CHAPTER 1

THE ECONOMIC AND ENVIRONMENTAL FOOTPRINTS OF TRANSPORTATION

Lester B. Lave and W. Michael Griffin
Green Design Institute
Carnegie Mellon University
Pittsburgh, Pennsylvania

1 INTRODUCTION

This chapter explores both passenger and freight transport in the United States for a recent year, and over time where available. Our focus is on commercial transport:

1. Sales, ton-miles or passenger-miles, employment for each industry
2. Fuel use and CO_2 emissions for each industry
3. Air pollution emissions for each industry
4. Injuries and deaths by industry
5. Direct resource use and environmental discharges and the full life cycle
6. Social cost in dollars of the externalities, compared to the industry revenue

Passenger transportation and freight transportation, from commuting to oil pipelines, play an essential role in our economy and lifestyles. Mass-transit strikes all but shutter major cities; winter storms interrupt truck and air traffic, reducing our food choices. We Americans are mobile people who prefer to choose where we want to live, work, and shop, assuming that inexpensive transportation will be available to get us from one place to another. We choose to purchase petroleum from Kuwait and Nigeria, apples from New Zealand and Chile, and electronics from China and Japan, assuming that transportation of these goods will be reliable and inexpensive. We make our purchasing decisions at the local store or on the Internet with little concern for transportation prices, since they are generally low. Few Americans regard the fuel economy of a new automobile or light truck as of central concern relative to the appearance, size, and power of the alternatives. Even for a vacation across the continent or around the world, the cost of transportation is generally a small fraction of the total price of a vacation.

In short, we take transportation of passengers and freight for granted, unless there is a strike or storm that disrupts the flow. Even the doubling of the prices for gasoline and jet fuel caused little more than a momentary ripple of concern for most Americans.

Modern transportation is a remarkable achievement, compared to most of human existence. For transporting passengers on foot or by horse, 20 miles is a day's journey; an aircraft could transport a passenger 500 times faster. If freight is carried by a porter or yak, as is still done in the mountains of Nepal, transportation becomes a major fraction of the price of a good. In contrast, petroleum is transported in a supertanker from the Persian Gulf to the United States for about $1 per barrel, about 7/100 of a cent per ton-mile.

The remarkable achievements use large quantities of fuel and raw materials, emit large amounts of air pollution and greenhouse gases, and use large amounts of land and labor. Here we review and estimate the economic and environmental costs of passenger and freight transportation for the United States. We estimate the direct effects of transportation, as well as the full life-cycle implications of the activities.

2 ECONOMIC ACTIVITY

Table 1 shows that the transportation modes had a total revenue of $541 billion in 2000, just over 5 percent of GDP (2000 was the last year not distorted by 9-11 that is available).[1] Trucking was the dominant mode, with $223 billion in revenue, follow by air transport at $130 billion, then gas pipeline at $72 billion, rail at $36 billion, water at $33 billion, transit at $24 billion, oil pipeline at $9 billion, and bus at $4 billion. These figures are for commercial transportation and so don't include cars and light trucks driver by consumers, which are about 10 percent of GDP (consisting of the purchase of new vehicles, service and maintenance, fuel and insurance, and licensing).

The sector employs 5 million workers, with 40 percent employed in trucking. Air employs 24 percent, transit 12 percent, rail and water each employ 6 percent, and the pipelines employ 5 percent of transportation workers.

The sector produces 933 billion passenger-miles, with air having 77 percent of the share, followed by bus at 17 percent, transit at 5 percent, and rail at 1 percent. The freight sector in 2000 had 4 trillion ton-miles. Truck and rail have the lion's share with 28 and 34 percent, respectively, followed by water at 15 percent, oil with 14 percent, and gas pipelines with 8 percent. Air freight is slightly less than 1 percent of the total.

