Global Warming on the Road

THE CLIMATE IMPACT OF AMERICA'S AUTOMOBILES

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Our mission
Environmental Defense is dedicated to protecting the environmental rights of all people, including the right to clean air, clean water, healthy food and flourishing ecosystems. Guided by science, we work to create practical solutions that win lasting political, economic and social support because they are nonpartisan, cost-effective and fair.

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Executive summary

For most Americans, the automobile is an essential part of daily life. It has shaped our culture and our landscape. The industries that build and serve cars form a key part of our economy. The automobile is not without its faults, but they often are concealed by the styling, performance and other features that make today's vehicles so desirable. Still, when a product is so widely used, its faults can add up to massive unwanted side effects.

Consider global warming. Motor vehicles play a major part in what scientists call the most serious environmental problem the world faces. The automobile's main contribution comes from the carbon dioxide (CO_2) emitted as the engine burns fuel.

The greenhouse gas pollution that causes global warming comes from numerous sources. Any single contribution may seem small in proportion to the world total, but collectively it becomes a problem of vast scale. To address a problem of such vast scale requires international agreements and national policies. But making good on such commitments will require changes in how we manage every activity that contributes to the problem. How much should we cut, and where? To answer this question, we need a clear picture of which sources contribute most to global warming.

The disproportionate impact of U.S. cars and light trucks

Automobiles—by which we mean personal motor vehicles, including light trucks such as pickups, SUVs and vans as well as sedans and wagons—emit roughly 10% of global CO_2 emissions from fossil fuels, which are the main form of greenhouse gas pollution. American automobiles have a disproportionate impact: U.S. cars are driven further each year and burn more fuel per mile than the international average. The United States has 5% of the world's population and 30% of the world's automobiles, but it contributes 45% of the world's automotive CO_2 emissions.

In 2004, U.S. cars and light trucks emitted 314 million metric tons of carbon-equivalent (MMTc). That equals the amount of carbon in a coal train 50,000 miles long—enough to stretch 17 times between New York and San Francisco. In fact, the amount of CO_2 emitted from oil used for transportation in the United States is similar to the amount from coal used to generate electricity.

America's 'rolling carbon'

This report details, for the first time, the global warming pollution emitted in the course of America's daily driving. It represents a complete picture of the nation's "rolling carbon," from the latest luxury SUV cruising through an upscale suburb to the oldest pickup truck bumping along a rural lane.

Many policy-related reports focus on emissions from new vehicles, since new vehicle sales are regularly reported in detail. Here, using national statistics on how long vehicles last and how far they are driven as they age, we examine the CO_2 emissions from all personal vehicles, both new and used. This analysis allows us to answer questions such as, "How much carbon is emitted by all the Ford-built cars now in use? From all the Hondas?" It also enables us to estimate the CO_2 emissions from all the sport-utility vehicles (SUVs) in use, from all the midsize cars, and so on—that is, according to vehicle class.

Table ES1 summarizes on-road carbon emissions by vehicle class in 2004.

TABLE ES1
Rolling stock carbon emissions by vehicle class, 2004

Vehicle class	Carbon emissions (MMTc)	Carbon emissions share
Small cars	77	25%
SUVs	67	21%
Pickups	60	19%
Midsize cars	54	17%
Vans	29	9%
Large cars	26	8%
Cars	157	50%
Light trucks	157	50%
Overall	**314**	**100%**

Perhaps surprisingly, small cars (compacts, subcompacts and two-seaters) were responsible for the most carbon emissions, amounting to 77 MMTc. Small cars once had been the dominant segment by sales; given the longevity of vehicles, many of them remain on the road today. Thus, despite their higher than average fuel economy, small cars still accounted for the largest share of rolling carbon emissions as of 2004.

This situation illustrates the relative durability of automobiles: In terms of usage, the U.S. light vehicle stock now has a "half-life" of roughly eight years; in other words, 50% of vehicles are replaced within that time. It takes 16 years for the fleet to be 90% replaced in terms of the carbon emitted during driving. In short, the choices made regarding new vehicles influence emissions for many years to come.

SUVs represent the second largest portion of rolling carbon. They soon will be the main source of automotive CO_2 emissions, having overtaken small cars in terms of market share in 2002. Their impact will be all the greater due to their lower than average fuel economy. As of 2004, all the SUVs on the road in the United States emitted 67 MMTc, an amount equivalent to the CO_2 spewed by 55 large coal-fired power plants. Next were pickup trucks, which collectively emitted 60 MMTc in 2004.

Car companies vs. electric companies: a comparison

Table ES2 gives the breakdown by car company, which shows that automakers' shares of rolling carbon follow historical market shares, led by GM. These results are highlighted in Figure ES1, which shows the quantity of carbon emitted by each automaker's products compared to the carbon emissions of major electric power companies. Car companies are on a par with—and some even higher than—electric utilities in terms of the carbon emissions associated with the use of their products.

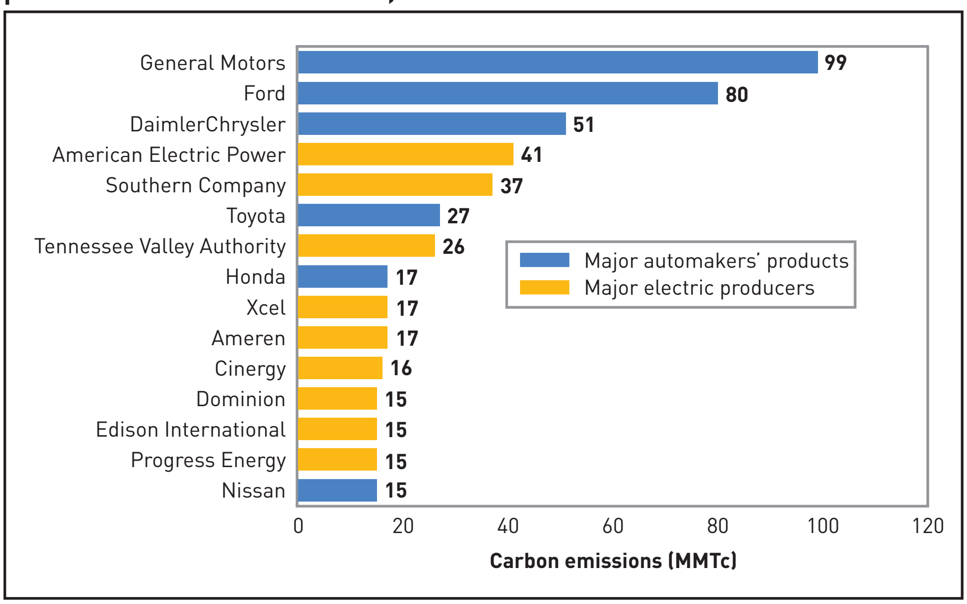
These estimates indicate that products made by each of the Big Three—GM, Ford and DaimlerChrysler—emitted more carbon in 2004 than the country's largest electric utility, American Electric Power (AEP). GM's products emitted 99 MMTc, and Ford's emitted 80 MMTc, nearly twice AEP's 41 MMTc. DaimlerChrysler's cars and light trucks in use emitted 51 MMTc. The total CO_2 emissions from Big Three automobiles in 2004 was comparable to the total from the top 11 electric companies. And the global warming pollution from vehicles made by Toyota (the fourth among automakers) edges out that from the Tennessee Valley Authority (the third among electric companies).

Electric utilities and automakers may seem like apples and oranges, but in fact they make a suitable comparison. In both cases, their carbon emissions include the impacts of long-lived products and equipment. The quantity of each sector's emissions also is determined by a number of actors, including end-users such as consumers and businesses. For example, AEP's CO_2 emis-

TABLE ES2
Rolling stock carbon emissions by automaker, 2004

Manufacturer	Carbon emissions (MMTc)	Carbon emissions share
GM	99	31%
Ford	80	25%
DaimlerChrysler	51	16%
Toyota	27	9%
Honda	17	6%
Nissan	15	5%
Volkswagen	5	2%
Hyundai	4	1%
Mitsubishi	4	1%
BMW	3	1%
Kia	2	1%
Subaru	3	1%
Others	4	1%
Big Three	230	73%
Overall	**314**	**100%**

FIGURE ES1
Carbon emissions of major automakers' products vs. major electric producers in the United States, 2004



Source: Table 1 and CERES et al. (2006).

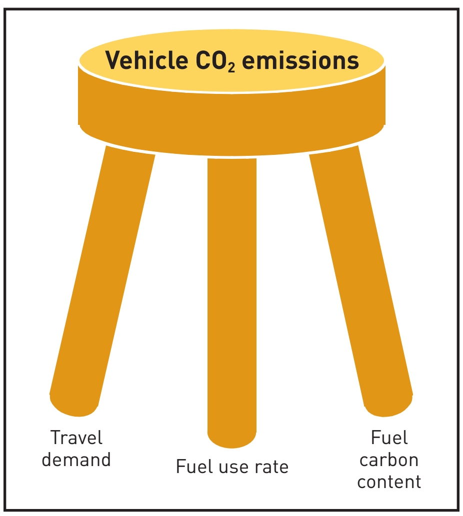
sions are the result of the electricity consumed in homes, offices, schools and other power-using facilities in their service area. Decisions by state and local officials are also important in both cases, through regulation of electric utility services and rates on one hand, and through transportation infrastructure and land use planning on the other. Moreover, greenhouse gas pollution from both sectors is influenced by the carbon intensity of their fuel supply. While each utility has its own mix of fuels, overall utility emissions reflect the fact that 54% of U.S. electricity comes from coal. Automobile fuel essentially all comes from oil.

The three-legged stool propping up emissions

Because automotive CO_2 emissions are influenced by many different decision makers, finding opportunities to cut carbon entails looking at the factors behind emissions. Figure ES2 illustrates the three main factors propping up rolling carbon:

- **Travel demand,** or the amount of driving, which is commonly measured as annual vehicle miles of travel (VMT). Total U.S. car and light truck VMT in 2004 amounted to 2.6 trillion miles.
- **Fuel use rate,** or the amount of fuel consumed per mile, which is the inverse of fuel economy. The fuel economy of the U.S. automobile stock averaged 19.6 mpg in 2004, implying an average fuel use rate of 51 gallons per 1,000 miles of driving.
- **Fuel carbon content,** or the amount of greenhouse gases emitted per gallon of fuel consumed. Counting only the CO_2 directly released when fuel is burned, this factor amounts to 5.3 pounds of carbon per gallon of gasoline.

FIGURE ES2
Three main factors behind rolling carbon



These three factors combined result in the 314 MMTc emitted by U.S. automobiles in 2004.

Among these factors, only decreases in fuel use rate (achieved by increasing fuel economy) have served to partially limit CO_2 emissions. Fuel carbon content has not significantly changed, reflecting the tenacity of oil as a useful resource and the barriers facing alternative fuels. And many forces drive travel demand, all of them serving to push auto sector CO_2 emissions upward.

Managing automotive rolling carbon

Ultimately, cutting auto sector CO_2 emissions will require attention to all three legs of the stool. Thus, policy discussions regarding transportation and climate are typically framed around the question of how to change travel demand, fuel economy or fuel type. A key challenge, however, is that each factor is the product of decisions made by many actors. In addition to consumers, automakers and others involved in the auto market, total auto sector CO_2 emissions are influenced by the energy industry as well as by the many interests and levels of government that shape land use, infrastructure and other parts of the transportation system.

The magnitude of the automotive global warming problem and the complexities of the associated decision making suggest a need to recast the question. Instead of asking "What policies are required to address the *factors* that prop up automobile carbon emissions?" decision makers can ask "What policies can motivate each *actor* to address the aspects of emissions that they can influence?" Such a view shifts the focus from technical factors and how they are determined to individual actors and the parts of the problem they each can control.

For some major actors, such as automakers, how much they can address emissions is limited by other players. The ability to increase fuel economy by redesigning vehicles depends in part on the extent to which consumers make fuel economy a priority. Nevertheless, it is implausible that automakers (or other actors) have no ability to lower carbon emissions. Similarly, while individual consumers cannot themselves redesign cars (or develop new fuels or reshape land use), their scope of influence is not zero. Better information on emissions, new evaluation tools and education are needed to enable all actors to understand how their decisions impact emissions.

This report seeks to aid that process. By underscoring the magnitude of automotive CO_2 emissions, it highlights the need to break the problem down into manageable pieces. Consideration can then be given to opportunities to reduce carbon by tackling each piece of the larger problem. Such a *carbon management* paradigm would enable each actor to address the emissions each influences, complementing existing policy strategies defined around the technical factors that characterize total emissions. A city government, for example, can change the emissions associated with its transportation operations. It might do this by carrying out its functions with less driving, increasing the efficiency of its vehicles or using low-carbon fuels.

