## Commission Briefing Paper 4D-03

# Evaluation of Surface Transportation-Related Strategies to Reduce Mobile Source Greenhouse Gas Emissions

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### Introduction

This paper is part of a series of briefing papers to be prepared for the National Surface Transportation Policy and Revenue Study Commission authorized in Section 1909 of the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU). The papers are intended to synthesize the state-of-the-practice consensus on the issues that are relevant to the Commission's charge outlined in Section 1909, and will serve as background material in developing the analyses to be presented in the final report of the Commission. This paper presents information on strategies available to reduce greenhouse gas emissions from surface transportation and addresses the effectiveness of these strategies, as well as implementation issues, potential revenue impacts, and other factors to consider.

### Key Findings

- Transportation is a major contributor to greenhouse gas (GHG) emissions in the United States and will likely be an important sector for policies designed to address the threat of global climate change.
- Because carbon dioxide (the most prevalent and important GHG) is produced in proportion to fossil fuel consumption, with slight differences by fuel type, reducing GHG emissions from surface transportation requires a reduction in the consumption of this type of motor vehicle fuel. This has important implications for transportation revenues given the current use of fuel taxes as the primary revenue mechanism for highway funding.
- Vehicle technologies offer significant potential to improve the fuel economy of motor vehicles and result in substantial GHG emissions reductions in the near term. Policies to advance production and consumer purchases of more fuel-efficient vehicles will affect vehicle manufacturers and consumers, but have limited effects on transportation infrastructure development.
- Increased use of certain alternative fuels, specifically those that are low in carbon or renewable, offers longer-term potential to substantially reduce GHG emissions; however, these strategies face some difficulties in achieving widespread adoption, including costs of production and limited infrastructure for refueling.
- Strategies to reduce the demand for vehicle travel and optimize the efficiency of the transportation system can play a supporting role in reducing GHG emissions from transportation but are generally expected to have relatively small impacts. Policies that require addressing GHG emissions in the transportation planning process, however, could strengthen efforts to increase use of transit, non-motorized modes, ridesharing, and operational strategies, and result in changes in the transportation planning process itself.

## Commission Staff Comments

The effectiveness of many of the strategies presented in this paper is portrayed affirmatively; however, it is sometimes difficult to predict how effective these strategies actually would be.

Ethanol also has a slightly lower energy density than gasoline, which leads to slightly decreased fuel economy of about 1 percent for an 85 percent ethanol, 25 percent gasoline blend. The production of ethanol on a scale capable of supplanting a significant portion of gasoline use is expected to require a significant portion of U.S. arable land. This could put significant upward pressure on corn prices, which are used both as direct food for humans and as a feedstock for cattle. An increase in total crop land would also stress water supplies in some regions and produce additional fertilizer and pesticide deposition in waterways. Very little hydrogen infrastructure currently exists

Heavy batteries made with existing technology provide a limited travel range. This range can be extended through the use of plug-in hybrid vehicles that run on a combination of gasoline, electricity, and possibly also biomass fuels. GHG emissions will again depend on the fuel source for the electricity and the particular combination of fuels, but in all cases are less than an equivalent vehicle running on only gasoline.

Alternative fuel vehicle (AFV) mandates can be difficult to implement if sufficient infrastructure and fuel availability is not present.

## Introduction

Although transportation is a vital part of the economy and is essential for everyday activities, it is also a significant and growing source of greenhouse gas (GHG) emissions. In 2004, the transportation sector accounted for nearly 28 percent of total U.S. GHG emissions, up from 25 percent in 1990. Transportation GHG emissions increased by a larger amount than any other end-use economic sector over this period, growing by 28.6 percent, while GHGs from all other sectors increased by 11.6 percent.[i] In 2004, about 84 percent of transportation GHG emissions came from surface transportation, with the vast majority from on-road vehicles (81 percent of the transportation total); 3 percent of GHG emissions were from rail. "Light-duty" vehicles (primarily passenger vehicles) produced about three-quarters of on-road emissions. "Heavy-duty" vehicles (primarily freight trucks), however, produced a disproportionately large share of GHG emissions compared to their level of travel, producing about 23 percent of on-road GHG emissions, while making up less than 8 percent of vehicle miles traveled. Overall, the U.S. transportation sector derived all but 1 percent of its energy from fossil fuels, 97 percent of which was petroleum.

