.00	0.05 - 0.10	0.01 - 0.02	0.11	0.01	0.17 - 0.24				1.00	0.17 - 0.24	1.17 - 1.24	1.15 - 1.21
	Other Aircraft	Jet Fuel	1.00	0.05 - 0.10	0.01 - 0.02	0.11	0.01	0.17 - 0.24				1.00	0.17 - 0.24	1.17 - 1.24	1.15 - 1.21
	International (Bunkers)	Jet Fuel	1.00	0.05 - 0.10	0.01 - 0.02	0.11	0.01	0.17 - 0.24				1.00	0.17 - 0.24	1.17 - 1.24	1.15 - 1.21
Boats and Ships	Domestic	Conv Gas	1.00	0.05 - 0.09	0.01 - 0.02	0.18 - 0.19	0.01	0.24 - 0.31				1.00	0.24 - 0.31	1.24 - 1.31	1.22 - 1.28
		Distillate Fuel	1.00	0.05 - 0.09	0.01 - 0.02	0.10 - 0.11	0.01	0.16 - 0.23				1.00	0.16 - 0.23	1.16 - 1.23	1.15 - 1.20
		Residual Fuel	1.00	0.04 - 0.08	0.01 - 0.02	0.05	0.01	0.10 - 0.16				1.00	0.10 - 0.16	1.10 - 1.16	1.09 - 1.13
	International (Bunkers)	Distillate Fuel	1.00	0.05 - 0.09	0.01 - 0.02	0.10 - 0.11	0.01	0.16 - 0.23				1.00	0.16 - 0.23	1.16 - 1.23	1.15 - 1.20
		Residual Fuel	1.00	0.04 - 0.08	0.01 - 0.02	0.05	0.01	0.10 - 0.16				1.00	0.10 - 0.16	1.10 - 1.16	1.09 - 1.13
Rail		Distillate Fuel	1.00	0.05 - 0.09	0.01 - 0.02	0.10 - 0.11	0.01	0.16 - 0.23				1.00	0.16 - 0.23	1.16 - 1.23	1.15 - 1.20
		Electricity	1.00	0.03 - 0.04	0.00	1.00 - 1.09	0.00	1.03 - 1.12				0.00	1.03 - 1.12	1.03 - 1.12	1.03 - 1.12
Pipelines		Natural Gas	1.00	0.03 - 0.04	0.00	0.05 - 0.11	0.01 - 0.05	0.09 - 0.20				1.00	0.09 - 0.20	1.09 - 1.20	1.08 - 1.15
		Electricity	1.00	0.03 - 0.04	0.00	1.00 - 1.09	0.00	1.03 - 1.12				0.0	1.03 - 1.12	1.03 - 1.12	1.03 - 1.12
Total											1.00	0.30 - 0.42	a	1.27 - 1.37	

a A "total" value is not calculated because it would be double-counting some transport emissions.

b Conv gas = convention gasoline; US RFG = reformulated gasoline; AFVs = alternative fuel vehicles

Note: The range in each cell is determined by the values provided by GREET and LEM. In some cases, GREET provided the lower values, while in other cases, LEM provided the lower values.

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Table 14-2. Total CO₂ Emissions from Various Components of the Transportation Lifecycle (Tg)

Mode	Vehicle	Fuel	Direct Emissions	Indirect Emissions	Total Lifecycle Emissions	Total Emissions, Excluding Transport
On-Road	Passenger Cars	Conv Gas ^a	395.2	151 - 197	546.2 - 592.1	532.3 - 565.4
		US RFG	235.1	91.9 - 111.3	327.0 - 346.4	318.6 - 331.5
		Diesel	3.4	1 - 1.6	4.4 - 5.0	4.3 - 4.8
		AFVs	+	- +	-+	-+
	Light-Duty Trucks	Conv. Gas	289.0	110.5 - 144.0	399.4 - 433.0	389.3 - 413.5
		US RFG	171.9	67.2 - 81.4	239.1 - 253.3	233 - 242.4
		Diesel	17.6	5.2 - 8.1	22.8 - 25.7	22 - 24.4
		AFVs	0.3	-+	0.3	0.3
	Medium/ Heavy Duty Trucks	Conv. Gas	24.8	7.4 - 12	32.2 - 36.8	31.5 - 35.5
		US RFG	14.8	4.5 - 6.8	19.3 - 21.6	18.9 - 20.8
		Diesel	301.1	63.2 - 134.4	364.3 - 435.5	355 - 417.6
		AFVs	0.5	+	0.5	0.5
	Buses	Conv. Gas	0.2	0.1	0.3	0.3
		US RFG	0.1	0.1	0.2	0.2
		Diesel	8.0	1.7 - 3.6	9.7 - 11.6	9.4 - 11.1
		AFVs	0.6	-+	0.6	0.6
	Motorcycles	Conv. Gas	1.0	0.2 - 0.5	1.3 - 1.5	1.2 - 1.5
US RFG		0.6	0.1 - 0.3	0.8 - 0.9	0.7 - 0.9	
Aviation	General Aviation Aircraft	Jet Fuel	9.4	1.6 - 2.3	10.9 - 11.6	10.8 - 11.3
		Aviation Gasoline	2.2	0.6 - 0.7	2.8 - 2.9	2.8 - 2.8
	Commercial Aircraft	Jet Fuel	122.8	20.4 - 29.6	143.2 - 152.3	141.3 - 148.3
	Military Aircraft	Jet Fuel	20.5	3.4 - 4.9	24 - 25.5	23.6 - 24.8
	Other Aircraft	Jet Fuel	16.3	2.7 - 3.9	19.1 - 20.3	18.8 - 19.7
	International (Bunkers)	Jet Fuel	59.6	9.9 - 14.3	69.5 - 73.9	68.6 - 71.9

