Transportation Greenhouse Gas Emissions:
Trends, Uncertainties and Methodological Improvements

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ABSTRACT

The transportation sector accounted for about 27 percent of total U.S. GHG emissions in 2003, according to the 2005 U.S. *Inventory of U.S. Greenhouse Gas Emissions and Sinks.* This document includes annual estimates back to 1990; these statistics indicate that transportation GHG emissions increased by a larger amount than any other sector over this timeframe. This paper 1). analyzes factors affecting transportation GHGs from personal and freight transport 2). examines sources of uncertainty in these estimates and 3). describes methodological improvements used in the 2006 *Inventory* and other planned improvements.

INTRODUCTION

This paper was developed using the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003* as its primary foundation for data (EPA 2005). The *Inventory* is prepared annually by the United States Environmental Protection Agency (EPA) and accounts for all national greenhouse gas (GHG) emissions within a framework specified by the United Nations Framework Convention on Climate Change (UNFCCC). This data is organized primarily around specific greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and hydrofluorocarbons (HFCs). Many of these gases are further characterized by source categories specified by the UNFCCC, such as fossil fuel combustion or non-energy use of fuels. This method of presentation is most useful for climate specialists, but is not easily understood by analysts focused on policies related to specific economic sectors such as transportation. To improve the usefulness of GHG data these professionals, the *Inventory* includes GHG emissions by economic sector. EPA also disaggregates transportation GHG emissions by mode (including passenger cars, light-duty trucks, heavy-duty vehicles, aircraft, boats and ships, etc.) and includes this information in the *Inventory*.

EPA's Office of Transportation and Air Quality (OTAQ) has recognized that further detail is necessary to identify significant trends and factors affecting transportation GHG output. In March 2006 OTAQ released *Greenhouse Gas Emissions from the U.S. Transportation Sector 1990-2003,* which provides complementary detail to the 2005 *Inventory* transportation estimates. The report contains analysis of historical trends, estimates of lifecycle GHG estimates and discussion of emerging issues (EPA 2006). This paper highlights significant findings from the report, including

1). variables affecting transportation GHGs from personal and freight transport, based on analysis assorted activity and economic data

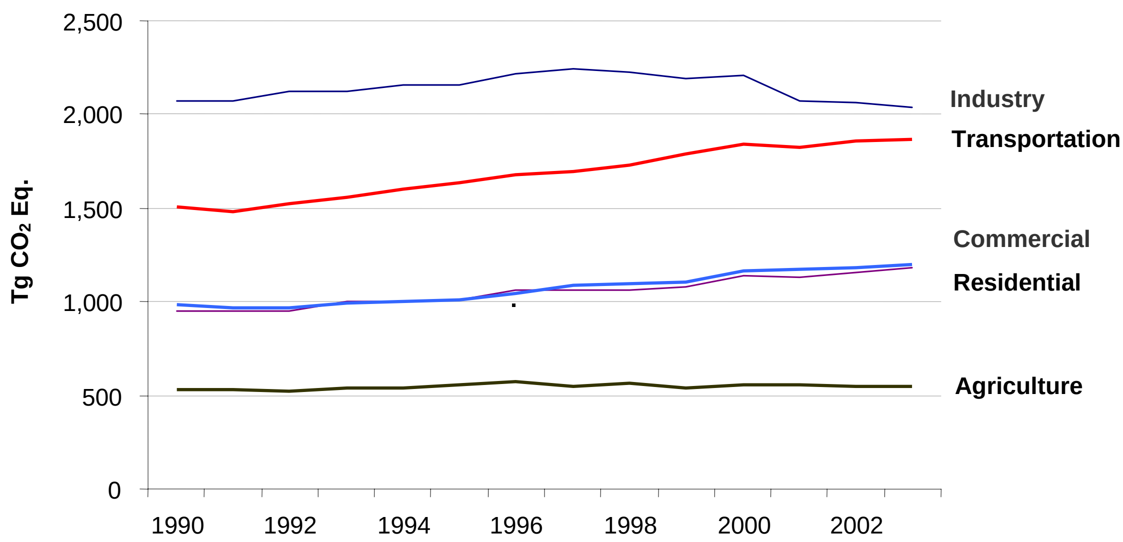
2). Sources of uncertainty in the *Inventory* estimates of transportation GHGs

3). Methodological improvements developed for the 2006 Inventory (*Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*) and possible improvements for the 2007 *Inventory*.

