1.0 Background, Objectives, and Context

1.1 Background

Personal transportation is highly dependent on the automobile. In the United States, there are approximately 240 million light-duty vehicles (LDVs). They comprise some 135 million cars and 105 million light trucks. The estimated fuel consumption of LDVs in 2005 was approximately 530 billion liters or 140 billion gallons of gasoline. Gasoline use by U.S. cars (i.e., cars driven in the United States) and light trucks (pickups, SUVs, and vans) accounts for approximately 44% of U.S. oil consumption and some 10% of world oil consumption [Davis and Diegel 2007]. The U.S. Energy Information Administration (EIA) estimates that more than 60% of liquid fuels used in the country will be imported during the next 25 years. Moreover, an increasing fraction of this supply will come from the Middle East and from the Organization of Petroleum Exporting Countries (OPEC) [EIA 2007a]. Regardless of its countries of origin, pervasive use of oil means that the U.S. economy remains vulnerable to the price shocks in the oil market.

Increasing consumption of petroleum results in increasing emissions of greenhouse gases, which contribute to global climate change. The transportation sector is the largest contributor among the end-use sectors of the economy to the emissions of CO$_2$ in the United States. The emissions of CO$_2$ from transport have grown by approximately 25% during the period from 1990 to 2005. The tailpipe CO$_2$ emissions from LDVs in 2005 were estimated to be 1,260 million metric tons, or about 22% of total U.S. emissions of CO$_2$. LDV energy use had been projected to grow at a rate of 1.3% per annum, but recent fuel economy legislation and estimates of higher fuel prices have lowered expected growth to 0.3% per year [EIA 2007a; EIA 2008]. Even taking these factors into account, the unrelenting increase in the consumption of oil in U.S. light-duty vehicles presents an extremely challenging energy and environment problem. Effective measures will have to be taken to significantly reduce fuel consumption if risks to the economy and the environment are to be reduced.

In October 2000, our Massachusetts Institute of Technology (MIT) research group issued a report titled “On the Road in 2020” [Weiss, 2000]. That report explored the potential of new propulsion system and vehicle technologies for improving fuel consumption and reducing greenhouse gas (GHG) emissions over the next 20 years. The report expanded the life-cycle analysis methodology to include the energy consumed and GHG emissions produced in fuel and vehicle production, in addition to vehicle use consumption and emissions. It made explicit the well-to-tank, tank-to-wheels, and cradle-to-grave components of the overall vehicle impact.

The world has moved on since 2000. Engine, transmission, and vehicle technologies have improved. The development of new technologies such as batteries and fuel cells has

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1 In this report, we refer to “fuel consumption” as the rate of consumption (in liters per 100 km or gallons per mile) of liquid fuels, expressed in gasoline-equivalent terms. Unless noted, this does not include energy supplied from electricity or hydrogen. Note that fuel consumption is the inverse of “fuel economy” (in miles per gallon), the more commonly used metric in the United States. “Fuel use” refers to total fuel used (in liters or gallons) by an individual vehicle or the larger vehicle fleet.
continued. Hybrids are now in production at modest volumes. Alternative fuels from oil sands in Canada and biomass are adding to our petroleum-based fuel supply at the few-percent level. Over the past few years, transportation fuel prices in the United States have increased sharply. Yet, until recently, there has been little action in the United States to develop strategies and policies that would decrease the petroleum consumption and GHG emissions from the in-use light-duty vehicle fleet.

Since our October 2000 report, our group has continued to work on this topic, as have many others. We have re-examined the potential for fuel cell vehicles and hydrogen [Heywood et al. 2003]. We have explained how a coordinated set of regulatory and fiscal policy measures is likely to be needed to ensure progress [Bandivadekar and Heywood, 2006]. We have estimated the likely time scales over which more efficient propulsion systems (both improved conventional systems as well as new technology systems) could be deployed. And in particular, we have focused our efforts on examining the impacts that the many more fuel-efficient technologies now being developed and deployed—and the changes in fuel supplies—might have on future total light-duty vehicle petroleum consumption and GHG emissions. We have examined these issues in the developed-world context, focusing primarily on the United States, but have also done similar analysis on major European countries. This report, “On the Road in 2035,” describes the results of our work on these questions during the past three or so years. As our title indicates, we have extended our timeframe out to 2035, some 25 years from today.