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Mode	Vehicle	Fuel	Direct Emissions	Indirect Emissions	Total Lifecycle Emissions	Total Emissions, Excluding Transport
Waterborne	Domestic	Conv. Gas	11.0	2.6 - 3.5	13.7 - 14.5	13.5 - 14.1
		Distillate Fuel	17.0	2.7 - 4	19.7 - 20.9	19.4 - 20.4
		Residual Fuel	29.5	3.1 - 4.8	32.5 - 34.3	32.1 - 33.4
	International (Bunkers)	Distillate Fuel	6.0	1.0 - 1.4	7 - 7.4	6.9 - 7.2
		Residual Fuel	18.6	1.9 - 3.1	20.6 - 21.7	20.3 - 21.1
Rail	Locomotives and Transit	Distillate Fuel	39.6	6.4 - 9.2	45.9 - 48.8	45.3 - 47.6
		Electricity	3.2	+	3.2	3.2
Pipelines		Natural Gas	34.8	3.1 - 6.8	37.9 - 41.6	37.6 - 39.9
		Electricity	+	+	+	-+
Lubricants		All oils	10.2	0 - 0	10.2 - 10.2	10.2 - 10.2
TOTAL			1,864.9	563.6 - 789.7	b	2,372.7 – 2,547.3
Total %						1.27% - 1.37%

a Not estimated to avoid double-counting transport-related emissions

b Conv gas = convention gasoline; US RFG = reformulated gasoline; AFVs = alternative fuel vehicles

15 Abbreviations, Acronyms, and Units

AAR	Association of American Railroads
AEO	Annual Energy Outlook
AFV	Alternative fuel vehicle
APTA	American Public Transportation Association
Btu	British thermal unit
⁰ C	Degree Celsius
CAFE	Corporate Average Fuel Economy
CARB	California Air Resources Board
CFC	Chlorofluorocarbon
CH ₄	Methane
CNG	Compressed Natural Gas
CO	Carbon monoxide
CO ₂	Carbon dioxide
CO ₂ Eq.	Carbon dioxide equivalent
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EIA	Energy Information Agency
EPA	U.S. Environmental Protection Agency
⁰ F	Degree Fahrenheit
FHWA	Federal Highway Administration
GHG	Greenhouse gas
REET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation
GWP	Global warming potential
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HPMS	Highway Performance Monitoring System
H ₂ O	Water
IPCC	Intergovernmental Panel on Climate Change
lbs	Pounds
LC	Lifecycle
LCA	Lifecycle assessment
LEM	Lifecycle Emissions Model
LEV	Low Emissions Vehicle
LPG	Liquefied petroleum gas
mpg	Miles per gallon
MMBtu	Million British thermal units
mph	Miles per hour
MTA	Metropolitan Transportation Authority
NEI	National Emission Inventory
NHTS	National Household Travel Survey
NHTSA	National Highway Traffic Safety Administration
N ₂ O	Nitrous oxide

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NO _x	Oxides of nitrogen
NPTS	Nationwide Personal Travel Survey
ORNL	Oak Ridge National Laboratory
OTAQ	Office of Transportation and Air Quality
PFC	Perfluorocarbon
PPM	Parts per million
RFG	Reformulated gasoline
RV	Recreational vehicle
SF ₆	Sulfur hexafluoride
SO ₂	Sulfur dioxide
SUV	Sport utility vehicle
Tg CO ₂ Eq.	Teragrams carbon dioxide equivalent
TIUS	Truck Inventory and Use Survey
VIUS	Vehicle Inventory and Use Survey
VMT	Vehicle miles traveled
VOC	Volatile organic compound

Conversions

1 Tg = 1 MMT (million metric ton)

1 Tg = 1×10^{12} grams

1 metric ton = 1,000 kilograms = 1.1023 short tons

1 pound = 0.454 kilograms

1 gallon = 3.785412 liters

1 mile = 1.609 kilometers

To convert degrees Fahrenheit to degrees Celsius, subtract 32 and multiply by 5/9.