Table 1 Select Transportation Statistics for 1990 and 2000

Sector	Revenue ($ Millions in 2000 $)		Employment (Thousands)		Passenger-Miles (Millions)		Ton-Miles (Millions)	
	1990	2000	1990	2000	1990	2000	1990	2000
Air	93,085	130,299	589	732	472,567	708,926	16,514[a]	30,863[a]
Truck	156,037	223,197	1,247	1,406	—	—	854,000	1,203,000
Transit	19,675	24,243	262	348	41,143	47,666	—	—
Bus	10,999	13,237	1,649	2,136	121,398	160,919	—	—
Rail	36,374	36,213	240	194	6,057	5,498	1,033,969	1,465,960
Water	26,365	33,333	364	361	—	—	833,544[b]	645,799[b]
Oil pipeline	10,425	8,958	19	13	—	—	584,100	577,300
Gas pipeline	80,923	72,075	192	125	—	—	280,692[c]	350,889[c]
Total	433,881	541,555	4,562	5,315	641,165	923,009	3,602,829	4,273,811

Note: From Ref. 1. and Ref. 2 .
[a]Freight-related ton-miles only.
[b]Domestic only.
[c]Data found in Table 1-46b update of Ref. 1.

The importance of the sector is far greater than its 5 percent share of GDP. The transportation sector has gotten highly efficient at moving goods and people, so the costs are relatively small. The low costs have led to rapid expansion from 1990 to 2000, particularly rail and trucking for freight traffic (31% and 29%, respectively) and air for passenger traffic (46%). Revenue expanded more rapidly: 29 percent for air, 30 percent for truck, 19 percent for transit, 20 percent for water, and 17 percent for bus. Pipeline and rail revenue fell when viewed in constant 2000 $.

Efficiency is also measured by the revenue per passenger-mile or per ton-mile and the number of workers by passenger-mile or per ton-mile. Revenue per passenger-mile increased from 25 to 27 cents from 1990 to 2000, and air fell by the same amount from 20 to 18 cents. Interestingly, if you include government subsidies for transit, the "revenue" per passanger-mile was 48 cents in 1990 and increased to 51 cents in 2000. The bus sector's revenue per passanger-mile dropped from just over 9 cents to 8.2 cents from 1990 to 2000.

Revenue per ton-mile increased from 18.3 to 18.6 cents for truck, remained essentially flat for water at a cent, and fell from 3.5 to 2.5 cents for rail. Natural gas pipelines fell from 29 to 20 cents while oil pipelines dropped slightly from 1.8 to 1.6 cents per ton-mile. It should be noted that the water transport revenue shown in Table 1 includes revenue revenues generated from international freight and domestic and international passenger transport, and the ton-mile data are only freight related. Only domestic freight-related revenue was used in the calculated.

Employees per million passenger-miles increased only in the transit sector, going from 6.4 to 7.3. In contrast, employees per million ton-miles fell from 1.3 to 1.0 for air, 39.6 to 35.3 for rail, and remained essentially flat for bus varying from 13.6 to 13.3. Employees per million ton-miles for truck, rail, and oil and gas pipelines all dropped. Truck dropped from 1.5 to 1.2, rail from 0.23 to 0.13, oil pipelines from 0.03 to 0.02, and gas pipelines from 0.68 to 0.36. Employees per million ton-miles rose only for water transportation during this period from 0.4 to 0.6. Thus, the record is one of decreased productivity for passenger traffic and increased productivity for freight traffic.

3 ENERGY USE

The United States uses a great deal of energy, about 100 quadrillion Btu per year. Commercial transportation is an energy-intensive sector using about 7 percent of the total, while automobiles and light trucks for personal use contribute another 18 percent. Table 2 provides energy use by transportation mode in 2000. Trucks use 57 percent of total energy, followed by air with 32 percent, rail with 7 percent, and transit with 4 percent.[2] Surprisingly, trucking uses the most Btu per dollar of revenue, followed by air, rail, transit, and pipelines, in that order. Per passenger-mile, transit is less efficient than air. Rail is a factor of 10 more efficient than truck in Btu per ton-mile; pipelines are three times less efficient than rail.

Table 3 shows fuel use by transport mode. Cars and trucks use the lion's share of fuel, 163 billion gallons of gasoline or diesel. Air uses 16 billion gallons of jet fuel and aviation gasoline. Water transport uses 6 billion gallons of residual fuel oil, 2 billion gallons of distillate, and 1 billion gallons of gasoline. Rail uses 6 billion gallons of distillate and 350 million kilowatt-hours of electricity. Transit uses 5.5 billion kWh of electricity and almost 1 billion gallons of diesel and gasoline. Pipelines are the only major user of natural gas, consuming 640 billion cubic feet.[3]

Table 2 Transportation Energy Use for 2000

	Energy Use		Energy Efficiency	
Sector	(Trilion Btu)	(Btu/$)	(Btu/Passenger-Mile)	(Btu/Ton-Mile)
Air	2,374	18,220	531–822	
Truck	4,252	19,050	—	3,565
Transit	300	12,375	1,403	—
Rail (Freight)	516	15,131		334
Pipelines	911	11,241		981
Total	8,353	76,017		4,880

Note: From Ref. 3.

