AN ASSESSMENT OF GHG EMISSIONS FROM THE TRANSPORTATION SECTOR

William Cowart
ICF Consulting, Hamilton House, Mabledon Place, Bloomsbury, London UK WC1H 9BB
BCowart@ICFConsulting.com

Veronika Pesinova and Sharon Saile
U.S. Environmental Protection Agency, 1200 Pennsylvania Ave., Washington, DC USA 20460
pesinova.veronika@epa.gov

ABSTRACT

The transportation sector accounts for 27 percent of total U.S. greenhouse gas (GHG) emissions and is the sector with the greatest annual growth in terms of GHG emissions. Understanding the nature of these emissions is essential for developing efficient strategies to reduce them. This paper describes emissions from the following perspectives: 1) by the GHG "intensity" of the transportation sector, in terms of emissions per unit of gross domestic product (GDP); 2) by trip purpose and economic activity area (e.g., freight mode, commodity carried, and public passenger transportation; 3) within the context of the full lifecycle of transportation emissions. This information should prove useful to policymakers and transportation planners in understanding and addressing GHG emissions from the transportation sector.

INTRODUCTION

Transportation is a vital part of the U.S. economy and is essential for the everyday activities of U.S. residents. However, along with providing benefits, transportation[i] also results in greenhouse gas (GHG) emissions and other adverse environmental effects. Currently, numerous federal, state, and local agencies are developing voluntary programs and partnerships to reduce transportation GHG emissions. However, in order to adequately evaluate the effectiveness of these programs, having a sufficiently detailed inventory for the transportation sector and its subsectors is necessary. This paper describes emissions from a number of additional perspectives:

1) by greenhouse gas "intensity" – how GHG emissions from the transportation sector have changed over time in comparison with economic indices such as gross domestic product (GDP);

2) by transportation mode, trip purpose, and economic activity area (such as freight or passenger transport and commodity carried);

3) within the context of the full lifecycle of transportation emissions.

This paper was developed using the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2001* ("the Inventory;" forthcoming) as its primary foundation for data. The Inventory attempts to account for all national GHG emissions using a methodology required by the United Nations Framework Convention on Climate Change (UNFCCC). One fundamental characteristic is that the Inventory presents its results primarily by greenhouse gas (e.g. carbon dioxide, methane, etc.). As a secondary organizational criteria, many emissions are next characterized by fuel type. Sectoral-level activity areas are characterized in the Inventory and some disaggregation is provided (e.g., by mode of transportation), however data generally is organized to be most useful for climate specialists rather than sectoral professionals. Several new tables in Annex E of this year's Inventory (EPA, 2003) have been added in order to present the Inventory's data in a manner that is more convenient for some transport policy professionals, and other new tables add some additional context regarding underlying activity and travel behavior patterns.

This paragraph describes the methodologies used to estimate all the transportation GHG emissions data presented in this paper. There are two basic methods, top down and bottom up, commonly used for estimating GHG emissions. Ideally, these two approaches can be used together to refine the GHG emission estimates. The CO_2 emissions were estimated based on the carbon content of fuels consumed and by calculating fuel consumption for the transportation sector by fuel type, vehicle type, and mode. The CH_4 and N_2O emissions were estimated by combining the activity-level data (e.g., vehicle miles traveled, fuel consumption) with specific emission factors for each vehicle and fuel type. The HFC emissions were estimated based on the number, size, and leakage rate of coolant equipment in use. More detailed description of the methodologies can be found in the Inventory report (EPA, 2003), in Annex A (for CO_2 emissions), Annex E (for CH_4 and N_2O emissions), and Annex K (for HFC emissions).

TRANSPORTATION GREENHOUSE GAS EMISSIONS AND ECONOMIC TRENDS

GHG emissions can be compared with economic indices to highlight trends over time. In February 2002, President George W. Bush proposed a new approach to measuring GHG emission trends. Instead of setting targets for the absolute quantity of GHGs emitted, GHG intensity—or how much is emitted per unit of economic activity—would be evaluated.[ii] Table 1 compares GHG emissions data from the transportation sector (Table 2) to an economic index (Gross Domestic Product (GDP) data). The transportation sector GDP data includes dollars attributed to such things as personal consumption of transportation (such as vehicles, parts, fuel, and services), public and private domestic investment in transportation structures and equipment, public and private purchase of transportation services, other transportation expenditures, and net exports of transportation-related goods and services as calculated by the Bureau of Economic Analysis and Bureau of Transportation Statistics.

Table 1 shows that since 1991, the annual average GDP growth rate (3.2 percent) has easily outpaced the annual average GHG emissions growth rate (1.3 percent). Thus, GHG intensity is decreasing relative to GDP, although GHG emissions are increasing relative to population growth (0.9 percent). Table 1 also shows the results of the calculation of GHG intensity for the transportation sector and the U.S. economy as a whole. Although transportation has a much higher GHG intensity than the economy overall and is the fastest growing end use sector as a source of GHG emissions, one can note that transportation GHG intensity is decreasing more quickly than GHG intensity overall.

One caveat of comparing emissions to GDP is that national economic accounting does not track activities that are not part of the formal economy. For example, GDP is accrued for housework performed for pay by a household employee, but identical work performed by a household member is not included in the same national economic accounts. Similarly, driving to a regional park for hiking or fishing is generally omitted from GDP whereas a similar drive to an amusement park is included, despite the fact that they essentially are two leisure activities with similar time, travel, and GHG characteristics. Because much of transportation involves travel in which personal time considerations are vital in determining travel benefits and activity choice, but are not accounted for in GDP, the ratio of transportation sector GHG emissions to GDP may be overestimated. Nonetheless, some general observations may be available from examining GHG intensities as described in the Administration's Global Climate Change Initiative. Further, this presentation of sector-specific GHG intensities will hopefully encourage further research to develop and refine this perspective of evaluating GHG emissions.