GREENHOUSE GAS EMISSIONS BY SECTOR

The transportation sector accounted for about 27 percent of total U.S. GHG emissions in 2003, up from 24.8 percent in 1990.[i] Transportation GHG emissions increased by a larger amount than any other economic sector over this period, growing from 1509.3 Tg CO_2 Eq. in 1990 to 1,866.7 Tg CO_2 Eq. in 2003, an increase of 24 percent. GHGs from all other sectors increased by a total of 9.5 percent over the same timeframe (EPA, 2005).

Figure 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.

These estimates of transportation GHGs are primarily representative of "tailpipe" emissions that result from the use of energy to power vehicles. They do *not* include "lifecycle" emissions from processes such as the extraction of crude oil and manufacture of vehicles, which are also a significant source of domestic and international GHGs. They also do not include GHGs from 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 CO_2 Eq.). OTAQ has analyzed lifecycle emissions from various transportation sources and fuel types and included these estimates in its report, *Greenhouse Gas Emissions from the U.S. Transportation Sector 1990-2003.*

Almost all of the increase in transportation GHG emissions has come in the form of CO_2 resulting from the combustion of fossil fuels. 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 CO_2, transportation sources emitted 1780.7 Tg in 2003, an increase of 319.0 Tg (or 22 percent) from 1990. The combined emissions of CH_4 and N_2O decreased by 4.0 Tg CO_2 Eq. over the same period, due largely to the introduction of control technologies designed to reduce criteria pollutant emissions. Meanwhile, HFC emissions from mobile air conditioners and refrigerated transport increased from virtually no emissions in 1990 to 42.7 Tg CO_2 Eq. in 2003; these chemicals were phased in as substitutes for ozone depleting substances which are being phased out under the Montreal Protocol and are *not* included in the official *Inventory* estimates.

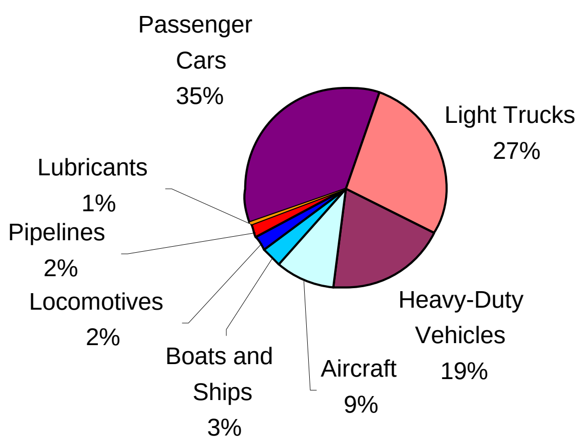
SOURCES OF TRANSPORTATION GREENHOUSE GAS EMISSIONS

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. "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).

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.