1.2 Study objectives and road map

The overall objective of our study has been to develop a methodology that quantifies the potential future energy and environmental impacts of the technologies and new fuels likely to be developed and deployed in light-duty vehicles. This would be done for the United States, and several major European countries that have different vehicle use, technologies, and fuel price contexts. Quantifying impacts requires adding estimates of production deployment schedules to vehicle-based technology assessments. It also raises a critical market issue: how will the vehicle performance, size, fuel consumption reduction trade-off—which historically has favored vehicle performance over actual fuel consumption reduction—play out? It also requires an assessment of how alternative fuel streams from non-conventional petroleum sources and biomass are likely to augment petroleum-based fuels as the future unfolds. Thus, our study involved the following components:

1. Identifying the propulsion systems (improved gasoline engines, clean diesels, hybrids, improved transmissions) and vehicle technology areas (such as weight and drag reduction) that have significant potential for affecting the light-duty vehicles petroleum fuel demand and GHG emissions over the next 25 years.

2. Quantifying with engineering simulations the fuel consumption, performance, and GHG emissions of an average car and pickup truck in the United States over several standard driving cycles, for appropriate combinations of the more promising technologies in current vehicles and in 2030 new vehicles. We also assessed the additional costs these improved technologies are likely to incur.
3. Developing an in-use fleet model for light-duty vehicles relevant to the developed world, such as the United States and Europe, along with appropriate baseline assumptions for the key issues of growth in new vehicle sales, trends in average vehicles lifetime and vehicle miles (or km) traveled, and vehicle scrappage rates.

4. Developing and then examining scenarios that incorporate various combinations of propulsion system and vehicle technologies, the evolving production volumes of these technologies, and the anticipated growing alternative fuel streams that will augment petroleum fuels. These scenarios have incorporated and examined the trade-offs among on-the-road vehicle fuel consumption, vehicle performance, and vehicle size and weight.

5. Using these scenarios to identify those options that would have a significant impact on total fleet fuel consumption and GHG emissions, and thus identify those options likely to be most effective as we address these challenges.

6. Parallel studies of the factors that determine fuel and environmental impacts in the United States and in major European countries, which have different contexts.

These individual tasks are essential steps in estimating the potential for changing the impact of future light-duty vehicles. Only if vehicles with improved technology are out there being driven in large numbers will the impacts of those technologies on fuel consumption and GHG emissions be substantial. The performance, operating characteristics, and costs of the various propulsion system and vehicle technology options will determine their marketability, and thus the timeframe of their initial deployment. The subsequent ramp-up of production volumes will then depend on the market attractiveness of these improved-technology vehicles, the newness of the technology (and thus its potential for improvement), and the rate at which production capacity can be built up. It will then take several years, working at substantial production volumes, before a significant fraction of total vehicle travel will be with these better-technology vehicles. Of course, we do not know precisely how all these factors will play out. However, we can develop sets of plausible assumptions and build these into scenarios that we can compare—and thereby learn what it takes to make a difference.

The scale and timing of the impact of new and improved propulsion system, vehicle technologies, and fuels, on fleet fuel use and GHG emissions is contingent on the fuel consumption of individual vehicles embodying these technologies, their market penetration, and their utilization. An overview of our approach is shown in Figure 1, in which the contents of each report section are outlined. The remainder of Section 1 provides the system context in which the U.S. LDV fleet operates.

Section 2 introduces propulsion system alternatives and describes their anticipated future performance characteristics, their fuel consumption and GHG emissions, and their costs.

Section 3 examines the opportunities for vehicle weight and size reduction, and the fuel consumption reductions and costs associated with these vehicle changes.

Section 4 evaluates the trade-offs among vehicle performance, size, and fuel consumption for different propulsion systems, and introduces the concept of Emphasis on Reducing Fuel Consumption (ERFC) for quantifying these trade-offs.
Section 5 explains the logic of the fleet model used to calculate life-cycle energy use, fuel consumption, and greenhouse gas emissions from light-duty vehicles. The fleet model is then expanded on in the next sections, where we fully explore the dynamics of the light-duty vehicle fleet.

Section 6 evaluates the impact of a changing fuel mix on the LDV fleet petroleum displacement and on GHG emissions. The section specifically evaluates the likely impact of increasing non-conventional oil and bio-ethanol content in the light-duty fuel mix, under different scenarios.