Exactly how to define a set of carbon management policies appropriate for the auto sector is a subject for future research as well as an important topic for discussion by everyone who holds a stake in the car-climate problem.

Introduction

America's cars are one of the world's largest sources of global warming pollution. Our personal vehicles—from the Mini Cooper to the Hummer and everything in between—emitted 314 million metric tons of carbon-equivalent (MMTc) annually as of 2004.[1] That equals the amount of carbon in a coal train 50,000 miles long, enough to stretch 17 times between New York and San Francisco.[2] In the United States, in fact, the amount of global warming pollution from oil used for transportation is similar to that from coal used for electric power generation.[3]

Such comparisons can help Americans understand the extent of our carbon problem, and they also help us think about how to solve it. Emissions from power plants depend on decisions by power companies, but also on decisions made by businesses and consumers who choose and use electrical equipment and appliances. Similarly, automobile emissions depend not only on automakers and fuel suppliers, but also on decisions by businesses and consumers who choose vehicles, and by local, state and federal officials who oversee America's transportation system and land use. Whether it is an issue of primary energy resources (fossil or otherwise), how the fuels are converted and distributed to consumers, or how efficiently the fuels are used through choices of technology and infrastructure, the interlocking nature and sheer magnitude of carbon emissions implies a shared task.

This report provides a detailed snapshot of carbon emissions from the "rolling stock" of all U.S. cars and light trucks on the road in 2004. We report results both by automaker and market segment. The statistics compiled here enable us to answer questions such as "What portion of CO_2 emissions is associated with pickup trucks?" or "What portion of CO_2 emissions is represented by all Toyota vehicles on U.S. roads?" The results also underscore the scope of the car-carbon problem and show how long it takes for changes in the characteristics of new car sales to influence the overall carbon emissions from the auto sector.

The approach taken here is similar to that of our previous reports[4] on automotive carbon burdens, referring to the annual CO_2 emissions associated with a given population of vehicles. However, while our *Automakers' Corporate Carbon Burdens* reports calculated CO_2 emissions as annual averages over the expected lifetime of a series of new model year vehicles, this report addresses the emissions from all vehicles (new and used) on the road in a given year. This particular analysis has never been done before. We present the results for 2004, the most recent year for which sufficient data are available.[5] The results depend not only on vehicle characteristics (such as fuel economy) but also on the extent of driving. Thus, these "rolling carbon" estimates reflect both the number of vehicles in use and how many miles they are driven each year. The carbon emissions from model year 2004 new auto sales represent 10% of the emissions from all automobiles on the road.

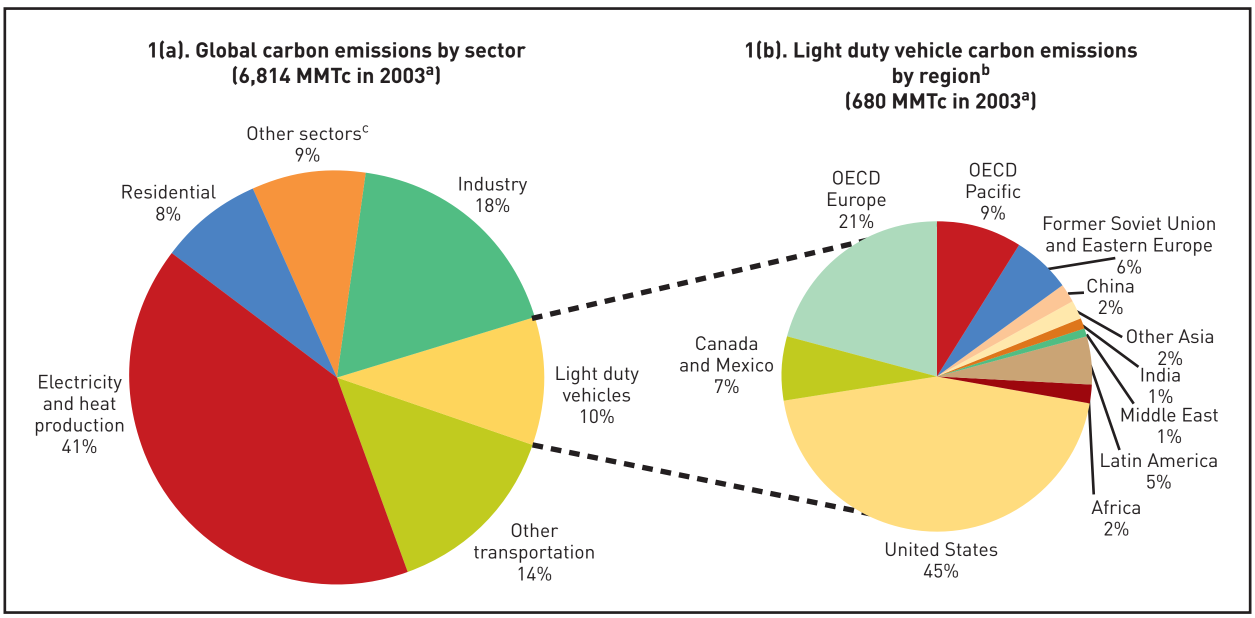
As the statistics assembled in this report show, the carbon emissions from all General Motors' vehicles on the road as of 2004 were more than double those from America's largest electric generating company, American Electric Power (AEP). In fact, the CO_2 emissions of the Big Three—GM, Ford, DaimlerChrysler—each exceeded those of AEP, and the emissions associated with most major automakers are comparable to or larger than those from the largest electric utilities in the country.

Perhaps even more surprising, the small car market segment (including compacts, subcompacts and two-seat sports cars) produced the most global warming pollution in 2004, simply because so many of them remain on the road. The small-car carbon tally reflects the longevity of vehicles, underscoring how decisions about the CO_2 emissions rate of new vehicles will affect the amount of global warming pollution for years to come. SUVs had the second largest share of CO_2 emissions. While their sales grew rapidly over the past 15 years, SUVs only overtook small cars in terms of new car market share in 2002. SUVs soon will become the dominant source of global warming pollution on America's roads, and their impact will be magnified because of their lower than average fuel economy.

Figure 1 places these estimates in a global context. Figure 1(a) breaks down global fossil fuel CO_2 emissions by major energy end-use in 2003. Worldwide, automobiles (cars and other light-duty vehicles) emitted 680 MMTc in 2003, about 10% of global CO_2 emissions from fossil fuels.[6] Oil, coal, natural gas and related fossil resources account for 84% of all human-caused CO_2 emissions (including other major sources such as deforestation). CO_2 is the dominant greenhouse gas (GHG, the term for any form of air pollution that contributes to global warming). It accounts for 72% of all human-caused GHG emissions. Thus, the light duty vehicle slice in Figure 1(a) represents an estimated 6% of all global warming pollution.[7]

Figure 1(b) breaks down global light vehicle CO_2 emissions by country or

FIGURE 1
Global fossil carbon emissions by economic sector



These estimates include only CO_2 emissions from fossil fuel use, and so exclude emissions from biofuel use or deforestation.

[a] Global emissions by sector are estimates for 2003 from IEA (2005). Global light-duty vehicle CO_2 emissions for 2003 are projections from WBCSD (2004).
[b] Light duty vehicle emission shares by region are estimates for 2000 from WBCSD (2004).
[c] Other sectors include commercial, public services, agriculture and energy industries other than electricity and heat production.

major region as of 2000. U.S. cars and light trucks—the subject of this report—are 45% of this total. The 202 million automobiles on America's roads in 2000 represent 30% of the estimated 683 million automobiles (light duty vehicles) in use worldwide that year.[8] The U.S. share of automotive CO_2 emissions is disproportionately high because our vehicles are driven more than those in the rest of the world; the 11,000 miles per year average for U.S. automobiles is about 29% greater than the global average of 8,500 miles per year.[9] U.S. automobiles also consume more fuel, emitting about 15% more CO_2 per mile than the average light duty vehicle globally.[10]

Methodology and assumptions

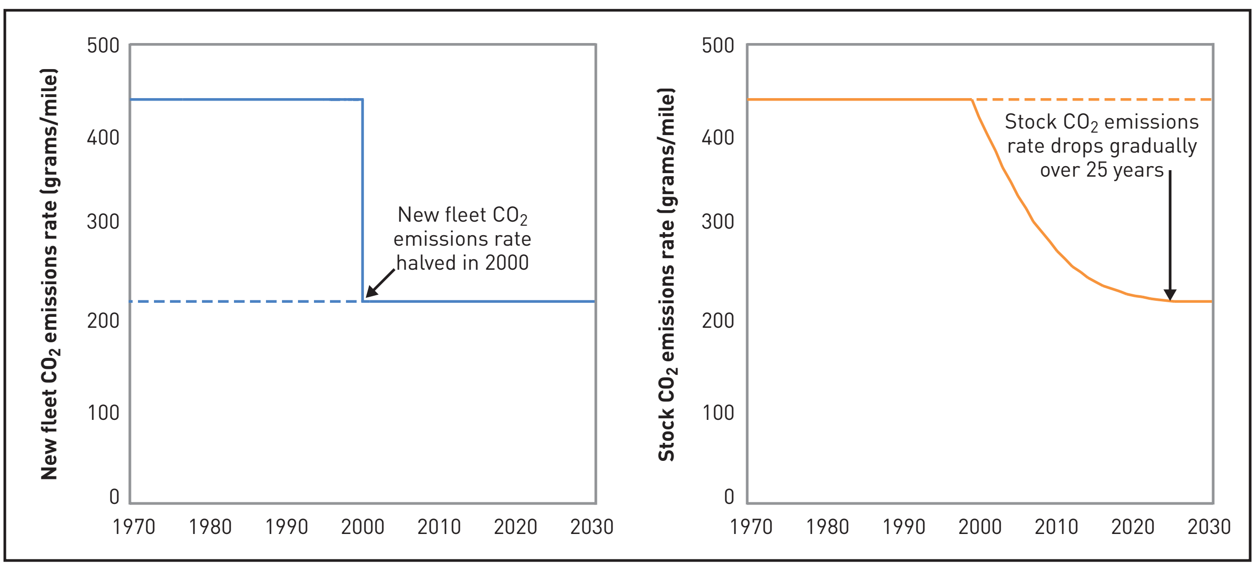
Characterizing rolling stock CO_2 emissions involves data on new vehicle sales plus statistics on how long vehicles last and how much they are driven as they age. To perform this analysis, we use what is termed a stock model: a computer-based accounting framework that calculates fuel consumption and CO_2 emissions for various groupings of vehicles. Given the sales volumes and fuel economy of a group of new vehicles in a given year and previous years, the model computes the CO_2 emissions rate of all such vehicles remaining on the road in the given year.

Figure 2 illustrates how a stock model works, showing what would happen if the CO_2 emissions rate of new cars suddenly were cut in half as of model year 2000. The left graph shows the CO_2 emissions rate of the new fleet; the right graph shows the resulting impact on the rolling stock emissions rate. In this simplified example, we assume an initially constant new fleet average CO_2 emissions rate of 440 grams per mile (g/mi) prior to 2000, corresponding to an average on-road fuel economy of 20 mpg (similar to the actual on-road average in recent years). If the CO_2 emissions rate of new vehicles were halved, down to 220 g/mi (corresponding to a doubling of on-road fuel economy to 40 mpg) in 2000, the effect would not be fully reflected in the rolling stock until 2025. The gradual change in the stock average CO_2 emissions rate reflects the slow turnover of vehicles; lower-emitting new vehicles gradually replace older vehicles as they are driven less and then retired. However, progress is more rapid at first; 90% of the lower CO_2 emissions rate is achieved within 16 years, even though it takes approximately another decade for the oldest vehicles to be completely replaced.

For our stock model, new vehicle characteristics are obtained from federal sales and fuel economy data, covering cars and light trucks of up to 8,500 pounds gross vehicle weight (GVW). The stock turnover parameters, including

FIGURE 2

How the rolling stock responds to a cut in the new fleet CO_2 emissions rate



age-dependent vehicle survival probabilities and usage rates, are also based on government statistics. We calibrated our fuel use (and therefore CO_2 emissions) calculation to the most recently available data on total light duty vehicle fuel use, ensuring that our total rolling carbon estimate matches national statistics on the auto sector's share of U.S. CO_2 emissions. We performed sensitivity analyses to examine the effects of different vehicle survival and usage parameters, confirming that our estimates of manufacturer and vehicle segment shares are insensitive to changes in such parameters.