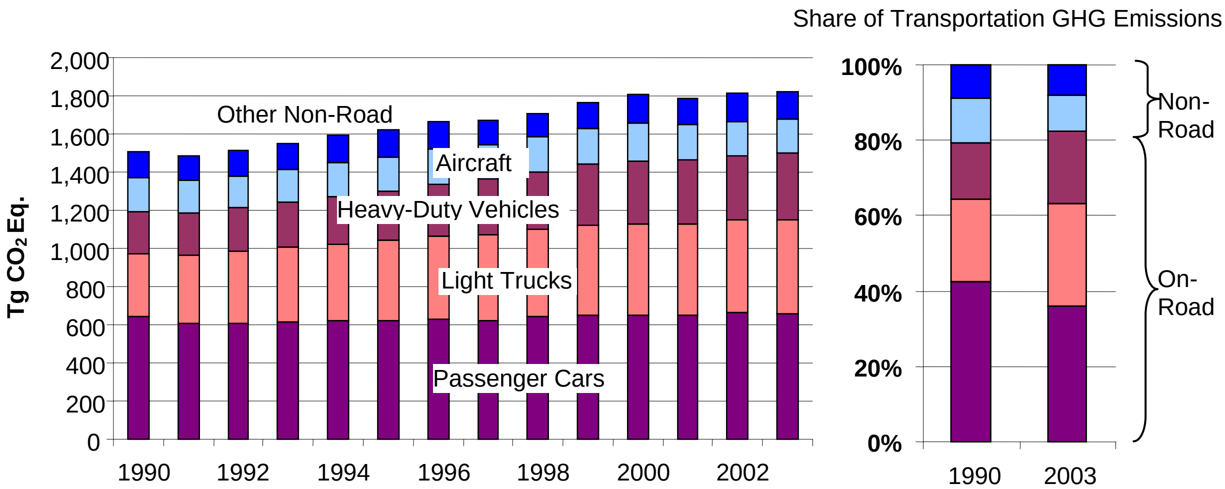
Figure 2: 2003 Transportation Greenhouse Gas Emissions, by Source



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

Transportation fuel consumption is broadly affected by travel activity and the amount of energy vehicles use to move people and goods by various travel modes. In the short-term, changes transportation GHG emissions primarily reflect variation in travel activity that accompanies year-to-year economic fluctuations. Additional factors are influential over longer timeframes, especially the cost of fuel, which in turn can influence travel patterns and vehicle energy efficiency. From 1990 to 2003 there has been a significant increase in travel associated with three major categories: light-duty vehicles, heavy-duty trucks and aircraft. The growth in activity for these three sources has been roughly comparable: commercial aircraft passenger miles traveled (PMT) increased by 48 percent, heavy-duty truck vehicle miles traveled (VMT) also increased by 48 percent and light-duty VMT grew by 34 percent. By contrast, the change in energy efficiency has been directionally different for on-road vehicles and aircraft: while the fuel economy of light-duty vehicles and freight trucks has remained roughly constant over this period, commercial aircraft have become noticeably more energy efficient. These trends have resulted in significant differences in the GHG growth rate of major transportation sources. GHGs from heavy-duty trucks have increased by 57 percent, GHGs from light-duty vehicles have increased by 19 percent, and commercial aircraft GHG emissions have increased by only 4.7 percent.

Figure 3: GHG Emissions by Mode 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.

Light-Duty Vehicles

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.

Heavy-duty vehicles

GHG emissions from heavy-duty vehicles (predominantly freight trucks) grew by 57 percent from 1990 to 2003—three times the rate of light-duty vehicles. An increase in truck freight haulage (BTS 2004) caused heavy-duty truck VMT to rise 48 percent over the same period (BTS 2004, FHWA 2004). Meanwhile, overall heavy-duty truck fuel economy declined from 6.0 to 5.7 miles per gallon, although the average vehicle size has increased slightly and data for this mode is less certain (FHWA 2003, 1997 and 1995).

Aircraft

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. 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. As a result, aircraft passenger miles grew faster than aircraft miles traveled between 1990 and 2000 (49 percent versus 43 percent) (BTS 2005, NTS 2004). The reduced energy intensity of commercial aviation also reflects improvements in aircraft fuel efficiency, measured in fuel consumed per aircraft-mile traveled. For new production aircraft, the fuel economy improvements have averaged 1 to 2 percent per year since the 1950s (IPCC 1999).

Other Non-Road Sources

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. Pipeline emissions were virtually unchanged between 1990 and 2003.

PASSENGER AND FREIGHT GHG EMISSIONS TRENDS

Freight GHG emissions increased by 46 percent between 1990 to 2003, while GHGs from passenger modes increased by 20 percent (EPA 2005).[ii] 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 (DOE 2004). 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, accounting for most of the overall increase in freight GHG output and intensity.