Table 3 Fuel Use by Sector

Sector	Fuel	1990	2000
Air	Jet fuel (million gallons)	12,323	14,845
	Aviation gasoline (million gallons)	353	333
	Jet fuel (million gallons)	663	972
Highway	Gasoline, diesel and other fuels (million gallons)	130,755	162,554
Transit	Electricity (million kWh)	4,837	5,510
	Gasoline, diesel and other fuels (million gallons)	685	889
Rail	Distillate/diesel fuel (million gallons)	3,197	3,776
	Electricity (million kWh)	330	350
Water	Residual fuel oil (million gallons)	6,326	6,410
	Distillate/diesel fuel oil (million gallons)	2,065	2,261
	Gasoline (million gallons)	1,300	1,124
Pipeline	Natural gas (million cubic feet)	659,816	642,210

Note: From Ref. 3.

4 POLLUTION EMISSIONS

Burning these huge quantities of fossil fuel generates millions of tons of air pollutants and billions of tons of carbon dioxide and other greenhouse gases. Extracting petroleum, transporting it, distilling it into products, and then transporting the products generate still more air pollution and greenhouse gases.

While transportation was the dominant source of carbon monoxide (CO), Oxides of nitrogen (NO_x), volatile organic compounds (VOC), and lead in 1970, eliminating lead from gasoline and installing catalytic converters on automobiles actually reduced the emissions of these pollutions by 2000, with the most spectacular decrease in lead emissions—from 173,000 tons to 560 tons. These declines testify to the success of major social efforts to clean the air by reducing emissions, especially for automobiles. Eliminating lead from gasoline was the key for reducing emissions of CO, NO_x, VOC, and lead because it eliminated the major source of lead emissions and allowed installation of the modern three-way catalyst that reduces CO, NO_x, and VOC by about 90 percent.

The amount of economic activity in the United States increased from \$3.8 trillion in 1970 to \$10 trillion in 2000 (in 2000 dollars). In the absence of air pollution control laws, emissions of each of these pollutants should have increased. The significant drop in all pollutants is a testimony to the will, enforcement, and ingenuity in finding ways to lower air pollutant emissions.

The improvements in air pollution emissions is in marked contrast to the increases in carbon dioxide emissions. Each mode expanded, using more fuel and emitting more CO_2. The energy efficiency of the U.S. economy increased from 1990 to 2000, going from 11,600 Btu/\$ of GDP to 10,100 Btu/\$ of GDP.[4] The transportation section increased its energy efficiency as well, going from 50,500 Btu/\$ of sector output to 49,100 Btu/\$ of sector output.[4] The transportation sector

Table 4 Transportation Direct and Life-Cycle Emission for 2000 for Selected Priority Pollutants

Sector	Direct (Tons)	Life Cycle (Tons)
CO	92,239	100,678
NO_x	12,560	13,738
SO_x	697	1,546
VOC	7,969	8,667
PM10	552	795

Note: From Ref. 4.

is five times more energy intensive than the U.S. economy as a whole, but both are learning to use energy more efficiently.

One indication of the energy intensity of transportation is that, while the sector uses almost 7 percent of total energy, it employs only about 2 percent of the total work force.

Shown in Tables 4, 5, and 6 are air pollution emissions from transportation. Table 4 estimates air pollution emissions for carbon monoxide (CO), oxides of nitrogen (NO_x), sulfur oxides (SO_x), volatile organic compounds (VOC) and suspended particulate matter less than 10 microns is diameter (PM_{10}) for the entire transportation sector using the Economic Input-Output Life-Cycle Analysis (EIOLCA) model.[5] This model brings together the input-output table of the United States for 1997 together with emissions data from EPA. Transportation is directly responsible for huge amounts of CO emissions, large amounts of NO_x and VOC emissions, and smaller amounts of SO_x and PM_{10} emissions. Life-cycle emissions for CO, NO_x, and VOC are about 9 percent higher than the direct emission, but SO_x and PM_{10} are dramatically increased: 120 percent for SO_x and 44 percent for PM_{10}. The air pollution emissions come mainly from the reliance of this sector on burning gasoline and distillates in internal-combustion engines. This link is illustrated in Table 5, albeit obliquely.