Table 1. Transportation GHG Emissions and GDP

	1990	1996	1997	1998	1999	2000	2001	% Change 1990-2001
Transportation contributing to U.S. GHG Emissions* (Tg CO2 Eq.)*	1525.6	1694.9	1707.5	1737.0	1799.2	1849.7	1865.5	22.3%
Domestic transportation-related final demand** (Chained 1996 $ billions)	751.1	880.2	921.5	983.6	1068.0	1094.8	1097.5	46.1%
Ratio	2.03	1.93	1.85	1.77	1.68	1.69	1.70	-16.3%
Net U.S. GHG Emissions (Tg CO2 Eq.)*	5033.0	5561.7	5860.5	5870.3	5933.1	6098.7	6150.6	22.2%
Total U.S. Gross Domestic Product (Chained 1996 $ billions)	6707.9	7813.2	8159.5	8508.9	8859.0	9191.4	9214.5	37.4%
Ratio	0.75	0.71	0.72	0.69	0.67	0.66	0.67	-11.0%

*Does not include bunker fuels, but does include pipeline emissions
**Sum of total personal consumption of transportation, total gross private domestic investment, net exports of transportation-related goods and services and total government transportation-related purchases.
Emissions Data: Inventory of U.S. Greenhouse Gas In Emissions and Sinks: 1990-2001, Tables 1-11, 1-14, E-21.
Transportation GDP Data: National Transportation Statistics 2001: Table 3-2b: U.S. Gross Domestic Product (GDP) Attributed to Transportation-Related Final Demand. Online at http://www.bts.gov/publications/nts/html/table_03_02_b.html
National GDP Data: Bureau of Economic Analysis, National Accounts Data. http://www.bea.doc.gov/bea/dn/gdplev.xls

TRANSPORTATION TRENDS BY TRIP PURPOSE AND ECONOMIC ACTIVITY

Table 2 shows that GHG emissions from transportation-related sources have increased by 22.3 percent from 1990 levels to the 2001 level of 1,865.5 Tg CO2 Eq. Transportation and other mobile source emissions have had the largest increase of the end-use sectors (EPA 2003, Table ES-5). Table 2 summarizes the relative shares and growth trends in GHG emissions from these different modes by fuel type. In addition, this section includes a discussion of trends in freight and public passenger transport, since these categories span across multiple transportation modes.

Figure 1 shows that transportation emissions are steadily increasing, although this is not consistent across modes. Highway vehicle emissions have gone up by 25 percent from 1990 to 2001, with much of the increase attributable to growing emissions in the light-duty truck (vans, pickups, and SUVs) and medium- and heavy-duty truck categories. Overall aviation emissions are nearly flat, but the increase is nearly 13 percent from 1990-2001 if military aircraft are excluded. Mobile air conditioners and refrigerated transport have rapidly increased as the HFCs that constitute these emissions have been phased in beginning in the early 1990s to replace CFCs. These emissions have not been allocated across the various modes, although vehicle air conditioning and the use of refrigerated vehicles and intermodal containers does span across virtually all modes.

This section describes travel data broken out by trip purpose, and for freight vehicles (including rail and waterborne, as well as trucking), by commodity. Two national-level surveys provide information on personal transportation by trip purpose, which can be used to examine travel associated with different economic activities:

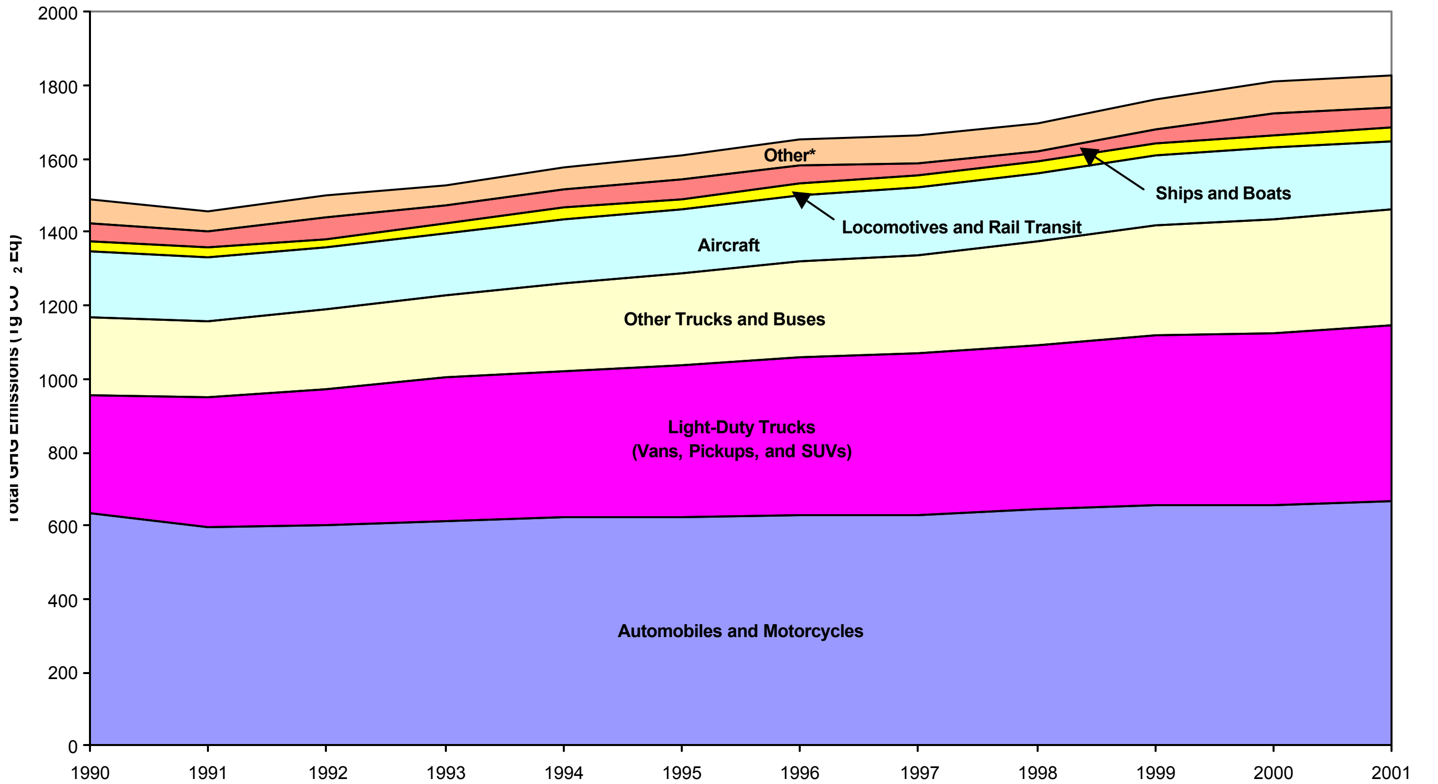
Table 2. U.S. GHG Emissions from Transportation and Mobile Sources (Tg CO_2 Eq.).