INVENTORY ESTIMATES OF TRANSPORTATION GHGs: IMPLICATION OF "TOP-DOWN" AND "BOTTOM-UP" APPROACHES

U.S. CO_2 estimates are developed using a multi-stage "top-down" methodology. To summarize, this process starts with estimates of fuel consumption from the Energy Information Administration (EIA) of the U.S. Department of Energy (EIA 2004). EIA disaggregates these data by fuel type and economic sector. In developing estimates for the UNFCCC, EPA adjusts these values so that they correspond with the accounting framework specified by the UNFCCC reporting guidelines. EPA then estimates CO_2 by multiplying these fuel consumption estimates by carbon content of each fuel and adjusting for carbon that does not oxidize during combustion. Finally, EPA allocates the transportation-sector estimates to specific vehicles and modes using separate estimates of fuel consumption and activity data such as FHWA's *Highway Statistics* and Oak Ridge National Laboratory's *Transportation Energy Data Book.*

Unlike CO_2 emissions, which are proportional to vehicle fuel consumption, CH_4 and N_2O emissions are affected by a complex set of combustion dynamics that includes the type of emissions control system used. As a result, *Inventory* estimates of these gases require the use of laboratory-based emissions factors that are specific to fuel type, vehicle type and vehicle control technology. Emissions factors are expressed in grams per mile (for on-road vehicles) and grams per unit of fuel consumed (for non-road vehicles). CH_4 and N_2O are calculated multiplying emissions factors by estimates VMT and fuel consumption. These activity data are also from FHWA's *Highway Statistics* and ORNL's *Transportation Energy Data Book.*

SOURCES OF UNCERTAINTY TRADITIONALLY AFFECTING TRANSPOTATION GHG ESTIMATES (THROUGH THE 2005 *INVENTORY*)

CO_2

Since 96 percent of transportation GHG emissions are in the form of CO_2, uncertainty in CO_2 estimates is much more significant than uncertainty associated with N_2O, CH_4, or HFC emissions. The largest source of uncertainty in sector-specific CO_2 estimates relates to fuel consumption statistics. The EIA estimates used in the *Inventory* are believed to be very accurate in accounting for the combined fuel consumption of all economic sectors. However, there is greater uncertainty in EIA's apportionment of these values to specific economic sectors, which are also used to produce *Inventory* estimates. EPA apportions these fuel- and sector-specific estimates to specific sources such as transportation modes, resulting in further uncertainty. As noted above, EPA uses "bottom-up" data to allocate these estimates to specific transportation sources. These two data sources generally indicate different levels of transportation fuel consumption.

A second and related source of uncertainty involves estimates of international bunker fuels, which are associated with marine diesel fuel oil, marine distillate fuel oil and aviation jet fuel. 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. International bunker fuel estimates are reported in the *Inventory*, but are *not* counted toward a national total. However, differentiating domestic and international fuel consumption is often difficult, resulting in significant year-to-year variations in the official estimates. For instance, estimated GHGs from marine and aviation in 2003 were 84.1 Tg. CO_2 Eq., down from 114.6 Tg CO_2 Eq. in 1998. The disparity of these estimates largely reflects uncertainty in distinguishing the domestic and international components of this fuel consumption.

CH_4 and N_2O

Uncertainty in CH_4 and N_2O emissions from highway vehicles is a product of uncertainty in VMT estimates, the distribution of VMT to control technology types, and emissions factors. The *Inventory* reports that the uncertainty range of on-road CH_4 and N_2O emissions is greater than that of CO_2 emissions (EPA 2005). This uncertainty range is considered to be of less significance given the smaller magnitude of CH_4 and N_2O produced. For non-road sources, CH_4 and N_2O are estimated by applying emissions factors to estimates of the quantity of fuel consumed. Both the fuel economy estimates and emissions factors for non-road sources are considered to be very uncertain. However, the estimated production of non-road CH_4 and N_2O is also relatively small and considered to be of low significance.