Section 7 details the supply- and demand-side constraints in building up production of advanced vehicle technologies, and their impact on fleet-wide fuel use. We develop three market penetration scenarios to illustrate the likely scale and impact of these technologies on LDV fleet fuel use over the next three decades. Additional scenarios are included which illustrate specific issues, such as the impact of delays, reducing 5% of light-duty fleet fuel use and GHG emissions by 2025, and doubling the fuel economy of new vehicles by 2035.

Section 8 summarizes the key conclusions of this report and outlines the agenda for the road ahead.

Figure 1  Report overview
1.3 The U.S. context

This section summarizes the context in which U.S. light-duty vehicle (LDV) technology and policy changes operate. Three topics are reviewed: 1) The factors that drive the growth in LDV fleet fuel use and greenhouse gas emissions, 2) the major stakeholders or actors involved in this arena, and 3) the policy alternatives available to affect the LDV fleet fuel use and greenhouse gas emissions. See Section 5.11 for a discussion of how these factors relate in a European context.

1.3.1 The factors

The fuel consumption from in-use motor vehicles depends on the efficiency of driving (LPK), and the total amount of driving (VKT). The greenhouse gas emissions resulting from that fuel consumption additionally depends on the GHG intensity of the fuel (FI) as shown by the following identity:

\[
\text{GHG emissions} = \text{LPK} \times \text{VKT} \times \text{FI} \quad (1.1)
\]

Where,
- GHG emissions = Greenhouse Gas Emissions (tons/year)
- LPK = Liters per Kilometer (L/100km)\(^2\)
- VKT = Vehicle Kilometers Traveled (VKT in km/year)
- FI = GHG Intensity of Fuel (GHG tons/liter of fuel)

All three factors, if reduced, contribute to reductions in GHG emissions; in addition, the three factors may interact with one another. For example, the carbon intensity of diesel fuel is slightly higher than gasoline, but diesel-powered vehicles are typically 30% more fuel efficient than gasoline vehicles. As a result, diesel-powered vehicles have a greater greenhouse gas reduction potential than gasoline-powered vehicles for the same amount of driving. As experience in Europe has shown, however, since diesel vehicles are more fuel efficient, they are likely to be driven farther than their gasoline counterparts. This “rebound effect” may reduce the GHG emissions benefit from diesel vehicles.

Vehicle fuel consumption

The average fuel consumption of new vehicles (as measured in liters of fuel consumed per kilometer traveled) was reduced considerably in 1970s and early 1980s due to federal fuel economy standards, as well as increased fuel prices in the aftermath of the oil shocks of 1973 and 1979. Since the mid-eighties, however, fuel consumption has stagnated at around 10 liters/100 km for new cars (23.5 mpg) and 13.5 liters/100 km for new light trucks (17.5 mpg) when adjusted for on-road performance [Davis and Diegel 2007]. The sales-weighted fuel consumption of new vehicles has been increasing during this period as a result of the increasing number of light trucks in the new-vehicle mix. As a result, the average fuel consumption for the light-duty vehicle fleet remained roughly constant, at 11.7 liters/100 km (20 mpg), as shown in Figure 2.

\[^2\text{1 liter/100 km} = 235.2 \text{miles per gallon (mpg)}\]
The lack of any significant reduction in vehicle fuel consumption during the last 25 years does not imply a lack of technology innovation. In fact, engine and vehicle technology improved steadily during this entire period. Technology improvements are “fungible,” however, in that their efficiency gains can be used to enable other functions such as increased amenities, vehicle power, and weight, rather than directly improve fuel consumption [Plotkin 2000; An and DeCicco, 2007]. EPA analysis of vehicle characteristics during 1981–2003 indicate that if the new 2003 light-duty vehicle fleet had the same average performance and same distribution of weight as in 1981, it could have achieved about 33% higher fuel economy [Hellman and Heavenrich, 2003]. These trade-offs among performance, size, and fuel consumption are discussed further in Section 4.

Vehicle kilometers traveled

The total fleet vehicle kilometers traveled (VKT) in the United States has more than doubled in the past 30 years, as shown in Figure 3 [Davis and Diegel, 2007]. This growth has been steady except for the years 1974, 1979, 1980, and 1991. This large growth in VKT can be attributed to the following factors:

Increased number of vehicles. The number of vehicles in the U.S. LDV fleet increased from about 110 million vehicles in 1970 to over 235 million vehicles in 2005. Most of the growth has come in the light trucks segment, which now accounts for more than half of all sales, as compared to about 15% of sales in 1970.