Growing concern about the potential threat of climate change and the contribution of transportation activities to GHG emissions and energy consumption are likely to spur increased policy focus on strategies to reduce GHG emissions from transportation. As of January 2006, 42 States and Puerto Rico have developed GHG inventories, and 29 of them have developed detailed Climate Change Action Plans. Seven States have actually set numerical GHG emissions reduction targets, and at least four have considered transportation measures in the portfolio of options that will be used to achieve those targets. California has adopted regulations to reduce GHG emissions from new vehicles by 22 percent by the 2012 model year and 30 percent by the 2016 model year. As States aim to address global climate change, and if national policy also increases focus on the issue, there will be increased emphasis on transportation strategies to reduce GHG emissions. These strategies, in turn, may have important implications for vehicle technologies, fuels, travel demand, and the transportation planning process.

## Overview of Transportation Strategies to Reduce GHGs

A range of strategies are available to reduce GHG emissions from surface transportation. Because carbon dioxide (the most prevalent and important GHG) is produced in proportion to fossil fuel consumption, with slight differences by fuel type, strategies to reduce transportation GHG emissions target one or more of the basic determinants of transportation energy demand, focusing on the following activities:

1. improving the fuel economy of the vehicle fleet;
2. increasing the use of low carbon or renewable fuels that emit fewer greenhouse gas emissions than conventional (gasoline and diesel) fuels; and
3. reducing the demand for motor vehicle travel or improving the energy efficiency of the transportation system, such as through transportation planning or investment that encourages greater use of transit, ridesharing, and non-motorized modes, teleworking or telecommunications, or through traffic flow improvements and operational enhancements (e.g., reducing congestion, faster clearing of incidents).

Within these broad strategy areas for reducing GHG emissions, a number of policies can be implemented. These range on a continuum from regulatory to incentive-oriented policies to voluntary/educational programs. The type, scope, and stringency of policies implemented therefore play a key role in determining emissions reduction potential. For instance, the expected effects of increased motor vehicle fuel economy standards will depend upon the degree to which standards are raised; similarly, the impact of fuel taxes will depend on the level of the tax increase.

Both beneficial and adverse consequential impacts are associated with these GHG reduction policies. Among the co-benefits are improvements with regard to energy security/oil dependence, air quality, land use, infrastructure needs, and agricultural production opportunities. Potential adverse impacts are highly speculative, but could affect vehicle manufacturing (decreased vehicle miles traveled [VMT] lowering vehicle demand), fuel stations (due to improved fuel economy across all fuels), petroleum refining, sunk infrastructure and land development investments, and distributional and transitional costs for indirectly impacted workers, industries, and businesses. While these critical issues merit further attention, they are beyond the scope of this paper.

## Vehicle Technologies/Improved Vehicle Fuel Economy

***Available Technologies*** A variety of technologies are available to increase vehicle fuel efficiency, which is typically expressed in terms of miles per gallon (mpg). Once a vehicle is manufactured, its fuel economy is largely fixed for its useful life. Therefore, improving the energy efficiency of the total stock of on-road vehicles requires changes in the characteristics of new vehicles. The average fuel economy of new light-duty vehicles sold in the United States has not changed substantially since the late 1980s.[ii] However, substantial improvements in the fuel economy of new vehicles are possible given existing and emerging technologies.