Table 5 shows a detailed breakdown of air pollution emissions by vehicle class, e.g., light- and heavy-duty gasoline or diesel engine vehicles. Unfortunately, there is no easy way to aggregate various categories of vehicles and allocate separate emissions to a specific transportation sector.[6] Aircraft are of course the dominant vehicle in air transportation, and it is likely that passenger aircraft are the dominant emitters. The data in Table 5 likely reflect this, but the others are not straightforward.

Table 6 shows estimates for air pollution emissions for each mode. The EPA estimates from Table 5 for air, railroad, and water are shown. They are supplemented with emissions estimates from the EIOLCA model.[5] The two sets of estimates are not identical since the EPA figures are for 1990 and 2000, while the EIOLCA estimates are for 1997. EPA sources do not provide estimates for the

Table 5 Priority Pollutant Emission from the Transportation Sector

Sector	CO		NO_x		SO_x		VOC		PM10	
	1990	2000	1990	2000	1990	2000	1990	2000	1990	2000
	(1,000 short tons)									
TRANSPORTATION TOTAL	**131,702**	**92,239**	**13,373**	**12,560**	**874**	**697**	**12,790**	**7,969**	**713**	**552**
HIGHWAY VEHICLES	**110,255**	**68,061**	**9,592**	**8,394**	**503**	**260**	**10,175**	**5,325**	**385**	**230**
Light-duty gas vehicles & motorcycles	67,237	36,398	4,262	2,312	111	103	6,268	2,903	56	51
Light-duty gas vehicles	66,972	36,229	4,240	2,297	111	102	6,217	2,877	56	51
Motorcycles	265	169	22	15	1	0	51	25	1	0
Light-duty gas trucks	32,228	27,041	1,504	1,436	52	70	2,720	1,929	31	31
Light-duty gas trucks 1	19,739	18,138	962	999	31	47	1,618	1,251	17	22
Light-duty gas trucks 2	12,489	8,903	542	437	21	23	1,102	678	14	10
Heavy-duty gas vehicles	8,921	3,422	567	453	16	14	710	256	17	10
Diesels	1,869	1,200	3,259	4,192	324	73	476	238	281	137
Heavy-duty diesel vehicles	1,806	1,185	3,194	4,178			441	230	266	135
Light-duty diesel trucks	25	7	23	6			17	4	5	1
Light-duty diesel vehicles	38	8	43	7			19	3	11	1
OFF-HIGHWAY (Tier 1–12)	**21,447**	**24,178**	**3,781**	**4,167**	**371**	**437**	**2,616**	**2,644**	**328**	**322**
Nonroad gasoline	19,356	21,647	120	192	9	11	2,322	2,344	58	70
Recreational	1,876	1,892	7	10			409	467	5	5
Construction	805	711	4	6			79	53	2	2
Industrial	1,215	847	18	14			63	29	1	0
Lawn & garden	10,118	11,499	42	86			910	811	18	21
Farm	313	365	3	4			15	14	0	0
Light commercial	3,245	4,232	14	35			201	171	2	2
Logging	52	78	0	0			8	12	0	1
Airport service	11	9	0	0			1	0	0	0
Railway maintenance	6	7	0	0			0	0	0	0
Recreational marine vessels	1,716	2,008	32	35			637	787	30	38
Nonroad diesel	875	932	1,454	1,600	131	198	196	202	199	179
Recreational	2	3	1	2			0	1	0	0
Construction	396	444	702	762			82	90	82	74
Industrial	70	64	136	133			18	16	16	13
Lawn & garden	15	26	24	45			4	8	3	5
Farm	328	325	478	530			77	70	83	72
Light commercial	38	50	48	72			10	14	8	10
Logging	18	9	39	22			3	2	5	2
Airport service	3	4	7	9			1	1	1	1
Railway maintenance	2	3	2	3			0	1	0	1
Recreational marine vessels	3	4	16	22			1	1	0	1
Aircraft	239	270	70	88	7	9	29	27	3	4
Marine vessels	132	133	1,003	1,008	167	163	32	32	43	43
Diesel	132	133	1,003	1,008			25	32	43	43
Residual oil	NA	NA	NA	NA			7	NA	NA	NA
Other	NA	NA	NA	NA			NA	NA	23	25
Railroads	94	99	945	1,001	56	56	36	39	1	1
Other	752	1,097	189	278	0	0	1	1	1	1
Liquified petroleum gas	641	969	162	246			0	0	0	0
Compressed natural gas	110	128	27	32			0	0		

Note: From Ref. 6.