Increased driving per vehicle. The average annual distance traveled per vehicle increased considerably from 1976–2005. This increased driving can be attributed to growing affluence, increasing urban sprawl and commuting distances, the low cost of driving, and changes in household demographics, such as age distribution. When adjusted for inflation, the cost of
gasoline per liter or gallon has remained essentially constant for the past 35 years, except during the oil shocks of 1970s and since 2002, as shown in Figure 4.

**Figure 3** U.S. vehicle kilometers traveled, 1970–2005 [Davis and Diegel 2007]

**Figure 4** U.S. gasoline price in nominal and real terms, 1970–2006 [EIA 2007b]
Figure 5  U.S. average vehicle travel vs. average fuel cost per kilometer [EIA 2007b]
The average fuel consumption of cars and trucks decreased from 1976–2001. When combined with flat cost of gasoline over this period (inflation adjusted), the net effect is a drop in costs of travel per kilometer. The hypothesis that this has resulted in increased driving is known as the “takeback” or “rebound” effect. Figure 5 shows the increase in average annual distance traveled, while the average costs of driving every kilometer have declined for both cars and trucks. The rebound effect has been estimated to be on the order of 20%, based on historic data from 1970s and 1980s. More recent studies argue that the long-term rebound effect has declined to 10%, and may continue to fall as higher incomes and improved fuel consumption have insulated consumers from price changes [Greene et al. 1999; Greening et al. 2000; Small and van Dender 2007]. Figure 5 (a) also shows that while the cost of driving cars in real dollars has not changed much in the last 20 years, the average amount of travel per car has increased by approximately a one-third.

Greenhouse gas intensity of fuel

Greenhouse gas intensity of fuel used in the light-duty vehicle fleet in the United States has been essentially constant over time because most LDVs run on gasoline. The increasing amount of ethanol blended in gasoline is, however, altering the greenhouse gas intensity of the fuel. In Europe, diesel accounts for a third of fuel use in the light-duty vehicle fleet, since some half of these vehicles use diesel engines [CONCAWE 2007]. In the future, the use of diesel and/or electricity-powered vehicles, as well as different types of biofuels, is likely to increase. However, the greenhouse gas emissions intensity of the fuel may increase or decrease depending on the fuel/electricity production pathway. Sections 6 and 7 discuss the effect of a changing fuel mix on well-to-wheel energy and greenhouse gas emissions from light-duty vehicles.

1.4 Fiscal and regulatory policy options in the United States

In the past, regulation and oil prices have both played an important role in improving vehicle fuel consumption in the U.S. LDV fleet. The stagnation of reductions in vehicle fuel consumption and the relentless increase in vehicle travel since the early 1980s, however, suggest that policy changes will be required in the short- and longer-term future to achieve substantial reductions in fuel use and GHG emissions. Several of the options available to policy makers are reviewed in this section.

1.4.1 Fuel economy standards

Fuel economy standards are mandates placed on manufacturers that regulate the rate of vehicle fuel consumption. In the United States, vehicle fuel consumption is controlled by the Corporate Average Fuel Economy (CAFE) standard, which was first enacted as part of the Energy Policy and Conservation Act of 1975. These standards have established a binding limit on the fuel economy of cars and light trucks in the U.S. over the past three decades, as shown in Figure 6.
Corporate Average Fuel Economy (CAFE) standards have been the dominant policy lever for reducing the fuel consumption of new vehicles in the United States. Since their enforcement, CAFE standards have played an important role in lowering the rate of fuel consumption during the period of high gasoline prices from 1975 to 1985, and in limiting a rebound in increased vehicle fuel consumption through the 1990s, when prices were low [Greene, 1990]. At the same time, they have been criticized for bluntly enforcing fuel economy standards while market forces have maintained a strong preference for larger, heavier, and more powerful vehicles at the expense of fuel savings. As a result, CAFE standards remained relatively constant for two decades, between 1987 and 2007, although light-truck standards increased slightly in the early 1990s. In 2003, the light-truck standards were increased substantially for model years 2005–2007. Proposed standards for 2008–2011 model year light trucks were handed back by the Ninth U.S. Circuit Court of Appeals for not going far enough in regulating fuel economy.