Mode / Vehicle Type / Fuel Type	1990	1996	1997	1998	1999	2000	2001	Contribution to U.S. Transportation Total	Change from 1990-2001
Highway Vehicles	**1170.5**	**1318.2**	**1339.9**	**1374.9**	**1419.5**	**1434.8**	**1463.4**	**78.4%**	**25.0%**
Passenger Cars	**633.6**	**629.3**	**627.1**	**642.0**	**651.6**	**653.6**	**665.4**	**35.7%**	**5.0%**
Gasoline	627.3	624.5	622.5	637.6	647.2	649.5	661.1	35.4%	5.4%
Diesel	6.3	4.7	4.6	4.5	4.4	4.1	4.3	0.2%	-32.7%
AFVs	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.0%	105.3%
Light-Duty Trucks	**321.8**	**429.3**	**441.9**	**449.8**	**468.1**	**471.6**	**480.2**	**25.7%**	**49.2%**
Gasoline	312.8	416.9	428.5	436.2	453.4	456.8	465.0	24.9%	48.7%
Diesel	9.0	12.3	13.2	13.5	14.6	14.7	15.1	0.8%	68.0%
AFVs	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.0%	197.6%
Medium/Heavy-Duty Trucks	**205.9**	**249.5**	**260.6**	**272.5**	**288.0**	**298.0**	**306.0**	**16.4%**	**48.6%**
Gasoline	40.8	37.4	36.0	35.9	35.1	34.8	35.5	1.9%	-12.9%
Diesel	165.2	212.2	224.6	236.5	252.9	263.2	270.5	14.5%	63.8%
AFVs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0%	244.7%
Buses	**7.4**	**8.3**	**8.5**	**8.8**	**9.9**	**9.7**	**9.9**	**0.5%**	**33.9%**
Gasoline	1.7	0.9	0.7	0.7	0.7	0.6	0.6	0.0%	-64.9%
Diesel	5.8	7.3	7.5	7.9	8.9	8.7	8.9	0.5%	54.6%
AFVs	0.0	0.1	0.2	0.3	0.3	0.5	0.4	0.0%	n.e.
Motorcycles	**1.8**	**1.8**	**1.8**	**1.8**	**1.9**	**1.9**	**1.9**	**0.1%**	**7.8%**
Gasoline	1.8	1.8	1.8	1.8	1.9	1.9	1.9	0.1%	7.8%
Aircraft	**178.4**	**181.7**	**180.5**	**184.6**	**188.3**	**196.9**	**185.5**	**9.9%**	**3.9%**
General Aviation Aircraft	**9.4**	**8.4**	**8.8**	**10.2**	**11.9**	**12.0**	**11.8**	**0.6%**	**25.1%**
Jet Fuel	6.4	5.8	6.1	7.8	9.2	9.5	9.4	0.5%	48.2%
Aviation Gasoline	3.1	2.6	2.7	2.4	2.7	2.5	2.4	0.1%	-22.3%
Commercial Aircraft	**119.2**	**125.9**	**130.4**	**132.5**	**138.4**	**142.1**	**132.7**	**7.1%**	**11.3%**
Jet Fuel	119.2	125.9	130.4	132.5	138.4	142.1	132.7	7.1%	11.3%
Military Aircraft	**35.2**	**23.3**	**21.3**	**21.7**	**20.9**	**21.2**	**23.1**	**1.2%**	**-34.3%**
Jet Fuel	35.2	23.3	21.3	21.7	20.9	21.2	23.1	1.2%	-34.3%
Other Aircraft	**14.7**	**24.1**	**19.9**	**20.1**	**17.2**	**21.6**	**17.9**	**1.0%**	**22.0%**
Jet Fuel	14.7	24.1	19.9	20.1	17.2	21.6	17.9	1.0%	22.0%
Boats and Ships	**48.9**	**48.6**	**33.9**	**27.7**	**39.1**	**60.7**	**59.3**	**3.2%**	**21.1%**
Gasoline	11.3	8.6	8.5	8.2	9.4	9.7	9.8	0.5%	-13.0%
Distillate Fuel	14.1	15.1	14.7	13.2	15.8	16.0	17.0	0.9%	21.0%
Residual Fuel	23.6	24.8	10.8	6.2	13.9	35.0	32.4	1.7%	37.4%
Locomotives	**28.2**	**32.1**	**31.9**	**32.6**	**34.4**	**34.1**	**34.7**	**1.9%**	**22.9%**
Distillate Fuel	27.6	31.5	31.2	32.0	33.7	33.3	33.9	1.8%	22.7%
Electricity	0.6	0.6	0.7	0.6	0.7	0.7	0.8	0.0%	28.4%
Pipelines	**38.3**	**41.1**	**43.3**	**37.3**	**37.8**	**37.7**	**36.2**	**1.9%**	**-5.4%**
Natural Gas	35.9	38.7	40.9	34.9	35.3	35.0	33.5	1.8%	-6.7%
Electricity	2.4	2.4	2.4	2.5	2.5	2.6	2.8	0.1%	14.8%
Agricultural Equipment	**33.4**	**34.6**	**34.7**	**32.4**	**29.8**	**31.6**	**32.1**	**1.7%**	**-3.9%**
Gasoline	7.1	8.0	8.5	7.8	6.0	5.6	5.7	0.3%	-19.7%
Diesel	26.3	26.6	26.2	24.6	23.7	26.0	26.4	1.4%	0.3%
Construction Equipment	**15.9**	**16.0**	**16.3**	**16.5**	**16.1**	**17.6**	**17.9**	**1.0%**	**12.7%**
Gasoline	2.8	2.5	2.6	2.0	1.5	1.7	1.7	0.1%	-39.7%
Diesel	13.1	13.5	13.7	14.5	14.6	16.0	16.3	0.9%	23.8%
Lubricants	**11.7**	**10.9**	**11.5**	**12.0**	**12.1**	**12.0**	**12.1**	**0.6%**	**3.0%**
Mobile Air Conditioners	**0.0**	**9.8**	**12.9**	**15.7**	**18.2**	**20.4**	**20.4**	**1.1%**	**n.a.**
Refrigerated Transport	**0.0**	**1.9**	**2.5**	**3.2**	**3.8**	**3.8**	**3.8**	**0.2%**	**n.a.**
Other*	**0.2**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.0%**	**-22.4%**
Total	**1525.6**	**1694.9**	**1707.5**	**1737.0**	**1799.2**	**1849.7**	**1865.5**	**100.0%**	**22.3%**