We report the CO_2 emissions (given on a carbon-mass equivalent basis) released directly from fuel combustion by the car—in other words, only the CO_2 coming from the tailpipe. However, the tailpipe is not the only source of greenhouse gases associated with each gallon of motor fuel consumed. Additional CO_2 and other greenhouse gases are released when crude oil is extracted and shipped, when it is refined into gasoline or diesel fuel, and when these motor fuels are distributed through pipelines, barges and tanker trucks, even before they go into a vehicle's fuel tank. These *upstream* emissions add about 31% to the global warming impact of each gallon of gasoline burned in the United States and about 23% to each gallon of diesel fuel.[11] The CO_2 directly released when burning gasoline amounts to 19.4 pounds per gallon.[12] Counting the roughly 6 pounds of CO_2 and other greenhouse gases emitted upstream would bring the total, *full fuel cycle* emissions to 25.3 pounds per gallon.[13]

While developing our vehicle stock model, we reviewed the models used by several government agencies and research institutes, including the Department of Energy's VISION and NEMS (Energy Information Administration) models, the Stockholm Environment Institute's LEAP model and EPA's MOVES model. VISION, LEAP and NEMS use approaches similar to the one we adopted, estimating stock carbon emissions based on vehicle sales, fuel economy and stock turnover rate. They are more complex, however, in that they are designed to calculate future stock changes that reflect numerous hypothetical alternatives and couple the calculations to a broader energy modeling framework, neither of which are needed for our purposes. EPA's MOVES model combines vehicle-specific, second-by-second emissions calculations with travel activity data to project stock fuel consumption, allowing users to generate results for smaller geographic areas (e.g., at the county level) and in smaller temporal units (e.g., by time of day). Although we did not run these other models, we confirmed the consistency of our stock modeling results by comparing them to published results from NEMS and MOVES. Appendix A provides further detail on our stock model and the assumptions behind it.

Carbon emissions from automobiles on the road

Our stock model tallies enable us to break down, by automaker and vehicle class, the 314 MMTc emitted by all of the passenger cars and light trucks up to 8,500 lbs gross vehicle weight (GVW) on U.S. roads in 2004.

Rolling stock impacts of major automakers

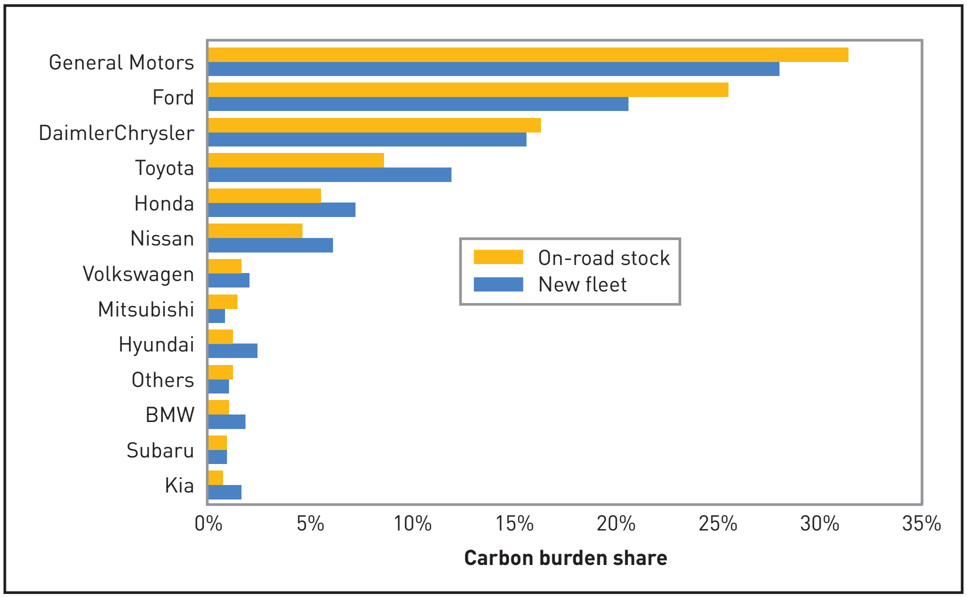
Table 1 lists our rolling stock results by automaker, including estimates of the number of vehicles in service, their average on-road fuel economy, average CO_2 emissions rate, and contribution to overall carbon emissions.[14] These values for the 2004 on-road stock can be compared to those for model year 2004 new sales to illustrate the trends as older vehicles are replaced by newer ones. For example, the overall stock on-road fuel economy of 19.6 mpg is greater than the 19.3 mpg overall average for new (model year 2004) vehicles.[15] In other words, the average older vehicle on the road actually burns less fuel and emits less carbon than the average new vehicle. This situation reflects the fact that new fleet fuel economy has been falling since 1988 due to the market shift from cars to light trucks. A comparison of rolling stock vs. new fleet carbon burden shares by automaker is given in Figure 3. It shows that the distribution of CO_2 emissions has been shifting away from the Big Three toward other firms who are gaining market share.

Vehicles built by the "Big Six"—General Motors (GM), Ford, DaimlerChrysler, Toyota, Honda and Nissan—made up an estimated 92% of the on-road light vehicle stock as of 2004. With their historically leading market shares, the Big Three (GM, Ford and DaimlerChrysler) alone

TABLE 1
Light vehicle stock, fuel consumption, and carbon emissions by automaker, 2004

	ROLLING STOCK AS OF 2004 (ALL VEHICLES NEW AND USED)						MY2004 (NEW FLEET ONLY)		
Manufacturer	Vehicle population (millions)	On-road fuel economy (mpg)	Fuel consumption (Mbd)	Carbon emissions (MMTc)	Vehicle population share	Carbon emissions share	On-road fuel economy (mpg)	Market share	Carbon burden share
GM	64.4	19.2	2.68	98.6	31.6%	31.4%	18.9	27.5%	28.0%
Ford	49.8	18.6	2.17	80.0	24.4%	25.5%	17.4	18.6%	20.6%
DaimlerChrysler	30.4	18.0	1.39	51.3	14.9%	16.3%	17.8	14.4%	15.6%
Toyota	18.6	21.6	0.74	27.1	9.1%	8.6%	21.3	13.2%	11.9%
Honda	13.3	24.2	0.47	17.3	6.5%	5.5%	23.2	8.7%	7.2%
Nissan	10.0	20.8	0.40	14.6	4.9%	4.6%	19.3	6.1%	6.1%
Volkswagen	3.7	22.7	0.14	5.1	1.8%	1.6%	21.6	2.3%	2.0%
Hyundai	2.8	23.8	0.10	3.8	1.4%	1.2%	22.0	2.7%	2.4%
Mitsubishi	3.0	21.8	0.12	4.3	1.5%	1.4%	22.4	0.9%	0.8%
BMW	2.0	19.7	0.09	3.3	1.0%	1.0%	20.0	1.9%	1.8%
Kia	1.3	21.0	0.06	2.2	0.6%	0.7%	20.0	1.7%	1.6%
Subaru	2.0	22.4	0.07	2.7	1.0%	0.9%	21.6	1.0%	0.9%
Others	2.5	19.1	0.10	3.8	1.2%	1.2%	19.0	0.9%	1.0%
Big Three	144.6	18.7	6.24	229.9	71.0%	73.2%	18.1	60.5%	64.2%
Overall	**203.7**	**19.6**	**8.53**	**314.2**	**100.0%**	**100.0%**	**19.3**	**100.0%**	**100.0%**

FIGURE 3
Stock vs. new fleet carbon burden shares by automaker, 2004



accounted for 71% of the stock, compared to their 60% share of the 2004 new vehicle market. Automakers' shares of rolling stock carbon emissions closely track their respective shares of the on-road vehicle population, with differences due to different average fuel economy levels and different mixes of older and newer vehicles on the road.

GM, which for many years has been the biggest automaker both in the United States and globally, had an estimated stock share of 31.6%, with 64 million light vehicles in 2004. The average fuel economy of all GM cars and light trucks on the road was 19.2 mpg, slightly lower than the overall average of 19.6 mpg.[16] As seen in Table 1, however, GM's estimated share of overall rolling CO_2 emissions, 31.4%, is slightly lower than its share of the vehicle population.[17] Thus, GM's rolling carbon amounted to 99 MMTc in 2004. This estimate compares well with the 93 MMTc estimate for 1999 based on information that GM supplied for the U.S. voluntary GHG reporting initiative (EIA 2001).[18]

Ford has the second largest share of carbon emissions. Its vehicles comprise 24.4% of the rolling stock and 25.5% of the stock carbon burden, amounting to 80 MMTc in 2004. In Ford's case, the shift to SUVs during the 1990s pulled down their overall average fuel economy more than GM's. Ford's own reporting of CO_2 emissions from its vehicles is given on a global, rather than U.S. basis, and Ford did not provide an estimate in its report to DOE's Voluntary Reporting of GHG Program, so direct comparison is difficult. In its Corporate Citizenship Report 2003–04, Ford estimated that all the greenhouse gases (CO_2 and other GHGs, including refrigerants) emitted by Ford vehicles on the road worldwide, including light and heavy duty vehicles, amounted to 109 MMTc in 2000.[19]

DaimlerChrysler follows in third place, accounting for 14.9% of the rolling stock and for 16.3% of stock carbon burden. That amounts to 51 MMTc, a level greater than that from any U.S. electric company as of 2004. To our knowledge, neither DaimlerChrysler nor other automakers (besides GM and Ford) have publicly reported estimates of GHG emissions from their vehicles in use. Vehicles of the Big Three taken together accounted for nearly three quarters (73%) of U.S. light vehicle carbon emissions in 2004.

Toyota, Honda and Nissan have the fourth, fifth and sixth largest shares of the stock respectively. Since their fuel economy levels are higher than average, these three firms have rolling stock carbon shares (8.6%, 5.5% and 4.6% respectively) that are lower than their shares of the on-road vehicle population. Other players in the U.S. market, including Volkswagen, Mitsubishi, Hyundai, BMW and Subaru, each accounted for about 1%–2% stock share. Kia, though it still has a small market share, is an example of another company where mix differences lead to a stock carbon share slightly greater than the population share of their vehicles (see Table 1), even though their fleet has been more fuel efficient than average.

Another interesting note: Even though the market share of the Big Three has been generally declining since the mid 1970s, and their combined market share had dipped to 60% by model year 2004, the Big Three still accounted for more than 70% of the vehicle stock. This lag reflects the lifetime usage and slow turnover of cars and light trucks, and also implies a similar persistence of rolling carbon impacts. According to Davis and Diegel (2004), the expected median lifetime for a 1990 model year (MY) car is 16.9 years, while that for a MY1990 light truck is 15.5 years,[20] and lifetimes have been continuing to lengthen. It should be noted, however, that light vehicle lifetimes are still shorter than those of many other energy-consuming items; freight trucks and aircraft last longer than cars, and buildings last much longer (although appliances and equipment may not).