Table 6 Emissions from Transportation Sectors

Sector	CO EPA 1990 (1,000 short tons)	CO EPA 2000	CO EIO 1997 Sector	CO EIO Life Cycle	NO_x EPA 1990 (1,000 short tons)	NO_x EPA 2000	NO_x EIO 1997 Sector	NO_x EIO Life Cycle
Air	250	279	331	1,046	70	88	103	209
Railroads	102	109	104	339	947	1,004	902	936
Water	132	133	158	605	1,003	1,008	1,217	1,242
Truck Transportation	—	—	26,777	27,602	—	—	1,930	2,125
Transit & Ground	—	—	118	196	—	—	854	867
Pipeline	—	—	499	761	—	—	26	126

Sector	SO_x EPA 1990 (1,000 short tons)	SO_x EPA 2000	SO_x EIO 1997 Sector	SO_x EIO Life Cycle	VOC EPA 1990 (1,000 short tons)	VOC EPA 2000	VOC EIO 1997 Sector	VOC EIO Life Cycle
Air	7	9	7	133	30	27	45	115
Railroads	56	56	48	73	36	40	42	62
Water	167	163	230	256	32	32	1,170	1,186
Truck Transportation	—	—	81	233	—	—	1,992	2,101
Transit & Ground	—	—	22	35	—	—	60	71
Pipeline	—	—	3	140	—	—	13	80

Sector	PM_{10} EPA 1990 (1,000 short tons)	PM_{10} EPA 2000	PM_{10} EIO 1997 Sector	PM_{10} EIO Life Cycle	CO_2 EIO 1997 Sector	CO_2 EIO Life Cycle
Air	3	4	6	26	161,310	203,815
Railroads	1	2	20	27	28,889	36,968
Water	43	43	113	118	47,857	36,396
Truck Transportation	—	—	47	93	373,497	430,080
Transit & Ground	—	—	30	33	7,931	12,536
Pipeline	—	—	0	15	124,732	162,358

Note: From Refs. 2 and 7.

EIOLCA sectors Truck Transportation, Transit & Ground, and Pipeline. For the modes where comparison is possible, the emissions data are reasonably comparable, given the accuracy of the emissions estimates and the way they are tabulated. The EIOLCA estimate for VOC emissions from water transport has an error that we were not able to reconcile within the time limits of this paper.

Table 6 shows the dominant role of trucks in emissions of CO, since emissions are 50 times higher than pipelines, the next highest mode. CO emissions indicate inefficient combustion. For NO_x emissions, trucks are again the leading source, but are followed closely by water, railroads, and transit. Emissions from air and pipelines are small. Truck transport is again responsible for the larges emissions of VOC. Water transport is the largest source of SO_x emissions, since a great deal of residual fuel oil is used, which has a high sulfur content. PM_{10} emissions are smaller than other categories, with water having the most emissions.[8]

Table 6 also shows CO_2 emissions for each sector. CO_2 emissions are roughly proportional to fuel use, since almost all modes rely on petroleum products. Air and truck transportation are the two largest CO_2-emitting sectors, releasing over 200 and 400 million tons of CO_2, respectively.

5 INJURIES AND DEATHS

Table 7 shows the fatalities and injuries for each sector for 1990 and 2000. The fatality data are more accurate, since there is no problem with defining the outcome, as there is with injuries. The injury data tend to follow the same patterns as the mortality data.

The fatality and injury rates for air and the two pipelines are subject to major statistical variation from year to year. For example, in many years, there are no fatalities for domestic scheduled airline operation. The mortality rate rose slightly for trucks, but fell slightly for transit, and fell significantly for rail and water. Somewhat surprisingly, rail has the most fatalities, due to collisions at grade crossings. Trucks are somewhat safer, despite the much greater number of trucks and truck-miles and the greater possibility of crashes, since they operate on highways with other vehicles. Transit has the third-highest number of fatalities, which is not surprising, given that buses and taxicabs operate in crowded urban settings.