TRANSPORTATION FUEL CONSUMPTION ESTIMATES AND RELATED UNCERTAINTY THROUGH THE 2005 *INVENTORY*

EIA fuel consumption estimates have historically differed from those available in bottom-up data sources such as *Highway Statistics*. Given the significance of fuel consumption estimates in calculating CO_2 (96 percent of transportation GHG emissions) EPA and ICF Consulting investigated the differences in these data sources.

- EIA's estimates of transportation diesel fuel consumption, which are used in the *Inventory*, are systematically 2.5 to 10.0 percent lower than estimates from various bottom-up sources for 1990 to 2003. (Bottom-up sources include FHWA's *Highway Statistics* for highway vehicles, EIA's Fuel Oil and Kerosene Sales Report for ships and boats, 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.)
- 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.

- 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. In the *Inventory*, EPA assigns the jet fuel to types of use (commercial aircraft, general aviation aircraft, military aircraft) based on primary data sources, and considers the remainder use by "other aircraft." As a result, EIA and EPA estimates of jet fuel consumption match up but there is uncertainty regarding where the other jet fuel is used.

Table 1 provides a summary comparison of estimates of transportation CO_2 emissions reported in the *Inventory* for 1990 and 2003 compared with estimates developed based on a bottom-up approach.

Table 1: Comparison of U.S. GHG Inventory Estimates and Bottom-Up Estimates of CO_2 for Selected Transportation Fuels and Sources

	1990			2003		
Fuel Type/Vehicle Type	**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	-	

In January 2005, EPA *Inventory* staff met with fuel consumption specialists from EIA and FHWA to discuss differences in these fuel consumption estimates. It was agreed that FHWA's figures represented the best source of highway fuel consumption, and that both EIA uses these calculation in developing its own estimates of motor gasoline and diesel fuel consumption. However, the timing of EIA's fuel consumption estimates requires the use of older FHWA data, meaning that their estimates for 2003 would reflect FHWA estimates from 2002. It was recognized that EPA should calculate transportation CO_2 emissions directly from best available data sources, which typically are bottom-up data.

UPDATED METHODOLOGY FOR CO_2 ESTIMATES IN THE 2006 *INVENTORY*

Starting with the 2006 *Inventory*, EPA adjusted the transportation diesel estimate provided by EIA based on "bottom-up" analysis showing their estimate to be potentially low. Accordingly, the transportation sector diesel fuel estimate was adjusted higher to match the bottom-up estimate.[iii] Because EIA's estimate of total diesel fuel consumption across all sectors is believed to be relatively accurate, the EIA diesel estimates for residential, commercial and industrial sectors were adjusted downward proportionally. This process was used to calculate both the most recent values presented in the 2006 *Inventory* (2004) as well as earlier estimates (1990-2003) that are also presented in the document. This adjustment represented the only substantive modification to EIA energy statistics used in the *Inventory*. A similar adjustment using bottom-up based gasoline estimates is being contemplated for future Inventories, but was considered beyond the scope of the 2006 *Inventory* effort.

A second methodological improvement involved the use of updated oxidation fraction for light-duty motor vehicle engines. A 2004 EPA study indicated that the fraction of fuel combusted for light-duty gasoline motor vehicles is 100 percent (EPA 2004). This value was used to calculate both the most recent values presented in the 2006 *Inventory* (2004) as well as earlier estimates of CO_2 from gasoline engines. 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 may be conduct further research to examine these estimates for transportation and non-transportation sources.

PLANNED IMPROVEMENTS

Several areas of potential improvement have been identified that could potentially be implemented given available resources.

- Continue to reconcile fuel consumption estimates used for calculating CO_2, N_2O and CH_4. As noted earlier, the most recent *Inventory* estimates reconciled EIA estimates of transportation diesel fuel consumption with those provided by FHWA. Future improvements include reconciling the EIA and FHWA estimates of transportation gasoline consumption.