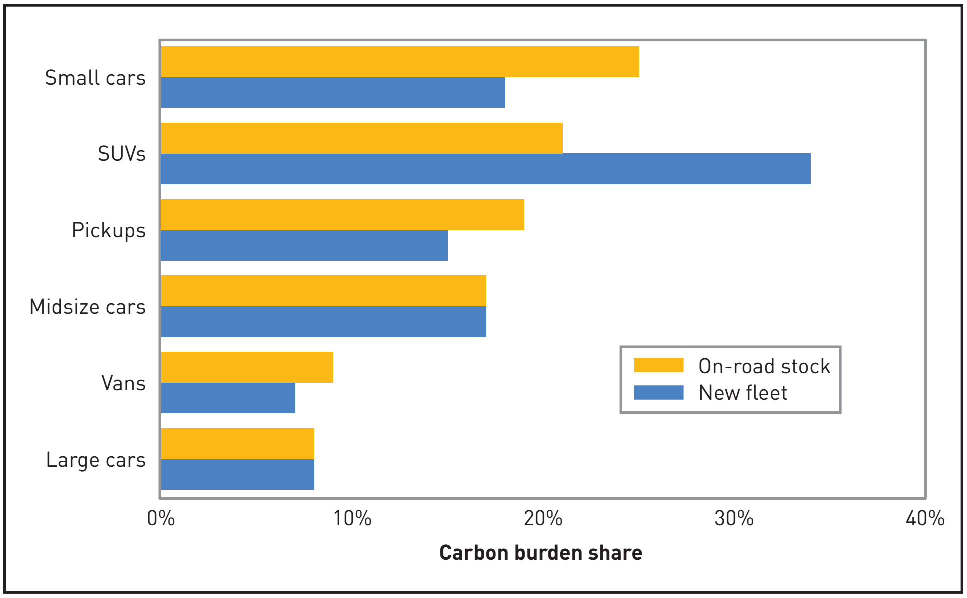
Rolling stock carbon burdens by market segment

Another way to examine carbon emissions is by major market segment (vehicle class): small cars, midsize cars, large cars, pickups, vans and SUVs.[21] Table 2 shows the stock share, carbon emissions and average fuel efficiency of these six vehicle segments. This

TABLE 2
Light vehicle stock, fuel consumption, and carbon emissions by vehicle class, 2004

	ROLLING STOCK AS OF 2004 (ALL VEHICLES NEW AND USED)						MY2004 (NEW FLEET ONLY)		
Vehicle class	Vehicle population (millions)	On-road fuel economy (mpg)	Fuel consumption (Mbd)	Carbon emissions (MMTc)	Vehicle population share	Carbon emissions share	On-road fuel economy (mpg)	Market share	Carbon burden share
Small cars	65.1	24.3	2.10	77.2	32.0%	25%	24.6	23%	18%
Midsize cars	38.5	21.4	1.46	53.7	18.9%	17%	23.2	17%	17%
Large cars	17.6	19.7	0.72	26.5	8.6%	8%	20.8	7%	8%
Pickups	32.2	16.3	1.63	59.9	15.8%	19%	15.6	16%	15%
Vans	17.3	17.9	0.80	29.5	8.5%	9%	19.1	5%	7%
SUVs	33.1	16.3	1.83	67.5	16.2%	21%	16.9	31%	34%
Cars	121.2	22.6	4.27	157.3	59.5%	50%	23.4	47%	43%
Light trucks	82.5	16.6	4.26	156.9	40.5%	50%	16.7	53%	57%
Overall	**203.7**	**19.6**	**8.53**	**314.2**	**100.0%**	**100%**	**19.3**	**100%**	**100%**

FIGURE 4
Stock vs. new fleet carbon burden shares by vehicle class, 2004



breakdown of carbon emissions share by vehicle class is also depicted in Figure 4.

Despite falling sales since 1987, small cars remained the largest segment of the on-road stock. The 65 million small cars (including small wagons) in use accounted for 32% of the total U.S. light duty vehicle stock in 2004, in contrast to their 23% share of new vehicle sales. Small cars still accounted for the largest share of rolling stock carbon emissions, emitting 77 MMTc in 2004, or about one-fourth of total light vehicle carbon emissions. The segment's 25% carbon share is substantially less than its 32% stock share because of its higher than average fuel economy. U.S. small cars averaged 24.3 mpg on-road in 2004, 24% better than the overall average, for an average emissions rate of 4.3 tons CO_2-equivalent per year.[22]

Midsize cars were the second largest segment of vehicle population, comprising 19% of the 2004 light vehicle stock. Averaging 21.4 mpg on the road, midsize cars accounted for 54 MMTc, or 17% of rolling stock carbon emissions, putting them in fourth place in terms of carbon share.

SUVs and pickups comprised the third and fourth largest segments, with 16.2% and 15.8% of the in-use vehicle population respectively. However, SUVs and pickups were in second and third place, respectively, in terms of carbon emissions in 2004. Each of these two segments contributed about one-fifth of total rolling stock emissions. SUV carbon emissions in 2004 amounted to 67 MMTc and pickup trucks emitted 60 MMTc. The disproportionate share of SUV and pickup emissions results from their below-par fuel economy, averaging 16.3 mpg for both segments. This fuel economy level is 17% lower than the stock average and corresponds to an average emissions rate of about 6.5 tons of CO_2-equivalent per year. The 67 MMTc emitted by all the SUVs on the road in 2004 is comparable to the carbon emissions from 55 large coal-fired power plants.[23]

The remaining segments, vans (mainly minivans) and large cars, accounted for smaller portions of the stock and contributed 9% and 8% of 2004 stock carbon emissions respectively. Overall, the 2004 vehicle stock composition was 59% cars and 41% light trucks. But the rolling carbon shares were roughly 50% each for cars and light trucks, reflecting the higher CO_2 emissions rates of trucks compared to cars.

Tables 3 and 4 cross-tabulate stock share and carbon share, respectively, by segment and automaker. Groups of vehicles that each contribute to more than 5% of stock carbon emissions include four segments of General Motor's products (small cars, midsize cars, pickups, SUVs) and two segments of Ford's products (pickups and SUVs). GM's and Ford's pickups are the two groups with the largest emissions overall, accounting for 6.8% and 6.6% of carbon share, respectively. Since our data exclude Class 2b trucks (8,501–10,000 lb GVW), which are mostly three-

TABLE 3
Vehicle population cross-tabulation by automaker and vehicle class, 2004

Manufacturer	Small cars	Midsize cars	Large cars	Pickups	Vans	SUVs	Overall
GM	8.2%	6.9%	4.4%	5.6%	2.1%	4.4%	31.6%
Ford	6.3%	4.0%	2.7%	5.6%	2.1%	3.8%	24.4%
DaimlerChrysler	2.9%	2.0%	1.2%	2.2%	3.2%	3.5%	14.9%
Toyota	3.2%	2.2%	0.4%	1.5%	0.4%	1.5%	9.1%
Honda	3.9%	1.5%			0.4%	0.8%	6.5%
Nissan	2.1%	1.1%		0.8%	0.2%	0.7%	4.9%
Volkswagen	1.4%	0.4%	<0.1%	<0.1%	<0.1%	<0.1%	1.8%
Hyundai	0.9%	0.3%				0.2%	1.4%
Mitsubishi	0.9%	0.3%		0.1%	<0.1%	0.2%	1.5%
BMW	0.8%	0.1%	<0.1%			0.1%	1.0%
Kia	0.3%	0.1%	<0.1%		0.1%	0.2%	0.6%
Subaru	0.7%	0.2%		<0.1%		0.1%	1.0%
Others	0.4%	<0.1%	<0.1%	0.1%	<0.1%	0.7%	1.2%
Overall	**32.0%**	**18.9%**	**8.6%**	**15.8%**	**8.5%**	**16.2%**	**100.0%**

TABLE 4
Rolling carbon share cross-tabulation by automaker and vehicle class, 2004

Manufacturer	Small cars	Midsize cars	Large cars	Pickups	Vans	SUVs	Overall
GM	6.3%	6.0%	4.0%	6.8%	2.4%	5.9%	31.4%
Ford	4.9%	3.5%	2.7%	6.6%	2.4%	5.3%	25.5%
DaimlerChrysler	2.3%	1.6%	1.2%	3.2%	3.3%	4.7%	16.3%
Toyota	2.2%	2.1%	0.4%	1.6%	0.5%	1.9%	8.6%
Honda	2.7%	1.5%			0.4%	0.9%	5.5%
Nissan	1.6%	1.1%		0.8%	0.2%	1.0%	4.6%
Volkswagen	1.2%	0.4%	<0.1%	<0.1%	<0.1%	<0.1%	1.6%
Hyundai	0.7%	0.3%				0.2%	1.2%
Mitsubishi	0.7%	0.3%		<0.1%	<0.1%	0.3%	1.4%
BMW	0.8%	0.1%	0.1%			0.1%	1.0%
Kia	0.3%	0.1%	<0.1%		0.1%	0.2%	0.7%
Subaru	0.6%	0.2%		<0.1%		0.1%	0.9%
Others	0.3%	<0.1%	<0.1%	0.1%	<0.1%	0.8%	1.2%
Overall	**24.6%**	**17.1%**	**8.4%**	**19.1%**	**9.4%**	**21.5%**	**100.0%**

quarter- and one-ton pickups, the actual carbon emissions share of pickups overall is greater still.[24]

Comparing automobile and electric sector carbon emissions

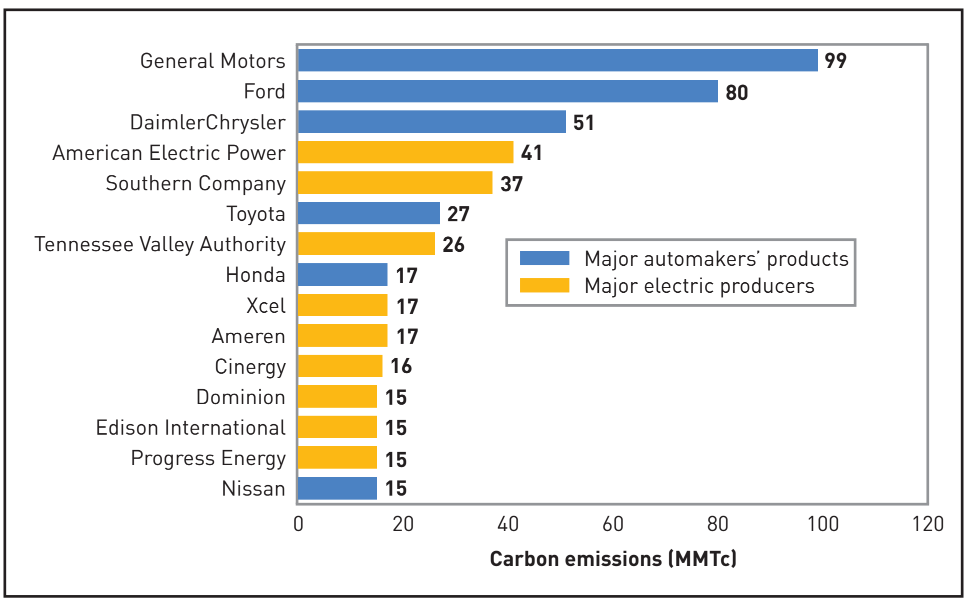
Accounting for roughly 20% of U.S. energy-related CO_2 emissions, cars and light trucks are a key source of the nation's global warming emissions. Viewed in a corporate impact context, GM, Ford and DaimlerChrysler vehicles are the first, second and third largest CO_2 emitters in the United States, all ahead of country's largest electricity producer, American Electric Power (AEP). Such comparisons are illustrated in Figure 5.

The 99 MMTc from GM vehicles in 2004 was more than double the 41 MMTc from AEP. Ford's cars and trucks emitted 80 MMTc, essentially double AEP's emissions that year, and DaimlerChrysler's products emitted 51 MMTc. The total CO_2 emissions from the Big Three's automobiles in 2004 were comparable to the total from the top 11 electric companies. Next down the list, the CO_2 emissions from Toyota vehicles were slightly higher than those from the Tennessee Valley Authority, the nation's third largest power producer.

Comparing CO_2 emissions from on-road stocks (rather than just new sales) to those from electric utilities is appropriate in that both include the emissions of long-lived products and equipment (automobiles and appliances or other electrical devices). Both are influenced by the actions of end-users, that is, consumers and businesses. For example, a power company's CO_2 emissions are the result of the electricity consumed in homes, offices, schools and other power-using facilities in its service area. Both are influenced by the carbon intensity of their fuel supply. For example, coal accounts for 54% of energy consumed by U.S. power generation[25] and 83% of carbon emissions from the electric

FIGURE 5

Carbon emissions of major automakers' products vs. major electric producers in the United States, 2004



Source: Table 1 and CERES et al. (2006).

sector.[26] Government decisions and policies are also important in both cases. State and local regulators oversee electric utility services and rates for the power sector, and multiple levels of government oversee transportation infrastructure, finance and land use planning for automobiles. The sectors are, of course, different in many other ways, particularly in the nature of the markets and the specific roles played by the other actors who influence usage.

Another way to view corporate CO_2 emissions impacts would be to tally those associated with the motor fuel sales by major oil companies, but we have not attempted such an analysis due to lack of data.[27]

Beyond the carbon tally

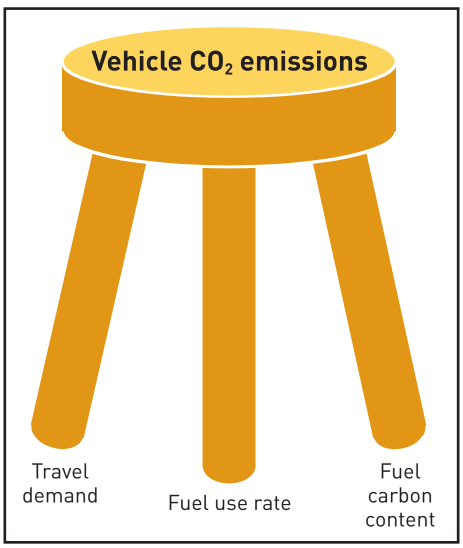
The rolling stock snapshot for 2004 is the product of many forces. Key factors include the amount of travel, the level of fuel economy and the carbon content of motor fuel. Among these factors, only fuel economy has served to partially control CO_2 emissions. Fuel carbon intensity has not significantly changed, reflecting the tenacity of oil as a source of motor fuel and the fact that no systematic effort has been made to reduce or offset GHG emissions associated with petroleum fuels. Many forces drive travel demand, and all of them have had a combined effect of pushing auto sector CO_2 emissions upward.