Per passenger-mile, air is safer than transit, with 0.3 deaths per billion passenger-miles compared to 4 for transit. Assuming that aircraft average 100 passengers on a flight, that is 30 deaths per billion aircraft miles, or 1 death every 33 million aircraft miles. Since some of the air fatalities are due to freight operations, dividing all fatalities by passenger-miles will overstate the fatalities for passenger operation. Thus, air is 10 times safer than transit operations, including city buses and taxis. This safety is testimony to the vast care to make air transport safe.

Per ton-mile, all modes are safe, although water and oil pipelines are much safer than truck or rail. Trucks are responsible for 0.6 deaths per billion ton-miles. For an 80,000 pound truck, that would be 2.4 fatalities every million

Table 7 Fatalities and Injuries by Sector for 1990 and 2000

Sector	1990 Fatalities	1990 Injuries	2000 Fatalities	2000 Injuries
Air	96	76	168	48
Truck	705	41,822	754	30,832
Transit	679	87,247	585	74,466
Rail	1,300	24,143	937	10,424
Water	85	175	53	150
Oil pipeline	3	7	1	4
Gas pipeline	6	69	37	77
Total	2,874	153,539	2,535	116,001

By Ton-Miles (Values $\times\ 10^{-6}$)

Sector	1990 Fatalities/ Ton-Mile	1990 Injuries/ Ton-Mile	2000 Fatalities/ Ton-Mile	2000 Injuries/ Ton-Mile
Air	0.0092	0.0073	0.0106	0.0030
Truck	0.0008	0.0493	0.0006	0.0258
Transit	—	—	—	—
Rail	0.0012	0.0227	0.0006	0.0067
Water	0.0001	0.0002	0.0001	0.0002
Oil pipeline	0.0000	0.0000	0.0000	0.0000
Gas pipeline	—	—	—	—

By Passenger-Miles (Values $\times\ 10^{-6}$)

Sector	1990 Fatalities/ Passenger-Mile	1990 Injuries/ Passenger-Mile	2000 Fatalities/ Passenger-Mile	2000 Injuries/ Passenger-Mile
Air	0.0003	0.0002	0.0003	0.0001
Truck	—	—	—	—
Transit	0.0040	0.5175	0.0027	0.3483
Rail	0.2146	3.9860	0.1704	1.8960
Water	—	—	—	—
Oil pipeline	—	—	—	—
Gas pipeline	—	—	—	—

truck-miles. For a 10,000 ton freight train, that would be 6 deaths every 10,000 train-miles.

6 LIFE CYCLE VERSUS DIRECT EFFECTS

The previous tabulations focus on the direct effects of the transportation sector. However, a more relevant analysis would examine the whole life cycle, from extraction of raw materials and energy through use and ultimate disposal. In this section, we estimate these full life-cycle effects using the EIOLCA model developed at Carnegie Mellon University.[5]

Table 4 shows the direct and total life-cycle emissions of air pollutants for the whole transportation sector. The transportation sector is so energy intensive and has such high direct emissions, that the life-cycle emissions are only 9.1 percent higher for CO, 9.7 percent higher for NO_x, and 8.8 percent higher for VOC. SO_x and PM_{10} are the major exceptions, with life-cycle SO_x emissions being 121.8 percent higher for SO_x and 44.0 percent higher for PM_{10}.[5] Transportation fuels, with the exception of residual fuel oil, have little sulfur. However, half of electricity is generated by coal, so the indirect SO_x emissions are high.

7 TRANSPORTATION EXTERNALITIES

Murphy and Delucchi estimates the externalities associated with motor vehicle use.[9] It is not possible to estimate the externalities for the whole transportation sector in the same detail. Nonetheless, it is possible to translate the air pollution emissions, as well as injuries and deaths, into dollar costs to society.