Recently, the Energy Security and Independence Act of 2007 (EISA) increased CAFE standards for both cars and light trucks to a combined average of 35 mpg by the 2020 model year. The new standards will be attribute-based, meaning that fuel economy requirements will be matched to related vehicle characteristics such as curb weight, interior volume, or “footprint”—the area covered by a vehicle’s wheelbase multiplied by its track. Attribute-based standards were used in a previous National Highway Traffic Safety Administration (NHTSA) rule-making for light trucks, to address safety concerns by removing the option of downsizing as a way of meeting CAFE requirements, and to remove the incentive to categorize large cars as small light trucks (NHTSA, 2006a, p. 10).

The EISA 2007 legislation also introduced a credit-trading program as part of the CAFE regulations. Manufacturers that exceed the fuel economy standard for a given model year may earn credits that can be sold to those who fail to meet the requirements, provided that
all manufacturers comply with a specified minimum standard for cars. Automakers may also transfer credits within their own fleets between cars that are made domestically, cars made non-domestically, and light trucks. For internal trading, credits may be used up to a limit that gradually becomes more lenient from 2011–2020. It is believed that these measures will grant auto manufacturers more flexibility in determining how to achieve CAFE requirements within the mix of products that they offer to consumers.

1.4.2 Feebates

Feebates are financial incentives that use a sliding scale to adjust the retail price of cars and light trucks. Under a feebate system, a rebate is subtracted from the price of vehicles that consume fuel at a low rate, while a fee is added to the price of those that consume fuel at a high rate. In this way, consumers are free to choose larger, more powerful vehicles that consume fuel more rapidly, but they must pay an extra fee at the time of purchase. Others who select fuel-sipping vehicle models are subsidized through a rebate on the purchase price.

Applying fees and rebates in such a manner at the time of vehicle purchase induces a response from both consumers and from auto manufacturers. First, when fees and rebates are applied to the price of vehicles at the time of purchase, these price changes are visible to consumers, who shift their purchases towards vehicles with attributes that favor smaller fees or larger rebates (i.e., lower rates of fuel consumption or greenhouse gas emissions). Second, manufacturers can choose to apply technologies that reduce the rate of fuel consumption in order to lower the fee or increase the rebate assessed on a given vehicle.

The amount of the fee or rebate applied to a vehicle is determined by the schedule of the feebate. A linear schedule is the simplest type of feebate. Here, a flat rate is applied per unit of the attribute upon which the feebate is based (e.g., \(x\) dollars per liter/100 km, or \(y\) dollars per mpg, etc.). Feebate schedules may apply continuously across a full range of vehicle offerings, or they may be discretely applied across a limited range. Nonlinear feebate schedules have been suggested that increase the rate of fee or rebate across the range where most vehicles fall, increasing the impact of the policy without placing large feebates on the few vehicles with low or high rates of fuel consumption. Size-based schedules have also been suggested that would normalize feebates to some measure of vehicle size, such as interior volume [Davis et al. 1995].

An advantage of feebates is that they can be made revenue-neutral, such that the rebates disbursed to fuel-sippers balance the revenue collected from the fees minus administrative expenses. This is controlled by the pivot point or zero point of the feebate, or the point where the feebate is zero: vehicles that do better than this point receive a rebate, while vehicles that do worse than this point are levied a fee. Instead of a point, the pivot may be a band or range of values across which the feebate is set to zero. If revenue neutrality is desired, it is necessary to continually adjust the zero point downward as the fuel consumption of vehicles improves under a feebate system.

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3 Credits may be used to achieve no more than one mile per gallon of fuel economy compliance between 2011 and 2013. This limit is relaxed to 1.5 miles per gallon between 2014 and 2017, and to 2 miles per gallon in 2018.
Another advantage of feebates is that they do not discriminate between vehicles that employ different technologies, but focus on improving fuel economy in a technology-neutral manner. One drawback is that they require oversight in how fees and rebates are calculated. Modeling studies of feebates have found that rates on the order of $200 to $500 for every liter per 100 kilometer reduction in fuel consumption are sufficient to incentivize lower consumption in new vehicles.