Factors determining auto sector CO_2 emissions

As illustrated in Figure 6, auto sector CO_2 emissions can be depicted as a three-legged stool, with the overall level propped up by the three major factors noted. These factors are generally quantifiable and can be tracked through time, and examining them forms a common basis for analyzing the car-climate problem.

FIGURE 6

Three main factors behind rolling carbon



For the 2004 rolling carbon snapshot discussed in this report, total U.S. auto sector CO_2 emissions can be viewed as the product of:

- Travel demand (2.6×10^{12} miles/year)
- Fuel use rate (51 gallons/1000 miles)
- Fuel carbon content (5.3 pounds of carbon/gallon)

The result rounds out to the 314 MMTc total of rolling stock carbon emissions given in Tables 1 and 2.

The first factor, known as vehicle miles traveled (VMT), represents the total amount of driving in cars and light trucks.[28] The second factor, average fuel use per mile, is based on the stock average fuel economy of 19.6 mpg. The third factor, fuel carbon content of 5.3 pounds/gallon, represents the carbon in gasoline.[29]

A look at what's behind each of the three legs of the car-carbon stool sheds light on the multifaceted nature of auto sector carbon emissions and puts into perspective the challenge of addressing a problem of this magnitude.

TRAVEL DEMAND

Demographic and economic factors, urban and regional development, changes in transportation infrastructure and evolving land-use patterns all influence the amount of driving. The travel demand factor, however, is often given but passing attention in U.S. climate policy, and discussions frequently focus on the politically charged issue of raising fuel taxes.

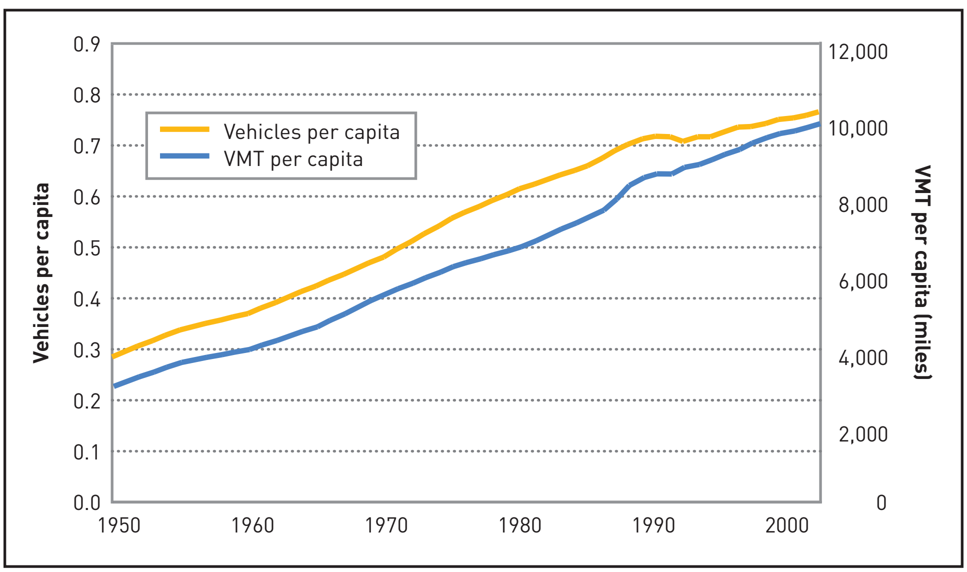
In the United States, road building, automaking and the supply of petroleum fuels form a three-way symbiosis that has served to sustain steady increases in driving. The public appreciates the benefits of automobiles enough to support fuel taxes that help pay for roads. Yet taxes receive great scrutiny, and taxes on fuel generally have been limited to the minimum needed to cover basic highway costs.

The personal value of the car is high enough that this major part of the transportation system is privately financed by consumers themselves. Even during price spikes, fuel cost is generally a small fraction of the total cost of owning and operating a car.[30] Thus, U.S. fuel prices provide little restraint on VMT. Absent effective policies to manage transportation demand at the national scale, VMT has increased steadily for many years. Net VMT growth was 158% between 1970 and 2004, for an average growth rate of 2.8% per year.[31]

A key factor driving travel demand is population. The U.S. population in 2002 was 288 million, representing an increase of 41% since 1970, and an increase of 90% since 1950.[32] Compounding population growth are increases in vehicle ownership rates and average VMT per capita, as shown in Figure 7. Both have grown steadily over the second half of the 20th century. VMT per capita has increased 82% since 1970—double the population growth over this period—rising from roughly 5,400 miles per year to 9,900 by 2002. Car ownership (vehicles per capita) has risen essentially in parallel. Figure 7 shows ownership over the entire population, including children, the very old and others who do not drive. The intensity of auto use is highlighted by the fact that there are now more cars than drivers, with the latest statistics showing that the United States has 1.06 personal vehicles per licensed driver.[33]

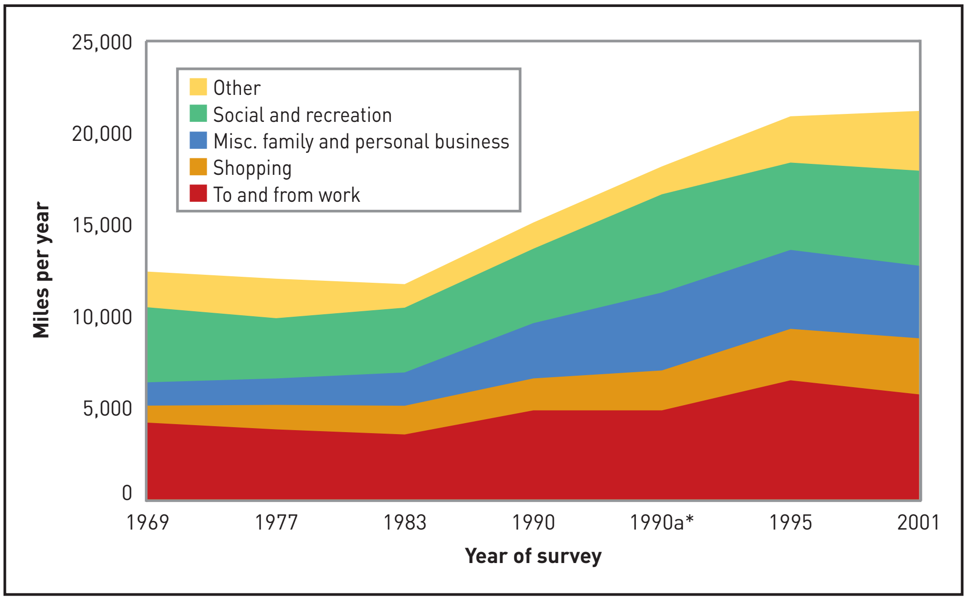
Surveys of how Americans use their cars are commonly reported on a household basis, as shown in Figure 8. The average household drove roughly 21,000 miles in 2001, 17% more than the household average in 1990. While commuting trips still had the largest share of driving, American households

FIGURE 7
U.S. vehicle ownership and VMT per capita (1950–2002)



Source: Davis and Diegel (2004), Table 8.2

FIGURE 8
VMT trend by travel purpose



Source: Hu and Reuscher (2004), Table 6.

*The survey methodology changed in 1995 and so the 1990 results are shown in two forms: using original survey definitions (labeled "1990") and adjusted for comparison to the 1995 and 2001 surveys (labeled "1990a").

are using their vehicles more often for shopping. The number of miles for shopping trips steadily increased since 1969, and grew by 40% from 1990 to 2001, as a result of increased shopping trips and extended trip lengths.[34] These statistics highlight the trend of Americans' increasing reliance on personal vehicles, a natural consequence of burgeoning auto-oriented development that has been the norm in most parts of the United States over the past several decades.

The issue of how to manage travel demand, which is intimately linked to land use and many other factors, is quite involved. However, a growing sense of the limitations of traditional transportation priorities reveals many reasons to pursue policies that would serve to dampen VMT growth (TRB 2005). As noted in the next section, catalytic converters have succeeded in cutting air pollution in spite of VMT growth; nevertheless, such technology-based reductions have not been enough to achieve healthy air in many regions (Scott et al. 2005). Thus, in addition to ongoing efforts to improve technology, renewed attention is being placed on improved land use, transportation alternatives and rationalized pricing to achieve a more efficient transportation system that is less reliant on motor vehicles.

FUEL ECONOMY

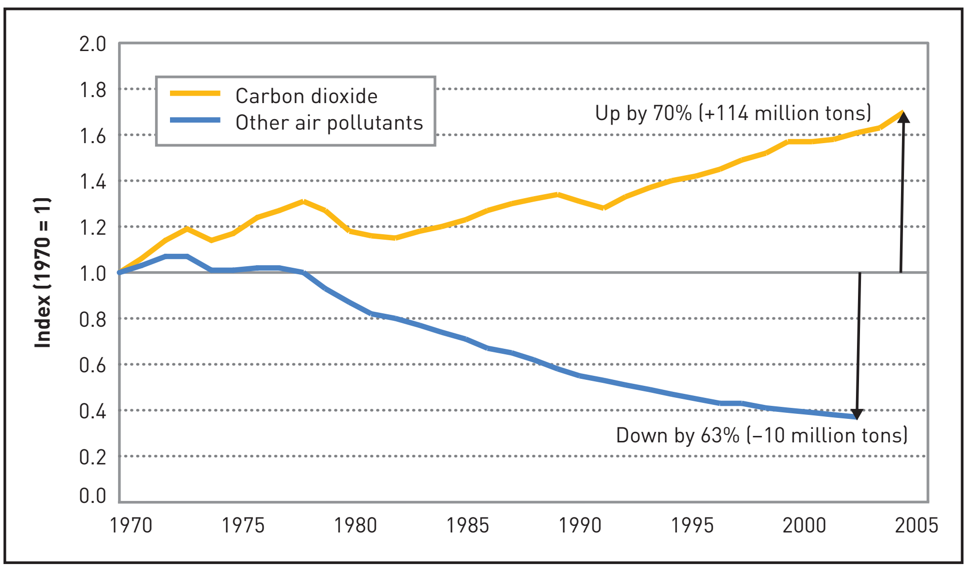
The 1970s oil crises—with gasoline lines, fears of shortages and suddenly higher fuel prices, plus the policy response of Corporate Average Fuel Economy (CAFE) standards—drove a leap in new light vehicle fuel economy between 1975 and 1981. Fuel economy continued to slowly increase between 1981 and 1988 but then began declining due to the rising popularity of light trucks and largely unchanged CAFE standards. Nevertheless, the EPA-rated fuel economy of the new automobile fleet saw a net 78% increase from 1974–2004. Adjusting for increased shortfall, average on-road fuel economy improved by roughly 50% over that period.[35] This efficiency gain implies a 33% reduction in CO_2 emissions per mile from today's vehicles compared to those of a generation ago.

It is instructive to compare the fuel-economy driven reductions in CO_2 emissions with the reductions in the emissions of other forms of vehicle pollution. Efforts to seriously control smog-forming automobile emissions also began in the 1970s. The Clean Air Act limited tailpipe emissions of hydrocarbons (HC), nitrogen oxides (NO_x) and carbon monoxide (CO) by model year 1975 to levels that most vehicles could attain only through the use of catalytic converters (Mondt 2000). Today, after an ongoing tightening of tailpipe standards and a generation of effort, the United States has achieved over a 60% reduction in automotive "rolling smog," that is, health-harming pollution from cars and light trucks.[36] This drop in total emissions was achieved by cutting stock-average per-mile emission rates to roughly 15% of their pre-control levels. In short, catalyst-based emissions control—incorporating computerized engine management, reformulated low-sulfur gasoline and related devices—has been a potent enough technological fix to achieve net pollution reductions in spite of increased driving.