Table 8 shows the direct and life-cycle implications for each mode separately, accounting for the air pollution emissions, CO_2 emissions, and fatalities and injuries.[10] The air pollution emissions are valued using current allowance prices, where available. They are valued at the cost of abatement in other cases. CO_2 is valued at the price that allowances were recently trading in the European Union. Fatalities are valued at \$5 million, the figure used by EPA in its “Cost of Clean Air” report.[11] The severity of injury is not specified; we assume that the reported injuries are serious and so value each at \$50,000. Also shown is the revenue for each mode and the proportion of mode revenue needed to account for the externalities. Total external costs are about a quarter of the sector revenue costs, with CO_2 external cost being the largest single value.

8 SUMMARY AND CONCLUSION

The transportation sector is energy intensive. When the modes were largely uncontrolled, prior to 1970, they emitted large quantities of air pollution. Eliminating lead from gasoline permitted the use of catalytic converters, leading to reductions of 90 percent or more in emissions of CO, NO_x, and VOC. The

Table 8 Transportation Emissions and External Costs

	Emissions		External Costs	
Pollutant	Sector (1,000 Short Tons)	Life Cycle (1,000 Short Tons)	Sector ($ Million)	Life Cycle ($ Million)
CO	92,239	139,144	47,964	52,353
NO_x	12,560	13,331	35,168	38,465
SO_x	697	1,365	1,394	3,092
VOC	7,969	9,591	12,750	13,866
CO_2	744,216	882,153	9,674	11,467
PM10	552	761	2,374	3,419
	Number			
Fatalities	2,535	—	12,675	—
Injuries	116,001	—	5,800	—
Total external costs ($ millions)			118,125	129,670
Total sector revenue ($ millions)			503,000	970,790
Ratio external costs/Revenue			0.23	0.13

Data from other tables
Note: From Ref. 10.

achievement of motor vehicles in reducing air pollution emissions has been immense, and the manufacturers are to be commended.

While there are some indications of greater energy efficiency, CO_2 emissions are high and growing. The energy intensity and sheer size of the sector leads to large externalities. The sector also shows that where regulation or other pressures have focused on a goal, such as reducing pollution emissions from cars and light trucks, major advances can be accomplished. The European Union (EU) is pressing manufacturers to build vehicles with lower CO_2 emissions per mile and more efficient jet aircraft. The preliminary indication is that major improvements are likely.

The transportation sector is to be commended for its essential contributions to our lives, from food and transport of goods to personal mobility. While consumers will continue to demand this level of performance, society will demand major reductions in environmental externalities, from air pollution emissions to CO_2 emissions. We feel confident that the transportation sector will rise to meet this challenge.

REFERENCES

1. Bureau of Transportation Statistics, Department of Transportation, *National Transportation Statistics, 2006*. U.S. Government Printing Office, Washington, D.C., February 2007.
2. U.S. Census Bureau, *The 2007 Statistical Abstract*, www.census.gov/compendia/stab/. Accessed on June 13, 2007.
3. S. C. Davis and S. W. Diegel, *Transportation Energy Data Book*, 22nd ed., Oak Ridge National Laboratory, Oak Ridge, 2002.
4. Authors' calculation from data in Refs. 1 and 3.
5. C. T. Hendrickson, L. B. Lave, H. S. Matthews, J. Bergerson, G. Cicas, A. Horvath, S. Joshi, H. L. MacLean, D. Matthews, and F. C. McMichael, *Environmental Life Cycle Assessment of Goods and Services: An Input-Output Approach*, Resources for the Future, 2006.
6. U.S. Environmental Protection Agency, *National Emissions Trends*, U.S. Government Printing Office, Washington, D.C., 2007.
7. Carnegie Mellon University Green Design Institute, "Economic Input-Output Life Cycle Assessment (EIOLCA) Model", http://www.eiolca.net/. Accessed on November 29, 2007.
8. Energy Information Agency, Department of Energy, 2006. *Annual Energy Review 2005*. DOE/EIA-0384(2005).
9. J. J. Murphy and M. A. Delucchi, "A Review of the Literature on the Social Cost of Motor-Vehicle Use in the United States," *Journal of Transportation and Statistics*, **1**(1) (January 1998): 15–42.
10. H. S. Matthews and L. B. Lave, "Applications of Environmental Valuation for Determining Externality Costs," *Environmental Science and Technology*, **34** (2000): 1390–1395.
11. U.S. Environmental Protection Agency, "Benefits and Costs of the Clean Air Act," www.epa.gov/air/sect812/design.html. Assessed June 13, 2007.