Surprisingly, these studies suggest that the largest share of the reduction in consumption comes not from consumers purchasing different vehicles, but rather from manufacturers who adjust their product mixes in order to take advantage of the feebate incentive against the retail price of their vehicles [Davis et al. 1995; Greene et al. 2005]. This may, to some extent, overlook the complex trade-offs manufacturers must make against vehicle attributes within a constrained budget [CAR, 2007]. Even with a feebate incentive, manufacturers may still prefer to direct technologies to improve the power and size of vehicles if the consumer willingness to pay for these attributes is higher than the feebate incentive for reducing fuel consumption.

1.4.3 Fuel and carbon taxes

Fuel taxes are taxes levied on the sale of gasoline, diesel, and other transportation fuels. They are typically applied as an excise tax, expressed in dollars per volume of fuel consumed. Governments levy fuel taxes for a number of reasons [Parry and Small 2005]. Primarily, they are seen as an efficient way of raising revenue, but can theoretically also correct for consumption-based externalities such as local air pollution and greenhouse gas emissions created in the consumption of gasoline and other fuels. By increasing the price of fuel, taxes also influence the price of travel, and can indirectly correct for externalities related to the amount of vehicle travel, such as congestion and traffic-related accidents that consumers might not otherwise take into account in their mobility decisions. Finally, taxes act as a user fee for the use of publicly provided roads and highways [Gordon 2005; Wachs 2003].

Carbon taxes are a charge on the environmental externality generated by the emission of greenhouse gases. In the transportation sector, greenhouse gas emissions are largely in the form of carbon dioxide released from the combustion of liquid fuels. Carbon taxes are used to incorporate the costs of climate change impacts into the price of activities that release greenhouse gas emissions, such as the combustion of transportation fuels. Typically, carbon taxes are expressed in terms of dollars per metric ton of carbon dioxide emissions, or simply in terms of dollars per metric ton of carbon. When applied to fuels, carbon taxes can be converted into a dollar-per-gallon amount that forms a portion of the fuel tax. Assuming one gallon of gasoline contains roughly 20 pounds of carbon dioxide, a carbon tax of $100 per metric ton of carbon (or $27 per ton of carbon dioxide) is equivalent to a fuel tax of 25 cents per gallon of gasoline.

Increases in the fuel tax induce two types of response: 1) a change in the amount of vehicle travel, and 2) a change in the rate of fuel consumption in vehicles. As fuel taxes increase, consumers respond by reducing vehicle travel. This can be done by adding or eliminating inefficient trips, carpooling, and switching modes of transportation (e.g., shifting from private to public transportation). Recent literature suggests that income growth and
improved rates of fuel consumption in vehicles have insulated consumers from short-term increases in fuel price, reducing this effect to as much as one-fifth of what it was in the early 1980s [CBO 2008].

When fuel price increases are sustained over a longer period of time, consumers begin to change their purchase decisions in favor of vehicles with lower rates of fuel consumption. Manufacturers respond to this demand by implementing technologies and vehicle designs that emphasize lower fuel consumption over other attributes. As long as prices remain high for sustained amounts of time (on the order of 10–15 years), studies have estimated that the magnitude of this response may increase by three to five times over the longer term [Small and Dender 2007; CBO 2008]. There is uncertainty in these estimates, and the level of response is likely sensitivity to a number of factors, such as income and the rate of fuel consumption in existing vehicles [Hughes et al. 2007].

It is argued that fuel taxes are the most effective way to limit fuel use and greenhouse gas emissions from vehicles. Fuel taxes influence both the amount of vehicle travel and the rate of fuel consumption in vehicles, and they act upon existing on-road vehicles as well as new automobiles entering the fleet. Studies have also estimated that fuel taxes are more cost-effective than CAFE regulations for saving fuel [Austin and Dinan 2005].

The disadvantages of increasing the fuel tax are that low-income and rural groups may be affected disproportionately by higher fuel prices. Increases are also politically sensitive, because small changes in the fuel tax generate a large amount of revenue for the government. At the same time however, studies have suggested that the current fuel tax is not sufficient to fully reimburse government expenditures on vehicle infrastructure and services [Delucchi 2007], nor is it enough to account for the various externalities associated with private vehicle travel [Parry and Small 2005]. This suggests that there are social benefits to raising the fuel tax, particularly if a portion of the revenue is rebated to lower-income groups to offset the regressive impact.

### 1.4.4 Pay-As-You-Drive and Pay-At-The-Pump charges

Motorists who drive often are more likely to get into an accident than others who drive less. Currently, automobile insurance is paid in an annual lump-sum amount that has been likened to an “all-you-can-eat buffet” [Bordoff and Noel 2008]. Once the lump-sum amount is paid, people tend to over-consume—in this case by driving further than they would if the price of insurance took into account their amount of travel relative to other consumers.