The difference between the effectiveness of tailpipe emissions controls and fuel economy improvement over this period is illustrated in Figure 9. The backdrop for both air pollution and CO_2 emissions from cars and light trucks is VMT growth, which, as described earlier, rose by more than a factor of 2.5 since 1970. Yet total health-damaging air pollution from U.S. automobiles dropped by nearly 10 million tons of NO_x-equivalent,[37] corresponding to the 60% reduction noted. Reductions will continue as even tighter tailpipe

FIGURE 9

Trends in carbon dioxide emissions and other air pollution from U.S. automobiles



Source: Authors' analysis of EPA (2005b), FHWA (2006) and historical editions of Highway Statistics. The "other air pollutants" trend is based on a health-damage-weighted composite for tailpipe emissions of nitrogen oxides (NO_x), volatile organic compounds (VOC), particulates (PM_{10}), carbon monoxide (CO) and sulfur dioxide (SO_2).

standards are phased in. Automotive CO_2 emissions, on the other hand, have increased by 70% since 1970 and are continuing to rise. Although many technologies are available to cut CO_2 emissions rates, none of the options (not even hybrid powertrains) are as effective as the catalytic converter has been for cutting conventional pollutants. Lacking such a technological fix, vehicle design changes will need to be complemented by other strategies, such as low-carbon fuels and reductions in travel demand, to see major progress in reducing rolling carbon.

LOW-CARBON FUELS

The 1970s energy crisis also prompted efforts to develop and commercialize alternatives to petroleum-based transportation fuels. Since then, the U.S. economy has seen major shifts in the structure of oil use; sectors that could switch to other fuels have largely done so. Non-transportation oil use is now lower in absolute terms than it was in 1970, even after three decades of economic growth. Transportation, however, remains 96% petroleum dependent, and the sector now accounts for two-thirds of U.S. oil use, compared to one-half in 1970.[38]

Throughout this time a variety of fuels have been promoted by federal and state policies. Alternatives that have seen support include synthetic fuels (synfuels) from coal and oil shales, natural gas, methanol (derived from natural gas or coal), various biofuels, electricity and hydrogen.[39]

Although nearly all alternative fuels are advertised as "clean," policies to promote them have had few if any stipulations regarding environmental performance beyond those already required for gasoline. California's 1990 low-emission vehicle (LEV) program was partly premised on levels of stringency that would favor alternative fuels. However, by the mid-1990s it became clear that all standards short of the zero-emission vehicle (ZEV) mandate could be met with improved catalytic controls and reformulated gasoline.

Most alternative fuels are now promoted as offering low GHG emissions. An ongoing debate plays out in numerous paper studies ("full fuel cycle" analyses) of which fuels might have low or zero GHG emissions under various assumptions. However, requirements to control GHG emissions throughout a fuel's life cycle are yet to be developed. Since little work has been done to systematically measure and track the actual fuel-cycle impacts of commercially produced fuels, the real-world greenhouse gas implications of alternative fuels remain uncertain. Moreover, one major U.S. policy to promote alternative fuels, giving automakers CAFE credits for selling flexible-fuel vehicles (FFVs), is counterproductive. The resulting trade-off in vehicle efficiency has increased oil consumption and carbon emissions over what they would have been without the FFV policy (DOT 2002).

One alternative fuel that has seen consistent backing is ethanol. Ethanol can be readily blended with gasoline in low concentrations and such "gasohol" has long been available in the Midwest. U.S. fuel ethanol use is now increasing rapidly toward the renewable fuel mandate of 7.5 billion gallons by 2012.[40] That level would amount to about 3% of U.S. light vehicle fuel consumption.[41] However, because the energy use and emissions associated with agricultural and ethanol production processes are not tracked, it is difficult to ascertain the net carbon impact of ethanol use. A recent meta-study found that replacing gasoline with corn ethanol has an ambiguous effect on GHG emissions (Farrell et al. 2006). Like most commercial and agricultural activity in the United States, ethanol production is now pursued without a need to manage carbon. To ensure reductions in GHG emissions through fuel substitution, protocols will need to be established for tracking fuel-cycle impacts and certifying that the net GHG emissions from ethanol or other fuels are measurably lower than those from gasoline.

Fuel supply infrastructure is long-lived, with large-scale investments needed to develop new fuel production facilities, so shifting to alternative fuels requires longer lead times than modifying vehicles. Although the past few years have seen high oil prices, and the U.S. Department of Energy revised its oil price outlook significantly upward (EIA 2005), the competitive environment for petroleum alternatives remains speculative. This uncertainty in commercial outlook compounds the uncertainty in the carbon impacts of any given fuel due to the lack of policies for managing GHG emissions associated with fuel production. Therefore, while shifting to low-carbon fuels is an essential complement to cutting travel demand and raising fuel economy, how well new fuels will serve to reduce GHG emissions depends on programs and policies that largely remain to be developed.

Managing auto sector carbon

While the major factors that determine emissions—the three-legged stool of travel demand, fuel economy and type of fuel—provide a convenient snapshot of the sector, such an analysis has limitations when considering how to cut emissions. Multiple decision makers ("actors") influence each leg of the stool. In other words, the factors that technically determine emissions are the product of choices made by many players in the marketplace, such as automakers, fuel suppliers and consumers, as well as by regional planning bodies and other transportation policy forums.

For example, consider fuel economy, a tangible and easy-to-track factor behind automotive CO_2 emissions.[42] Consumers influence fuel economy through their selection of vehicles as well as their driving and maintenance habits. Automakers influence fuel economy through their product strategies and design choices. But the decisions made by consumers and automakers are not independent; moreover, the net carbon impact of fuel economy depends on the broader influences that shape vehicle use.

RECASTING THE DISCUSSION

The complex, market- and policy-mediated nature of decisions that influence CO_2 emissions is not unique to the auto sector, of course. But our rolling stock tally underscores the magnitude of automotive CO_2 emissions and spotlights the roles of the many actors whose decisions are behind the 314 MMTc from U.S. cars and light trucks. Such a view suggests a need to recast the discussion of what to do about the car-carbon problem from

What policies are needed to address each *factor* behind automotive CO_2 emissions?

to

What policies can motivate each *actor* to address the aspects of CO_2 emissions under each actor's control?

In a market-based framework, only individual decision makers can determine the actual, perceived costs and benefits to themselves resulting from the decisions they make. Developing an actor-based carbon management framework can clarify the roles of all players and enable cost-effective decisions about carbon reduction. Under this framework, policies can be designed to motivate actors to consider and reduce carbon impacts of every decision they can control. Such an approach would be a step beyond factor-based analysis, which rests on assumptions about the costs and benefits to particular actors presumed to hold the most influence over a given factor.

A NEED FOR NEW TOOLS

Exactly how to define a set of auto-sector specific carbon management policies is a subject for future work. We can, however, illustrate the value of such an approach by considering the example of a city as an actor who can influence the CO_2 emissions associated with its transportation operations. The vehicles a city operates are, in fact, a microcosm of the larger rolling carbon situation.

To cut the carbon from a city's transportation operations, its agencies might consider ways to carry out their functions with less driving; they might change the number, type and efficiency of the vehicles they operate; or they might use low-carbon fuels.[43] Changes in vehicle purchases would influence the demand side of the market to which automakers respond. Moreover, under such a fleet carbon management approach, decisions about vehicle choice would no longer be made in isolation from looking at other (and sometimes more accessible) ways for the city to cut carbon from its vehicles.

Of course, a municipality's vehicle fleet is just a small fraction of all the vehicles within a community. In fact, beyond its own fleet, city officials have a measure of control over land-use, zoning and development decisions, parking and the availability of non-auto modes of transportation. A city can help lead other regional governments as well as state officials to explicitly manage carbon impacts in all aspects of transportation and land use planning. Such decisions are the clear area in which local governments can affect the "rolling carbon" impacts of their jurisdiction. Challenges and costs are likely be associated with any of the actions a city might consider for cutting carbon from transportation, but there might also be cost savings.

A city is just one actor, but the above example illustrates how any entity influencing auto sector CO_2 emissions can approach the problem under a carbon management paradigm. A private company or institution that uses vehicles in the course of business also has a measure of control over the associated CO_2 emissions, and opportunities to reduce emissions can be found once an effort is made to look for them. Right now, however, most cities (as well as most other entities who influence auto sector CO_2 emissions) have little way of knowing how their day-to-day or year-by-year transportation decisions impact CO_2 emissions. Thus, a starting point for finding ways to cut emissions is developing new evaluation tools that make the carbon impacts and costs of decision options explicit. Sector-specific carbon impact evaluation tools will facilitate "carbon-sensitive decision making," enabling each actor to make the decisions that most affordably reduce their portion of emissions. A broader question is how to motivate carbon-sensitive decision-making. Ultimately, those who reduce emissions might be able to realize a financial value from their actions in the market for carbon reductions that will emerge under national and international climate protection regimes.

In short, many different entities have some measure of control over auto sector CO_2 emissions. Opportunities to cut carbon can be found by examining the decisions made by any actor that influences the future trajectory of auto sector CO_2 emissions. Such an actor-based approach breaks the otherwise daunting rolling carbon problem into manageable pieces, and so can complement the traditional policy focus on the factors that determine emissions in a technical sense. Further work is needed on the issue of how to define carbon management policies for the auto sector; this is a subject we leave for future research and it will also be an important topic for discussion among policy makers, automakers, the energy industry, transportation planners and other stakeholders.

Conclusions

The global warming pollution from all U.S. cars and light trucks amounted to 314 MMTc in 2004. This "rolling carbon" accounts for about one-half of CO_2 emissions from all passenger vehicles around the world and about 6% of global energy-related CO_2 emissions. The amount of CO_2 emitted a year from the U.S. vehicle stock is equivalent to the amount of carbon in a coal train 50,000 miles long.

At the national level, data on the history of vehicle sales and statistics on vehicle usage enable us to breakdown the total rolling carbon by automaker and type of vehicle. Such an analysis shows, for example, that the CO_2 emissions from each of GM's, Ford's and DaimlerChrysler's vehicles exceed those from any electric power company. However one looks at the issue, the car's contribution to global warming pollution is enormous.

Rolling carbon can be analyzed in terms of the factors—VMT, fuel economy and fuel carbon content-that determine emissions. For developing new policies, however, it is instructive to consider the *actors* whose decisions influence each *factor*. Auto companies are, of course, a key actor through their product strategies and product design decisions. But other parties, including individuals and businesses that purchase and use vehicles, energy companies that provide auto fuel, and various levels of government that influence land-use and transportation decisions, all play a part in influencing the total rolling carbon. The total CO_2 emissions from all vehicles on the road are in fact the result of complex and interdependent decisions made by many actors.

Policy discussions on curbing automotive carbon emissions have tended to center on the technical factors that characterize the sector's emissions. However, changing these factors to reduce auto carbon emissions will require complementary decisions by multiple actors who influence emissions. Our rolling stock tally underscores the magnitude of automotive CO_2 emissions, highlighting the potential roles of the many actors in the system. It also suggests a need for new tools to help each actor understand how their decisions impact emissions, paving the way for new policies that can foster carbon-sensitive decisions making. Such a carbon management paradigm would serve to make carbon emissions reduction an objective in day-to-day decision making, so that each actor in sector can seek opportunities for reducing those aspects of total emissions that each can best influence.

APPENDIX A

Stock modeling methodology and assumptions

The stock turnover model used in this study is a spreadsheet-based accounting model for calculating fuel consumption of all light duty vehicles on the road (the "rolling stock"). The resulting fuel use and CO_2 emission estimates depend on fuel consumption rates of vehicles (computed from fuel economy data), new vehicle sales, as well as national-level statistics on how long vehicles last and how much vehicles are driven as they age. The last three factors—new vehicle sales, vehicle survival probability and usage rate by age—determine the rate of vehicle stock turnover.