* "Other" includes snowmobiles, small gasoline-powered utility equipment, heavy-duty gasoline-powered utility equipment, and heavy-duty diesel-powered utility equipment.

Source: Draft Inventory of U.S. GHG Emissions and Sinks: 1990-2001, Table 1-14, Table 2-7, Table 2-18, and Table 2-19.

Figure 1. 2001 Domestic GHG Emissions by Vehicle Type (Tg CO_2 Eq.).



*Other includes non-highway sources not in other categories, such as construction and agricultural equipment, pipelines, lubricants, mobile air conditioners, and refrigerated transport but does not include bunkers. Source: Table 2.

1. the 1995 Nationwide Personal Transportation Survey (NPTS) [iii] provides data on daily, local passenger trips; and

2. the 1995 American Travel Survey (ATS) provides data on long-distance personal travel (trips of 100 miles or more) in the United States.

Data on freight-related highway travel is available from the 1997 Commodity Flow Survey, which provides data on ton-miles and fuel consumption by mode and commodity shipped.

Daily Travel

As shown in Table 3, trips associated with earning a living comprised the largest share (nearly 38%) of total 1995 vehicle miles traveled (VMT) for person trips. Family and personal business, which includes activities such shopping and medical visits, made up the second largest share (approximately 36%), followed by social and recreational purposes (23%). In terms of the number of trips taken, family and personal business comprise roughly half of all trips, followed by earning a living (27%) and social and recreational (18%). The difference between this ranking and the rankings for VMT reflects the relatively short distances required for most family and personal business trips (shopping and errands) compared to commuting and business meetings. Table 3 also shows the difference between per-household VMT by trip purpose from 1990 to 1995. Typical households traveled over 2,700 more miles in vehicles in 1995 than in 1990, an increase of 15 percent. Over half of this increase was due to an increase average VMT associated with commuting to and from work, which occurred for two primary reasons: 1) because there are more workers per household than in the past; and 2) because the length

Table 3. Personal and Average Household Vehicle Trips and Vehicle Miles of Travel by Trip Purpose: 1990 and 1995

Trip Purpose	1995 Personal Vehicle Trips[(a)]		1995 Personal VMT[(a)]		1990 Average Household VMT[(b)]		1995 Average Household VMT[(b)]	
	Millions	%	Millions	%	Miles	%	Miles	%
Earning a Living	**62,703**	**27%**	**780,485**	**38%**				
To/From Work	54,782	24%	642,616	31%	4,853	27%	6,492	31%
Work-related Business	7,921	3%	137,869	7%				
Family and Personal Business	**114,833**	**50%**	**734,851**	**36%**				
Shopping	49,554	22%	277,887	13%	2,178	12%	2,807	13%
Doctor/Dentist	3,315	1.4%	30,614	1%				
Other	61,964	27%	426,350	21%	4,250	23%	4, 307	21%
School and Church	**9,734**	**4%**	**78,315**	**4%**				
Social and Recreational	**42,239**	**18%**	**471,566**	**23%**	5,359	30%	4,764	23%
Vacation	246	0.1%	20,319	1%				
Visiting Friends/Family	15,323	7%	195,072	9%				
Other	26,670	12%	256,175	12%	1,521[(c)]	8%[(c)]	2,525[(c)]	12%[(c)]
Miscellaneous	**237**	**0.1%**	**3,219**	**0.2%**				
Total	**229,746**		**2,068,436**		**18,161**		**20,895**	

(a) Vehicles trips and miles are only for privately owned vehicles driven by a member of the household surveyed.
(b) NPTS adjusted 1990 data for longitudinal comparison based on 1995 methodology but more detailed information based on trip purpose was not available.
(c) Includes trips to school, church, doctor, dentist, and work-related business trips.
Source: U.S. Department of Transportation (1999), 1995 NPTS, Table 1 and Table 5.
http://www-cta.ornl.gov/npts/1995/Doc/

of work trips has increased (from 8.85 miles per trip in 1990 vs. 9.06 miles per trip in 1995).[iv] VMT associated with family and personal trips was basically stable from 1990 to 1995, reflecting that errands are fairly consistent in their frequency and destination. Social and recreational trips decreased in aggregate travel.

Long Distance Travel

As shown in Table 4, according to the ATS, American households took over 650 million long-distance trips in 1995 (totaling 1 billion person trips). Approximately three-quarters of the long-distance household trips within the U.S. were taken in a personal use vehicle (car, truck, or van), resulting in over 280 billion vehicle miles of travel. The major trip purpose for these vehicle trips was pleasure, as shown in Table 5, with the category "visit friends or relatives" comprising the largest share. Business trips made up the next largest share of vehicle trips and vehicle miles traveled.