Measures that would roll the lump-sum cost of insurance into a variable rate based on the distance traveled or the amount of fuel used by a vehicle, could correct this to a certain extent. Figure 7 shows the costs of owning and operating an automobile in 2006. The cost of vehicle insurance is roughly equal to the cost of fuel. Since depreciation is not a cash transaction, insurance premiums have the greatest potential to impact driving costs, followed by registration and license fees.

A Pay-As-You-Drive (PAYD) system would correct this to a certain extent by rolling the up-front costs of annual insurance payments into a price per unit of distance traveled.
Under such a system, individuals who drive below average would pay lower premiums, while those who travel more than average would pay more; the premium of the average driver would remain unchanged. By calculating premiums on a pay-as-you-drive basis, rather than an all-you-can-drive basis, the approach would provide all drivers with a continuous price incentive to reduce vehicle travel.

An alternative approach, Pay-At-The-Pump (PATP) charges transfer a portion of the fixed costs of owning and operating a vehicle to a variable cost based on fuel use. Instead of an annual or semi-annual collection of charges such as insurance premiums, registration fees, and emissions-test fees, a PATP scheme collects these charges at the gas pump. The intent of PATP charges is to discourage low-value travel and promote the purchase of more fuel-efficient vehicles without raising the total costs of driving for the average driver. PATP proposals have been motivated more by efforts to reform auto insurance legislation rather than to correct the pricing of auto insurance.

A major advantage of a PATP insurance scheme is that all motorists would have insurance. Uninsured drivers, however, often come from low-income households, and some households will pay much more at the pump than they will save by not paying annual registration or insurance fees. Trial lawyers are also opposed to “no-fault” PATP program because they claim these programs would limit the ability of an individual to sue for non-economic damages [Wenzel 1995]. Finally, insurance and registration fees are state-dependent, so it would be difficult to coordinate a national-level PATP scheme. This makes such schemes an unattractive policy option at the federal level.

At the same time, although regulatory and cost barriers still exist, improvements in GPS technology and pilot programs conducted by insurance companies appear to have renewed interest in PAYD schemes. Under PAYD, the regressive impacts on lower income households may be less since these groups drive less than higher-income categories [Bordoff and Noel 2008; Figure 3, p. 9]. PAYD could more flexibly account for other important insurance risk factors, such as age, driving history, location, and time of day [Parry 2005]. Studies have estimated that substantial social benefits (on the order of $150 to $225 per insured vehicle) are offered by linking insurance premiums to annual travel. Suggested premiums are on the order of 6 cents per mile, or $1.20 per gallon [Bordoff and Noel 2008; Parry 2005; Edlin 2003].

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4 Assuming the current average light-duty vehicle fleet fuel economy of 20 miles per gallon.
1.4.5 Scrappage incentives

At the final stage of the vehicle life-cycle, *scrappage incentives* would provide a rebate to vehicle owners to promote earlier retirement of aging vehicles. To the extent that retired vehicles lead to new vehicle sales, and that these new vehicles travel farther on a liter of fuel, scrappage programs can increase the rate at which the on-road fleet achieves fuel consumption reductions. Early retirement also has a positive impact on local air pollution, as the oldest vehicles are responsible for a disproportionate share of total emissions.

Scrappage incentives can be combined with feebates or other differentiated vehicle taxes in order to promote the adoption of vehicles with lower rates of fuel consumption upon retirement of an older vehicle. For example, France’s proposed feebate system includes a scrappage incentive for vehicles 15 years or older [Government of France, 2008].

Two drawbacks to scrappage programs are that they may increase the price of used vehicles, which can affect low-income groups that typically purchase older vehicles; also, that they may increase the migration of older vehicles into the area where the incentive is offered, thus offsetting some of the policy’s benefits. One study in California found the regressive effect of a scrappage incentive to be smaller than expected, with average used car prices increasing by at most 5%, or $300 per vehicle. Local emissions reductions were very dependent upon the assumptions made regarding the age of vehicles which migrate into the area—under a worst-case assumption, the base-case emissions reductions predicted for the incentive were offset by two-thirds [Dixon & Garber, 2001: pp. 63-64; Table 7.2, p. 58].