In our model, total stock fuel use in a given year (F_y) is computed as the sum of fuel consumption for each group of vehicles of a given age (cohort) weighted by the probability that a vehicle survives to the given age (p_i), as shown in Equation (1). In this calculation, the fuel consumption of a vehicle cohort is estimated by multiplying its sales (S_y) by its average fuel consumption rate (c_y) and the expected annual miles of travel for vehicles of the given age (v_I).

$$F_y = \sum_{i=0}^{N} p_i (S_{y-i} v_i c_{y-i}) \quad (1)$$

$$c_y = \frac{1}{(1-g)m_y} \quad (2)$$

where

c = fuel consumption rate (e.g., gal/mi; reciprocal of fuel economy)
F_y = total fuel consumption in year y
g = on-road adjustment (fuel economy shortfall)
i = vehicle age, i = 0, 1, ..., N (N=25)
m = new fleet fuel economy (unadjusted CAFE values)
p_i = survival rate (probability of surviving to age i)
S_y = new vehicle sales in year y
v_i = usage rate (miles per year per vehicle of age i)
VMT_y = total vehicle miles traveled in year y
y = year of cohort (model year)

Total stock vehicle miles traveled in year y is calculated as:

$$VMT_y = \sum_{i=0}^{N} (S_{y-i}\, p_i\, v_i) \quad (3)$$

Average stock fuel economy is then computed as:

$$\bar{m}_y = \frac{VMT_y}{F_y} \quad (4)$$

Stock carbon emissions are calculated by multiplying the stock fuel use estimate (F_y) from Equation (1) by a CO_2 emissions factor of 19.4 lb of CO_2/gal. Thus, the carbon emissions estimates given here include only emissions from vehicle use, rather than full fuel cycle emissions. Assumptions made and parameter values used in the stock model are presented in Table A1.

Data sources and model calibration

Historical data on new vehicle sales (S_y) and fuel economy (m_y) from 1979 to 2004 are taken from federal fuel economy databases, specifically, the National Highway Traffic Safety Administration (NHTSA) annual CAFE data reports and EPA (2005b). Light vehicle survival and usage rates

TABLE A-1
Key assumptions for rolling stock carbon analysis

Assumption or parameter value	Value
Fuel economy shortfall. Relative to CAFE (test) values, with same value assumed for all vehicles types.	20%
CO_2 emissions factor. Direct emissions only, assuming full combustion but excluding upstream emissions in the fuel supply chain (a 30% effect) and emissions from vehicle manufacturing (a 12% effect).	8,800 g/gal* (19.4 lbs/gal)
Oil consumption factor. One barrel of crude oil demand per barrel of gasoline or diesel fuel consumption, assuming that oil demand is driven by these high-value fuels, rather than the ratio based on refinery yields.	1 : 1 oil : gasoline
Carbon factor. Million metric tons of carbon (MMTc) per year corresponding to each million barrels per day of fuel consumption, corresponding to direct CO_2 emissions factor and oil consumption factor (i.e., not full fuel cycle).	36.83 MMTc/Mbd

*An assumed nominal value for conventional gasoline; this value is between the CO_2 emissions factor in the Argonne National Laboratory GREET model (8,750 g/gal) and the factor used by EPA (8,864 g/gal).

were adopted from the Preliminary Regulatory Impact Assessment for the proposed MY2008-11 light truck CAFE standards (NHTSA 2005, Table VIII). The CO_2 emissions estimates by automaker and vehicle segment are based only on tallies of the federal fuel economy data by automaker and segment; we did not have automaker- or segment-specific statistics on vehicle survival and usage rates.

The overall stock fuel consumption estimates from Equation (1) were calibrated to federal statistics for total light duty vehicle fuel consumption in 2004 (FHWA 2006, Table VM-1). This approach ensures that our carbon numbers add up to match the auto sector's share of national CO_2 emissions in government reports. Available fuel economy and sales data cover only cars and light trucks regulated under the fuel economy standards, i.e., cars and trucks with a GVW less than 8,500 lbs. However, the Federal Highway Administration (FHWA) light vehicle fuel use statistics cover cars and light trucks with GVW up to 10,000 lbs. Therefore, we parse out the fraction of light vehicle fuel use by assuming that trucks with 8,501–10,000 lbs GVW (Class 2b trucks) account for about 4% of the overall under 10,000 lb GVW light duty fuel use (EIA 2005, Table A7).

Because we calibrated to overall fuel consumption, rather than attempting to just add up fuel consumption from the vehicle stock, our modeled estimate of the number of vehicles in use (204 million for 2004) does not necessarily match the nationwide registration tallies from the Department of Transportation (DOT), which reported 228 million cars and light trucks in use as of 2004 (FHWA 2006, Table VM-1). One reason is that our estimates exclude Class 2b trucks; it is also likely that more very old vehicles are in use than are captured by our stock modeling parameters and the fact that our sales data only go back to 1979.

Sensitivity analysis

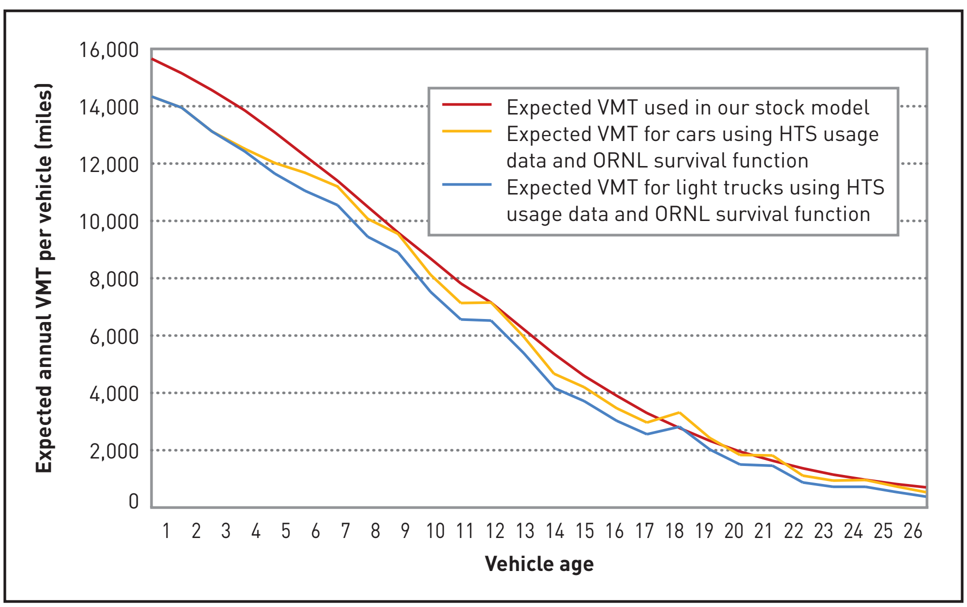
As shown in Equation (1), stock fuel consumption calculations entail assumptions about vehicle usage and survival rates. The product of usage rate and survival rate of a given cohort equals the expected annual miles traveled of vehicles of that cohort. Thus, the higher the product of usage rates and survival rates of a given cohort, the higher its fuel use and carbon emissions. However, because our estimate of overall stock fuel consumption is calibrated to FHWA statistics, it is independent of assumptions on survival probability and usage rates. Nevertheless, CO_2 emission breakdowns calculated for subsets of the stock (e.g., by automaker or vehicle type) can be affected by such assumptions.

This analysis adopts the survival rates and usage rates used by NHTSA (2005). Because NHTSA only provides the survival rates and usage rates of light trucks, we assumed the same survival and usage functions for cars and light trucks. Even though light trucks historically had lasted longer than passenger cars, the survival rates for new light trucks have been dropping and converging to those of cars (see NHTSA 2006 for further discussion).[44] Thus, the assumption of same survival and usage rates for cars and trucks seems reasonable. In addition, this analysis also assumes the same survival probability and mileage for all vehicle segments and for vehicles produced by all manufacturers, since public data are not available for discriminating survival and usage at that level of detail.

To examine how survival and usage assumptions affect the estimates of share of carbon emissions among segments and automakers, we performed a sensitivity analysis using vehicle usage statistics from the 2001 National Household Travel Survey (HTS) and the 1990 survival probabilities estimated by Oak Ridge National Laboratory (ORNL) (Davis and Diegel 2004, Tables 3.9 and 3.10). Figure A1 compares the expected VMT per vehicle used in our analysis with values derived from the HTS usage data and the ORNL survival rates. The sensitivity results suggest that our stock carbon

FIGURE A1

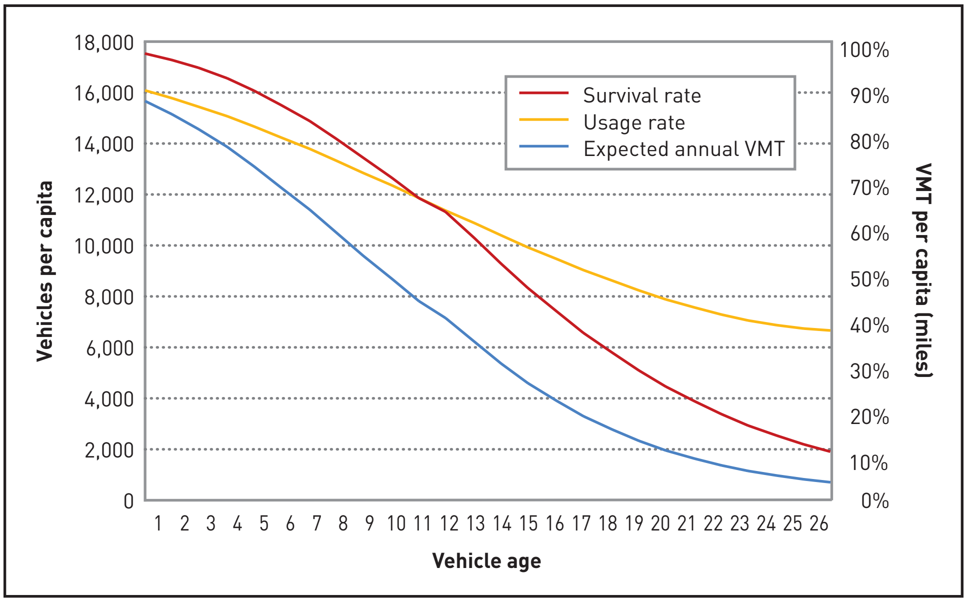
Comparison of expected VMT per vehicle from different sources



Expected VMT equals the product of survival probability and usage rate.

Source: NHTSA (2005), Table VIII; National Household Travel Survey (2001); Davis and Diegel (2004).

FIGURE A2
Survival, annual usage and expected VMT by vehicle age



Source: NHTSA (2005), Table VIII, and authors' calculations.

emissions estimates were about 2–3% higher for light trucks and 2–3% lower for cars than those derived using the HTS-ORNL assumptions. The impact on automakers' oil use and carbon emissions estimates are similarly small, ranging from −2% to 2%. These effects translate into differences of less than 1 percentage point in stock carbon shares by vehicle segment and less than 0.2 point in stock shares by automaker.

Figure A2 plots the survival rates (p_i) and annual usage rates (v_i) used in this analysis plus the expected VMT by vehicle age derived as a product of the survival and usage rates. Thus, under the assumptions we used, the "surviving miles" of annual driving by vehicles of a given age falls from just under 16,000 mi/yr for new vehicles to roughly 4,000 mi/yr for 16-year vehicles, for example.

Rolling stock fuel consumption and CO_2 emission estimates are also sensitive to the choice of the on-road fuel economy adjustment (shortfall) factor (g). Due to higher road speeds, increasing congestion and urbanization, increased use of accessories (like air conditioning) and other factors, actual on-road fuel economy is less than the EPA-test fuel economy used for CAFE compliance. The on-road adjustment factor reflects the gap between the actual fuel economy and test fuel economy. An under-estimated shortfall factor will result in under-estimated stock fuel consumption, and vice versa.

For vehicle labeling and consumer information purposes, EPA has used shortfall factors that average 15% since 1985; the agency now has a rulemaking underway to develop new estimates for on-road fuel economy. Although new estimates are not yet available, the expectation is that the average estimated shortfall will increase. Based on studies such as Mintz et al. (1993) and shortfall estimates used in NEMS, we adopt 20% shortfall as the assumption for this analysis. This level of shortfall also happens to yield a stock average fuel economy modeled on the basis of CAFE data (19.6 mpg) that closely matches the light vehicle average of

19.8 mpg derived from FHWA (2006) and Energy Information Administration (EIA 2005).[45]

Other stock turnover models

Several government agencies and research institutes have developed vehicle stock turnover models that are largely oriented to projecting future fuel use and carbon emissions under various scenarios. These software programs include the DOE VISION model, Stockholm Environment Institute-Boston Center (SEI-B) LEAP software system, the DOE-EIA NEMS model and the EPA MOVES model. The VISION model, the transportation module of LEAP and the Light Duty Vehicle (LDV) Stock module of NEMS use a stock turnover approach similar to the one we adopted in developing our stock model.