Freight

In addition to personal travel, freight transportation services are also an important contributor to GHG emissions from transportation. Table 6 and Figure 2 present GHG emissions for the category of freight transportation, comprised of heavy-duty trucks, freight locomotives, waterborne freight, air freight,[v] pipelines, and freight refrigeration units. It can be seen that heavy-duty trucks were the largest source of GHG emissions from freight transportation in the U.S. from 1990 to 2001, with the increase of 46 percent, resulting in significantly increased emissions from freight overall. Emissions from freight transportation comprised 23 percent of total transportation emissions in 2001 and 7 percent of all U.S. GHG emissions at 424.0 Tg CO_2 Eq.

Table 4. Long Distance (over 100 mi.) Travel in the U.S. by means of transportation: 1995

	Household trips		Person trips		Person miles	
Principal means of transportation	**thousands**	**percent**	**thousands**	**percent**	**millions**	**percent**
Personal use vehicle	505,154	77%	813,858	81%	451,590	55%
Airplane	129,164	20%	161,165	16%	355,286	43%
Bus	17,340	2.6%	20,445	2.0%	13,309	1.6%
Train	4,200	0.6%	4,994	0.5%	4,356	0.5%
Ship, boat, or ferry	391	0.1%	614	0.1%	1,834	0.2%
Other*	213	—	243	—	429	0.1%
Total	**656,462**		**1,001,319**		**826,804**	

Source: U.S. Department of Transportation, Bureau of Transportation Statistics.
1995 American Travel Survey Profile. BTS/ATS95-US, October 1997, Table 1.
* Other is not defined for this table, but presumably includes taxis and limousines.

Table 5. Long-Distance Travel (over 100 mi.) in the U.S. by Trip Purpose: 1995

	Household trips		Personal use vehicle trips*		Personal use vehicle miles**
Trip Purpose	**thousands**	**percent**	**millions**	**percent**	**millions**
Business	192,537	29%	125	25%	61,929
Visit friends or relatives	195,468	29%	160	32%	92,190
Rest or relaxation	65,017	9%	53.8	11%	33,598
Sightseeing	24,272	3%	18.1	4%	14,654
Outdoor recreation	39,899	6%	36	7%	19,407
Entertainment	37,456	5%	27.9	6%	14,531
Other Leisure	10,475	1%	9.8	2%	3,318
Personal business	91,319	14%	74.5	15%	40,490
Total	**656,443**		**505.09**		**280,117**

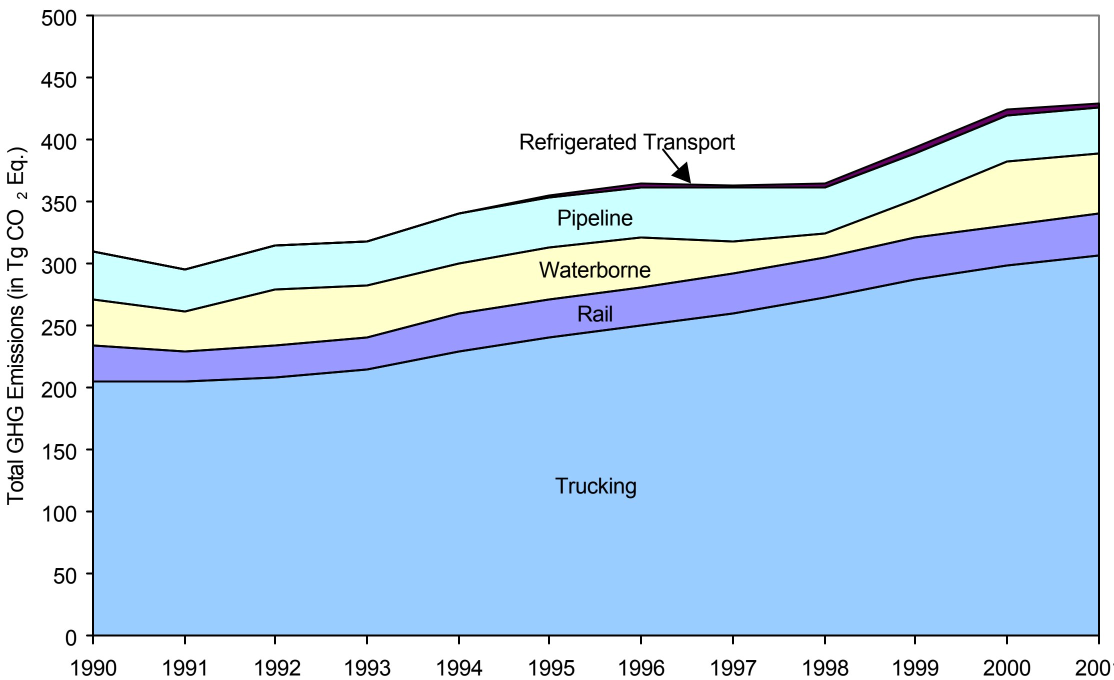
*Any trip in which the principle means of transportation was car, pickup truck, or van; other truck, rental car, truck, or van; recreational vehicle or motor home; or motorcycle or moped.
**Calculated using personal use vehicle miles in this chart.
Source: U.S. Department of Transportation, Bureau of Transportation Statistics.
1995 American Travel Survey Profile. BTS/ATS95-US, October 1997, Table 1.

Table 6. GHG Emissions from Domestic Freight Transportation (Tg CO_2 eq.)