- Improve estimates by vehicle / fuel category with improved VMT estimates. The current *Inventory* process for estimating VMT by vehicle/fuel type category involves apportioning VMT by vehicle type to each fuel type in the basis of fuel consumption. While this is a reasonable simplification, it implicitly assumes the same average fuel economy for gasoline and diesel vehicles. A more accurate apportionment of VMT by fuel type for light-duty trucks and medium/heavy-duty trucks could potentially be developed using data on vehicle travel from the Vehicle Inventory and Use Survey (Census 2000) and other publications, or using VMT breakdowns by vehicle/fuel type combinations from EPA's MOBILE6 or MOVES models.

- Updating CH_4 and N_2O emissions factors for highway vehicles. A number of recent efforts have focused on improving estimates of CH_4 and N_2O emissions factors for alternative fuel vehicles. These studies are expected over the course of this year. In addition, it is recognized that existing emissions factors may not characterize CH_4 and N_2O emissions from Tier 2 vehicles, which have entered the vehicle fleet.

- Improve consideration of emissions from trucks used off-road. Some light- and heavy-duty trucks travel for a portion of their mileage off-road. N_2O and CH_4 estimates for highway vehicles are developed based on vehicle mileage data from FHWA's *Highway Statistics*, which, in turn, are drawn from the Highway Performance Monitoring System (HPMS). These emission estimates do not address travel by trucks off-road. Gasoline fuel consumed by trucks used off-road for construction, agriculture, and other industrial/commercial uses is reported in *Highway Statistics*, and is included as part of the Inventory non-road agriculture and construction categories. However, diesel fuel consumed by trucks used off-road is not addressed in the *Inventory*, and further work should be conducted to develop estimates of off-road truck use of diesel fuel.

CONCLUSIONS

Transportation GHG emissions increased by 24 percent from 1990 to 2003, reflecting continued growth in passenger and freight travel, which has substantially exceeded improvements in the energy efficiency of most major transport modes. This has been especially true of heavy-duty (freight) trucks, which increased production of GHGs by 57 percent between 1990 and 2003, by far the largest increase of any major mode. GHGs from light-duty (passenger) vehicles increased by 19 percent over this timeframe. By contrast, total aircraft GHG emissions decreased by 3 percent and commercial aircraft emissions increased by only 4.7 percent, despite a rapid increase in passenger travel. Future calculations of transportation GHGs will hopefully provide further insight on the magnitude of these emissions and the factors affecting their production. Recent work has focused in improving the accuracy of these estimates, focusing on the use of “bottom-up” data to inform estimates of transportation diesel consumption and resultant GHGs. Future activities may include the use of similar data for transportation gasoline estimates, and the use of other activity data sources to improve mode-specific calculations.

KEYWORDS

Greenhouse gas emissions
Transportation
Mobile sources
Carbon dioxide

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ENDNOTES

[i] Based on the global warming potential of all gasses.

[ii] EPA does not explicitly calculate aircraft emissions associated with freight movement; these emissions are included in overall estimates for commercial aircraft, which are categorized as passenger transport. 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.

[iii] The methodology for developing “bottom up” fuel consumption estimates for other sources is as follows. For highway vehicles, annual estimates of fuel consumption by vehicle category were taken from FHWA’s *Highway Statistics’* annual editions, Table VM-1 (FHWA 1996 through 2004). For each vehicle category, the percent gasoline, diesel, and other (e.g., CNG, LPG) fuel consumption was estimated using data from the Appendix to DOE’s *Transportation Energy Data Book* (DOE 2004). The highway gas and diesel fuel consumption estimates by vehicle type were then adjusted for each year so that the sum of gasoline and diesel fuel consumption across all vehicle categories matched with the fuel consumption estimates in *Highway Statistics’* Table MF-21 (FHWA 1996 through 2003). Gasoline fuel consumption from recreational boats was taken from EPA’s NONROAD Model (EPA 2004c). Natural gas and LPG fuel consumption by vehicle type and mode were taken from DOE (1993 through 2004).