Designed as a tool for estimating mobile source emissions to facilitate infrastructure planning, EPA's MOVES model provides more detailed estimates of on-road vehicle fuel consumption and emissions for a small geographic region (such as at the county level), and allows users to generate estimates by small temporal units (month, day of week, hour), road type and technology type. Using second-to-second vehicle emissions data, the MOVES model estimates energy consumption rate for vehicles of different combinations of fuel, engine technology, engine size, weight and model year. Stock vehicle fuel consumption is computed by combining the estimated energy consumption rates of different vehicle combination with temporal VMT distribution (i.e., VMT fraction by month, day and hour), allocation of operation mode (idle, operating and braking) and vehicle population data (base year population, scrappage rates, sales growth rates and age distribution).

Even though we did not run these models, we validated our stock modeling results with published results from NEMS and MOVES. Our stock fuel consumption estimate of 8.53 million barrels per day (Mbd), which was calibrated to the latest federal highway statistics, is 0.2% higher than the projection from NEMS, while our estimate of stock fuel economy is about 3% lower than that from NEMS (EIA 2005). Our stock model estimates of on-road fuel economy of cars and light trucks for 2004 (22.6 mpg and 16.6 mpg respectively) also compare well with the modeling results from MOVES for on-road fuel economy of cars and light trucks for 2002 (22.8 mpg and 16.6 mpg respectively). In addition, the 2002 fleet fuel consumption estimates (8.58 Mbd or 131.5 billion gallons per year) from MOVES, which include light vehicles and some of the Class 2b trucks, is close to our modeling results on light vehicle stock fuel consumption for 2004 (Koupal and Srivastava 2005).

Notes

[1] Throughout this report, automobile GHG emissions are given on a carbon-mass basis, in million metric tons of carbon (C) mass-equivalent per year (MMTc), unless otherwise noted. Some climate-related studies (the Ceres 2006 report on electric sector emissions, for example) give results in short tons of CO_2 mass-equivalent; the conversion factor is 4.042 short tons of CO_2 per metric ton of C.

[2] The coal train comparison assumes the following: coal is 60% carbon by weight (Wang 2001); an average coal car carries 111.4 short tons (AAR 2005), implying 60 metric tons of carbon per carload; a typical coal car length is 50 feet (FreightCar America 2005); and New York-to-San Francisco distance of 2,902 miles (maps.google.com).

[3] According to EPA (2006), CO_2 emissions associated with petroleum use for transportation reached 496 MMTc in 2004, equal to 96% of the CO_2 emissions from coal use from power generation (517 MMTc).

[4] See DeCicco et al. (2005) for the most recent update of *Automakers' Corporate Carbon Burdens*, published by Environmental Defense.

[5] As noted below, some international comparisons are given for earlier years if 2004 data were not available.

[6] Based on projections by WBCSD (2004), global light duty vehicle CO_2 emissions were 680 MMTc in 2003, which is also 10% of the 6,814 MMTc of global CO_2 emissions associated with fossil fuel use in 2003.

[7] Light duty vehicle estimates are from WBCSD (2004); the estimates for global fossil fuel CO_2 emissions, all anthropogenic CO_2 emissions, and all GHG emissions are from IEA (2005).

[8] The U.S. vehicle stock estimate comes from the R.L. Polk Co., cited in Table 6.4 of Davis and Diegel (2002). The 2000 global vehicle stock estimate comes from WBCSD (2004). Vehicle stock estimates from other sources differ from the figures provided here because of different definitions for trucks and the uncertainties associated with unregistered vehicles.

[9] Fulton and Eads (2004, 33) estimate world average annual travel per vehicle per year at 13,755 km in 2000, which converts to 8,547 miles. The annual average travel of U.S. automobiles come from Table 8.13 of Davis and Diegel (2004), with data generated from the 2001 National Household Travel Survey (HTS). Even though estimates for 2000 were not available for comparison with the 2000 global figure, HTS findings from 1990 and 1995 suggest increasing levels of travel, implying that VMT per vehicle in 2000 is unlikely to be less than 11,000 miles.

[10] The fuel efficiency comparison assumes the following: World stock fuel economy is 22.5 mpg in 2000 (WBCSD 2004); U.S. stock fuel economy is 19.6 mpg in 2004 based on our stock model.

[11] Estimates from GREET 1.5a (Feb. 2000); see Wang (2001).

[12] A common question is, "Since a gallon of gasoline weighs only a bit more than 6 pounds, how do you get nearly 20 pounds of CO_2 emissions?" The answer is that when gasoline is burned, the carbon in it (which has an atomic weight of 12) is combined with two atoms of oxygen (which each have an atomic weight of 16) to form CO_2 (which has a molecular weight of 44). After adjusting for the hydrogen in the fuel (which gets combusted into water), the CO_2 released when gasoline is burned weighs about 3.14 times as much as the gasoline itself.

[13] Wang (2001).

[14] Unless otherwise noted, results shown in tables and figures are from the authors' calculations per the methodology and assumptions described in the text and detailed in Appendix A.

[15] The 19.3 mpg average on-road fuel economy for MY2004 vehicles is based on 2004 CAFE data, assuming 20% fuel economy shortfall. The 19.3 mpg on-road fuel economy value converts to 24.1 mpg in test fuel economy, which is lower than the preliminary estimate of 24.4 mpg new fleet fuel economy reported in EPA (2005b).

[16] All of the on-road MPG estimates given here assume a 20% fuel economy shortfall relative to CAFE compliance values based on EPA lab tests.

[17] While an automaker with lower than average fuel economy would usually have a

carbon burden share higher than its share of the vehicle population, the stock carbon burdens share also depends on the mix of old and new vehicles in its fleet. Old vehicles on average are driven fewer miles per year than new ones (see Figure A1 in the Appendix A). Thus, the larger the share of old vehicles in an automaker's on-road stock, the smaller their average annual miles driven per vehicle. For the case in point, we estimate that the GM-built vehicles on the road in 2004 were driven an average of 12,230 miles per year, compared to an average of 12,581 miles per year for all vehicles on the road as of 2004. Thus, even though their vehicle population-weighted fuel economy is lower than average, GM vehicles' share of the rolling stock carbon burden is lower than their share of the stock itself.

[18] The 93 MMTc value is a conversion of the 340.6 MMT CO_2-equivalent from the entire U.S. fleet of GM-built vehicles given in page 47 of EIA 2001. Since 2002, GM did not provide estimates of CO_2 emissions from its own fleet in the report submitted to DOE's voluntary reporting program. Given that overall VMT grew by roughly 9% 1999–2004 while GM's share has declined since 1999, we consider these results to be reasonably consistent given their independent derivation.

[19] Ford (2004) estimated that all the greenhouse gases (CO_2 and refrigerants) emitted by Ford's vehicles on the road worldwide, including light and heavy duty vehicles, amounted to 400 MMT CO_2-equivalent, which converts to 109 MMTc in 2000.

[20] The median lifetime represents the age to which 50% of vehicles survive; it is greater than the median age of all vehicles on the road, because the majority of vehicles are those of the more recent model years.

[21] Station wagons are included with cars of corresponding size.

[22] The stock average CO_2 emissions rate is presented in metric tons and converted from the on-road fuel economy of 24.3 mpg of all small cars in 2004.

[23] We assume coal generation emissions of 7,100 metric tons of CO_2-mass equivalent per megawatt (MW) and a typical large plant size of 600 MW capacity, implying 1.2 MMTc per year for a large coal plant.

[24] NHTSA does not track fuel efficiency of Class 2b trucks, so we are not able to include estimates of carbon impacts of these largest versions of light-duty trucks.

[25] Table 2.2 of Davis and Diegel (2004).

[26] Table 3.3 of EPA (2006).

[27] Sufficiently detailed and disaggregated data do not appear to be available for estimating emissions from the use of fuels supplied by oil company. The Carbon Disclosure Project (www.cdproject.net) compiles CO_2 emissions reports voluntarily submitted by major corporations, sometimes including emissions associated with their products. Reports are listed from several oil companies, but ExxonMobil (the largest) did not provide estimates of CO_2 emissions from their products; also, the emissions figures are given on a global rather than U.S. or other regional basis.

[28] The 2.6 trillion miles figure is generated from our stock model and is lower than the 2.7 trillion VMT statistic in FHWA (2006), which include miles traveled by light trucks between 8,500–10,000 lbs GVW.

[29] As noted earlier, these estimates account for only the direct CO_2 emissions from burning gasoline, not the larger, full fuel cycle emissions that includes CO_2 as well as other greenhouse gases emitted when producing and distributing gasoline. The fuel carbon content of diesel is slightly higher than that of gasoline (22.8 lbs of CO_2 per gallon). However, since diesel accounts for only about 3% of U.S. light duty vehicle fuel use (Davis and Diegel 2004, Table A5), this study assumes light vehicle fuel carbon content is the same as that of gasoline.

[30] According to Ward's (2005), costs of fuel on average account for 12–14% of total costs of owning and operating a vehicle.

[31] Light vehicle VMT from 1970-2003 comes from FHWA (2006) and earlier editions; 2004 light vehicle VMT estimate is extrapolated using monthly traffic volume data from FHWA (2004). The VMT data used here include Class 2b vehicles (those between 8,500 and 10,000 lbs GVW) because data excluding Class 2b vehicles are not available. But the growth in VMT excluding Class 2b should be similar to that including Class 2b vehicles. Also, note that U.S. VMT growth historically has followed a linear rather than exponential trend, so annual VMT growth rates computed from recent base years might seem to be decreasing even though the VMT increase remains steady.

[32] Statistical Abstract of the United States (Census Bureau 2005), Tables 1 and 2.

[33] Table 2 of Hu and Reuscher (2005).

[34] Table 6 of Hu and Reuscher (2005).

[35] The 50% net increase compares our stock-modeled 19.6 mpg estimate for 2004 with an on-road estimate of 13.1 mpg for 1974 derived from the online tables of Davis and Diegel (2004) and earlier FHWA statistics. A 20% shortfall factor is assumed in this analysis (see Appendix A).

[36] As of 2002, total health-damage weighted car and light truck pollution has dropped 63% since 1970, based on our calculations as shown in Figure 9. Pollution is continuing to decline as cleaner vehicles replace older vehicles in the stock. This air quality improvement corresponds to a 85% reduction in average per-mile emissions of the light vehicle stock acting against the 2.5-fold increase in VMT that occurred 1970–2004. Note that medium and heavy trucks (most of which are diesel powered) have seen much less progress in pollution control. Moreover, the need to control fine particles in addition to smog-forming pollutants means that additional efforts are needed to reduce the transportation sector's contribution to unhealthy air; see Scott et al. (2005).

[37] The graph weights all tailpipe pollutants according to their estimated health impacts relative to NOx, using damage cost values from Delucchi (1997) and pollution data from EPA (2005a).

[38] Davis and Diegel (2004), Table 2.2 and Table 1.12.

[39] In recent years, for instance, ethanol, biodiesel, and gasification-derived synthetic gasoline and diesel are receiving increased research attention.

[40] The renewable fuel standard established by the Energy Policy Act of 2005 (H.R. 6, Section 1501).

[41] The 3% estimate is relative to the EIA (2005) forecast of 18.25 quads for light vehicle fuel use in 2012 and reflects the fact that ethanol contains 34% less energy per gallon than gasoline.

[42] While there is often concern about the accuracy of fuel economy ratings and in-use fuel economy can vary greatly, on an aggregate basis average fuel economy is fairly well known, with its uncertainties being less than the level of growth that occurs over multi-year periods and far less than the magnitude of change needed to address a problem such as global warming.

[43] An example of such a city-oriented policy is given by the Green Fleets program, www.greenfleets.org.

[44] The NHTSA (2006) report provides updated survival rates and usage rates for cars and light trucks. The updated light truck survival rates are slightly higher than that used in NHTSA (2005), while the light truck usage rates are mostly the same. The updated survival rates and usage rates of cars suggest that expected VMT of cars seems to be lower than that of trucks, except for cars of age 8–11. If the most up-to-date survival functions were used, the share of carbon emissions of light trucks would be higher and so would be the share of carbon emissions of automakers with higher share of truck sales. However, the differences are not expected to be significant, given the low sensitivity we found when substituting HTS-ORNL usage and survival assumptions.

[45] The stock fuel economy of light duty vehicles is estimated assuming: fuel consumption and annual VMT of Class 2b trucks is 4,922 million gallons and 68,732 million miles respectively (EIA 2005); fuel consumption and stock fuel economy for all cars and light trucks with GVW up to 10,000 lbs is 138,632 million gallons and 19.6 mpg respectively (FHWA 2006). Because the Class 2b fuel economy and fuel consumption were estimates from the NEMS model, we checked our estimates using Class 2b fuel consumption and fuel economy estimates from Davis and Truett (2002), which imply a light vehicle fuel economy estimate of 19.8 mpg.

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