By Mode	1990	1995	1996	1997	1998	1999	2000	2001	% Change 1990-2001
Trucking	206.5	240.6	249.3	260.5	272.5	287.4	297.8	301.3	46%
Rail	26.4	30.5	30.2	29.9	30.7	32.3	32.0	32.4	22%
Refrigerated Transport	0.0	1.2	1.9	2.5	3.2	3.8	4.4	4.9	NA
Waterborne	37.8	43.0	40.1	25.6	19.6	29.8	50.7	49.2	30%
Aviation	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.
Pipeline	38.3	40.4	41.1	43.3	37.3	37.8	37.7	36.3	-5%
Total	**309.1**	**355.8**	**362.7**	**361.9**	**363.3**	**391.1**	**422.6**	**424.0**	**37%**

n.e. signifies data not estimated since there are inadequate data to provide a reliable breakdown of fuel consumption for air freight;
Source: Table 2; data from DOE (1993 through 2002) was used to allocate the passenger/freight split of rail emissions.

Figure 2. Greenhouse Gas Emissions from Domestic Freight Transportation by Mode (Tg CO_2 Eq.)



Highway Freight

Altogether, freight-related highway travel was responsible for approximately 301.3 Tg CO_2 Eq. in 2001 (16% of total U.S. transportation emissions). According to the most recent available (1997) Commodity Flow Survey, trucking services and related deliveries were responsible for nearly one trillion tons miles of travel in 1997. This travel resulted in approximately 30 billion gallons of fuel consumption (see Table 7 below). By commodity type, industrial products accounted for the most fuel consumption (29%), followed by farm and food (19%) and lumber and forest (15%).

Table 7. Ton-miles and Fuel Use from Highway Freight Travel for Major Commodities*

Commodity Description	Ton-Miles millions	Fuel Use million gallons
Energy	31,815	941
Lumber and forest	151,940	4,496
Mining	79,550	2,354
Farm and food	191,967	5,680
Equipment, machinery, and instruments	71,324	2,111
Industrial products	293,437	8,683
Consumer goods	45,152	1,336
Waste materials	45,846	1,357

*Note: These data are from the estimates generated by the Commodity Flow Survey, and provide an illustrative indication of the order of magnitude and relative size of various commodity groups within freight modes. Several smaller commodity categories are not included above.

Waterborne Freight

Domestic freight-related waterborne travel was responsible for approximately 49.2 Tg CO_2 Eq. in 2001 (3% of total U.S. transportation emissions). Table 8 provides summary statistics of waterborne freight for various commodity types. According to the Commodity Flow Survey, waterborne freight was responsible for nearly 262 billion tons miles of commodity movement in 1997, resulting in over 5.8 billion gallons of total fuel consumption. Additional fuel consumption and emissions were from bunkers consumed on international voyages, which are estimated but not included in totals for the US Inventory. Within waterborne freight by commodity type, farm and food products accounted for the most fuel consumption (31%), followed by industrial products (20%) and energy products (14%). Grain, coal and petroleum, and mineral ore are the dominant commodities within these classes for waterborne freight.

Table 8. Ton-miles and Fuel Use from Water Freight Travel for Major Commodities *

Commodity Description	Ton-Miles millions	Fuel Use million gallons
Energy	37,386	1,224
Lumber and forest	10	0
Mining	3,736	122
Farm and food	80,951	2,651
Equipment, machinery, and instruments	0	0
Industrial products	52,469	1,718
Consumer goods	0	0
Waste materials	3,856	126

*Note: These ton-mile data are from the estimates generated by the Commodity Flow Survey. The waterborne freight distillate and residual fuel use is obtained from 1997 U.S. Department of Energy, Energy Information Administration, Fuel Oil and Kerosene Sales (Washington, DC: Annual issues), tables 1 and 2, and similar tables in earlier editions.

Rail Freight

Rail transportation is one of major carriers of freight over long distances and thus it is also an important contributor to GHG emissions. Altogether, rail freight was responsible for approximately 32.4 Tg CO_2 eq. in 2001 (2% of total U.S. transportation emissions). Table 9 provides summary statistics of rail freight for various commodity types. According to the Commodity Flow Survey, rail freight was responsible for over 1 trillion tons-miles of travel in 1997. This travel resulted in over 3.5 billion gallons of total fuel consumption in 1997. By commodity, energy products accounted for the most fuel consumption (46%), followed by farm and food products (18%) and industrial products (18%).

Table 9. Ton-miles and Fuel Use from Rail Freight Travel for Major Commodities *

Commodity Description	Ton-Miles millions	Fuel Use million gallons
Energy	468,531	1,638
Lumber and forest	72,420	253
Mining	50,635	177
Farm and food	182,184	637
Equipment, machinery, and instruments	14,427	50
Industrial products	180,257	630
Consumer goods	11,756	41
Waste materials	26,557	93

*Note: These data are from the estimates generated by the Commodity Flow Survey, and provide an illustrative indication of the order of magnitude and relative size of various commodity groups within freight modes

Public Passenger Transportation

This section presents greenhouse gas emission estimates for "public passenger transportation", using a broad definition that includes all passenger vehicles available to the public for a fare or ticket price (or similar free services, such as many school buses or local shuttle buses). This category thus includes buses, passenger rail, commercial aviation, taxis, ferries, and shuttle services. This category was developed to complement the previous two categories, personal travel and freight, with the other main segment of the sector, public passenger transportation. Future research may help to estimate public transportation-related emissions from these last three modes, which currently cannot be estimated reliably. As shown in Table 10, commercial aviation makes up the largest share of public passenger transportation. In 2001, emissions from buses reached a total of 9 Tg CO_2 Eq., reflecting a 20 percent increase since 1990. Emissions from passenger rail also increased, totaling 2.3 Tg CO_2 Eq. in 2001.

Table 10. GHG Emissions from Public Passenger Transportation (Tg CO_2 Eq.)

Vehicle Type / Fuel Type	1990		1996	1997	1998	1999	2000	2001
Passenger Rail	**2.0**		**1.9**	**2.1**	**2.1**	**2.1**	**2.2**	**2.3**
Electricity	0.6		0.6	0.7	0.6	0.7	0.7	0.8
Diesel	1.4		1.3	1.4	1.4	1.5	1.5	1.5
Buses	**7.5**		**8.3**	**8.5**	**8.8**	**9.9**	**9.8**	**9.0**
Gasoline	1.6		0.9	0.7	0.7	0.7	0.6	0.5
Diesel	5.8		7.3	7.6	7.9	9.0	8.7	8.1
AFVs	0.0		0.1	0.2	0.3	0.3	0.5	0.4
Commercial Aviation	**120.0**		**126.8**	**131.3**	**133.4**	**139.2**	**143.0**	**133.5**
Jet Fuel	120.0		126.8	131.3	133.4	139.2	143.0	133.5
Taxis	**n.e.**		**n.e.**	**n.e.**	**n.e.**	**n.e.**	**n.e.**	**n.e.**
Ferries	**n.e.**		**n.e.**	**n.e.**	**n.e.**	**n.e.**	**n.e.**	**n.e.**
Other	**n.e.**		**n.e.**	**n.e.**	**n.e.**	**n.e.**	**n.e.**	**n.e.**
Total	**129.4**		**137.0**	**141.9**	**144.3**	**151.3**	**155.0**	**144.8**

n.e. signifies data not estimated.
Source: Draft Inventory of U.S. GHG Emissions and Sinks: 1990-2001, Table E-30.

LIFECYCLE PERSPECTIVE ON MOBILE SOURCE GREENHOUSE GAS EMISSIONS

While the majority of transportation GHG emissions come from fuel combustion during vehicle use, there are GHG emissions that come from so-called "upstream" sources that are accounted for in other sectors when using the IPCC methodology. This section brings together direct emissions from transportation and emissions from those 'upstream' sources (much as electricity-related emissions are distributed across transportation and the other end use sectors; see e.g., Tables 1-12, 2-6, etc. of the Inventory). While this lifecycle approach has certain shortcomings when used in the context of the Inventory (including substantial potential double-counting issues), it also provides value in illustrating an alternative way to understand the significance of various end use sectors such as transportation. The major sources of upstream GHG emissions related to transportation are: (1) the production, refining, and distribution of fuels, (2) the manufacture of vehicles, and (3) construction of transportation infrastructure.

Overview

The use of fuel by motor vehicles directly results in GHG emissions (CO_2, CH_4, and N_2O) from the tailpipe. These tailpipe emissions are accounted for as emissions from the transportation end-use sector (see for example Table 1-14 of the Inventory). However, the end-use of motor fuel in the transportation sector is associated also with GHG emissions in other sectors, such as industry. For example, transportation fuels are produced from crude oil by petroleum refineries, which emit significant quantities of GHG emissions. Before petroleum is processed at a refinery, it must be extracted from the earth, and this process also produces GHG emissions. These emissions are classified according to where they are directly emitted from end use; hence, emissions from petroleum extraction and refining are classified as industrial-sector emissions, not transportation-related emissions.

A lifecycle accounting differs from the direct end-use sectoral accounting because it assigns direct and indirect emissions to specific activities. Indirect emissions related to a specific activity that result from activities in other sectors can be linked to the specific activity being examined. For example, increased use of motor vehicles increases the demand for motor fuels, which increases the production of motor fuels at petroleum refineries. Besides the increase in GHG emissions associated with the combustion of larger quantities of fuel by motor vehicles, there will also be an increase in the GHG emissions associated with production by refineries.

Fuel Cycle

In the case of transportation, there are several systems of indirect linkages, or lifecycles, that may be relevant to an analysis of GHG emissions associated with transportation activities. Perhaps the most commonly considered lifecycle is that associated with the production and use of fuels. Upstream emissions from fuel use are the result of several steps. First, the drilling and production of oil, and the associated venting and flaring of gas, results in GHG emissions. The shipment of crude oil and feedstocks to refineries, via international and domestic marine vessels, pipelines and trucks, also contributes to transportation-related GHG emissions. Petroleum refining from crude oil into vehicle fuels requires energy and emits CO_2, N_2O and CH_4, in addition to some evaporative emissions of CH_4 that occur during the crude oil cycle. The shipment and distribution of motor fuels and petroleum products to points of final retail sale also contribute to GHG emissions. Finally, the marketing and dispensing of fuel is a further source of upstream emissions.

The emissions from the upstream portion of the lifecycle from feedstock production through fuel dispensing, excluding end use, can be significant in comparison with end use. For example, in the lifecycle of gasoline, upstream emissions of CO_2 are about 24-28% of end-use combustion emissions, with most of the upstream fuel cycle emissions coming from petroleum refineries.[vi] Upstream emissions of N_2O are only 2-5% of end-use N_2O emissions, but upstream emissions of CH_4 may be 6-13 times greater than end-use CH_4 emissions, on account of relatively large emissions of methane from oil fields and oil transport. Overall, for gasoline, total upstream GHG (in CO_2-equivalent) emissions are about 24-27% of end-use emissions. Note, though, that this upstream fuel cycle ratio varies dramatically from fuel to fuel: it is about 20% for diesel and natural gas (used for power generation), and may be as low as 10% for LPG (propane). (Note too that the ratio depends mainly on the fuel and feedstock, and not on the end use.)

Vehicle Manufacture Lifecycle

Another system of linkages (or lifecycle) pertinent to some analyses of transportation-related emissions of GHGs is that of the vehicle itself and its materials. Production of steel, aluminum, plastics, tires, and other vehicle components all require energy consumption with resulting GHG emissions. Vehicle distribution to auto dealers also requires energy and results in GHG emissions.

GHG emissions from the assembly and transportation vehicles, the complete lifecycle of the materials used in motor vehicles (e.g., the production and transportation of metal ores, the refining of ores into steels, the shaping and stamping of steel parts, the shipment of parts to automobile manufacturers, and assembly), and the use of lube oil and refrigerant are about 15-20% of end-use emissions from fuel use for an average highway vehicle. Most of this (about 75%) is from the lifecycle of the materials, with the remaining portion apread across assembly, shipping, and other activities.

Infrastructure Lifecycle

Finally, if one is interested in comparing the environmental effects of various transportation modes (such as rail systems and cars), then the emissions associated with the construction and maintenance of infrastructure are relevant. These lifecycle GHG emissions can vary substantially from mode to mode. For example, they may be low in absolute terms but quite high in percentage terms of direct end-use emissions for urban subways, while they may be quite high in absolute terms but low in percentage terms for highway construction and maintenance, especially relative to other infrastructure elements of the transportation sector.

Other Lifecycle Issues

It should be noted that the percentages given above -- for example, ~25% for gasoline fuel cycle-- are the ratio of upstream CO_2 emissions (from the gasoline lifecycle) to end-use CO_2 emissions (from gasoline vehicles). These ratios are specific to the particular fuel or vehicle types being analyzed, and cannot be generalized over the whole transportation sector. For example, a figure that applies to a certain kind of reformulated gasoline cannot be applied to all transportation fuels, or even to all gasoline. There is no way to derive a sector-wide figure for transportation without disaggregating fuel by fuel and vehicle type by vehicle type. Table 11 presents a partially completed illustration of what is required to develop a setor-wide figure. Even then, such a table is static and cannot account for interactive effects that would occur across elements (e.g., refineries can shift production between gasoline, diesel, and residual motor fuels). Thus, the lifecycle effects of even a sector-wide transportation policy cannot be estimated using a sectoral lifecycle inventory; they must be estimated by first determining how the policy affects travel by different vehicle types and fuel use by different fuel types, and then applying lifecycle analysis to the changes vehicle type by vehicle type and fuel type by fuel type.

Therefore, using a sectoral lifecycle approach is inappropriate for sector-wide policy analysis for two reasons. First, such an approach would be built up based on total or average conditions in the transportation sector, and any particular policy is not likely to have exactly "average" effects across the entire transportation sector. (For example, because of different price elasticities, a fuel tax might have more or less of an effect on diesel fuel use than on gasoline use.) Second, this approach would not capture the effects of changes within the transportation sector due to upstream effects (for example, changes in distribution of motor fuels), and hence would inappropriately omit a source of upstream emissions. Thus, lifecycle concepts can help illustrate the large role played by the transportation sector in overall GHG emissions, but the general numbers presented above should not be used as the basis for an explicit sectoral inventory or for sector level policy analysis.

CONCLUSIONS

GHG intensity for transportation sector was determined and compared to the GHG intensity for the U.S. economy as a whole. Although transportation had higher GHG intensity than the economy overall, it is important to note that the transportation GHG intensity was decreasing more quickly than the overall GHG intensity. In addition, since transportation involves a number of activities that are not accounted for in GDP, the ratio of transportation sector GHG emissions to GDP may be overestimated.

Trends in transportation emissions show that they are steadily increasing, although this is not consistent across the modes. The increase of 25% (from 1990 to 2001) in highway vehicle emissions was primarily caused by growing emissions in the light-duty truck (vans, pickups, and SUVs) and medium- and heavy-duty truck categories. Overall aviation emissions have increased only by 4 % between 1990 and 2001, but the increase is nearly 13% if military aircraft are excluded.

The analysis of the personal transportation data showed that trips associated with earning a living comprised the largest share (nearly 38%) of the total VMT and that there was a substantial increase in VMT associated with this category from 1990 to 1995. This increase occurred primarily because there are more workers per household and the length of work trips has increased. Regarding long distance travel, it is important to note that approximately three-quarters of trips within the U.S. were taken in a personal use vehicle (car, truck, or van) and the major trip purpose was for pleasure (e.g. visiting friends and relatives, recreation, entertainment, etc.).

In addition to the direct emissions from transportation, the emissions from so-called upstream sources were also estimated. Although there is some uncertainty associated with such estimates, the lifecycle analysis can illustrate the potential overall impact of GHG emissions from the transportation sector, which in turn can be helpful to design effective mitigation strategies.

REFERENCES

Draft (Public Review version) *Inventory of U.S. GHG Emissions and Sinks: 1990-2001*, U.S. EPA, 2003
U.S. Department of Transportation (1997), Bureau of Transportation Statistics.
U.S. Department of Transportation, 1995 Nationwide Personal Transportation Survey.
http://www-cta.ornl.gov/npts/1995/Doc/table1.pdf
DOT (1999) 1995 NPTS Summary of Travel Trends, Table 5.
1995 American Travel Survey Profile. BTS/ATS95-US.
1997 Commodity Flow Survey. Bureau of Transportation publication. US Census.

KEYWORDS

Greenhouse gas emissions
Transportation
Mobile sources
Lifecycle Emissions Analysis
Greenhouse gas intensity

ENDNOTES:

[i] Transportation is typically defined as including pipelines (which are stationary), but not construction equipment, agricultural equipment, and certain other mobile sources that do not provide transportation *per se*. Conversely, the term mobile sources does not include pipeline transportation, but does include construction equipment, agricultural equipment, and certain other mobile sources. Highway, rail, aviation, and waterborne vehicles all fall under both terms. This annex attempts to include all transportation-related and mobile sources, although the term transportation is primarily used for reading ease.

[ii] "President Announces Clear Skies & Global Climate Change Initiatives." White House Office of the Press Secretary. February 14, 2002. Accessed online at <http://www.whitehouse.gov/news/releases/2002/02/20020214-5.html>

[iii] The new NPTS survey, now recast as the National Transportation Survey, spans 2001-2002, and its data should be available later in 2003.

[iv] FHWA (1999) *1995 NPTS Summary of Travel Trends.* Table 2. U.S. Department of Transportation, Federal Highway Administration. December 1999.

[v] As described below, GHG emissions from air freight were not able to be reliably estimated.

[vi] All lifecycle emission numbers in this section are derived from The Argonne National Laboratory's GREET model and from M. A. Delucchi, "A Lifecycle Emissions Analysis: Urban Air Pollutants and Greenhouse-Gases from Petroleum, Natural Gas, LPG, and Other Fuels for Highway Vehicles, Forklifts, and Household Heating in The U. S.," World Resources Review 13 (1): 25-51 (2001). The numbers in Table 11 are based largely on the GREET model.