The generalized engineering equation for fuel efficiency accounts for engine efficiency, rolling resistance, and aerodynamic resistance.[iii,iv] Thus, vehicle-based improvements in fuel economy can be classified in terms of the following factors:

- vehicle technology (accounting for engine and transmission improvements),
- vehicle characteristics (in terms of rolling and aerodynamic resistance), and
- maintenance improvements (helping tire inflation, oil viscosity, and engine performance to remain near optimal design standards)

Among engine technologies, perhaps the most promising is the hybrid-electric engine (in combination with either gasoline or diesel). Already achieving an impressive penetration rate for a new engine type, this technology allows engines to turn off during what normally would be idle states. More importantly, the electric generator and regenerative braking allow for very high recovery of braking energy, nearly doubling fuel efficiency during stop-and-go conditions; however, little to no advantage is provided for highway driving. Still, with high adoption rates, total fuel savings could reach 15 to 20 percent for light-duty vehicles (LDVs, which account for 12 to 16 percent of total motor vehicle fuel).[v] Penetration rates for hybrid technology in medium- and heavy-duty trucks are highly speculative, and for long-haul trucks likely quite low. Given that approximately 40 percent of medium-duty truck fuel consumption (i.e., excluding tractor-trailers, SUVs, pickups, etc.) is used for non-interstate urban travel,[vi] 50 percent hybrid penetration of this market would mean fuel savings of 3.6 percent of all medium- and heavy-duty truck fuel use (0.7 percent of total motor vehicle fuel).[vii]

Advanced engine control systems provide another source of improvement, such as through optimized direct fuel injection, variable engine control, and idle off systems. Improvements to transmission efficiency provide another promising means of increasing fuel economy. Already being implemented in some models, technologies such as continuously variable transmissions allow for improved performance over both standard and automatic transmissions by optimizing gear-power ratios and eliminating shift loss.

Diesel engines provide an advantage over gasoline in terms of fuel economy, largely due to high engine compression ratios, as well as direct-injection and often turbo-charging. Consequently, shifts to diesel engines offer potential fuel economy improvements for light-duty vehicles (heavy-duty vehicles are already largely diesel) and could be implemented in a relatively short timeframe. For the whole of the European Union, the share of new cars registered that are diesel grew rapidly from 22.2 percent in 1995 to 36.4 percent in 2001.[viii,ix] Total fuel economy savings by switching to diesel could reach 20 percent or higher per vehicle. With a penetration rate of 15 percent, a total fuel savings of approximately 3 percent of LDV fuel consumption could occur.

Fuel economy in the freight system can be improved by idle-reduction strategies for trucking and locomotives; these can include both on-board and off-board units to provide auxiliary power needs. On-board idle reduction systems include auxiliary power units that provide electricity to the cab, direct-fired heaters and coolant systems that provide temperature control, and programmable automatic engine shut-off systems. Truck plazas equipped with truck stop electrification systems allow trucks to draw electrical power and, in some cases, heating, cooling, telecommunication, and Internet hookups from a ground source.[x]

Vehicles' physical characteristics also can be improved to increase fuel efficiency, primarily by reducing rolling resistance (through weight reduction or improved tires) or through reduced aerodynamic resistance. Weight reduction has been achieved within vehicle classes over recent years primarily by decreasing the weight of individual components (i.e., through the use of plastics, aluminum, or composites). Shifts to purchases of heavier classes of vehicles, primarily SUVs, have more than offset these improvements. However, the trend appears to be easing back toward lighter vehicles, especially through the recent popularity of some compact and sub-compact models and as a consumer response to high fuel prices. In addition to weight, improved tires (including automatic tire inflation systems) can also reduce rolling resistance. If implemented aggressively, together these measures could improve fuel economy up to 15 percent. Improvements in aerodynamics, while highly dependent on manufacturer inclinations, could provide an additional 5 to 10 percent improvement in fuel economy.

In total, fuel efficiency improvements from incremental vehicle technologies have been estimated to increase the fuel economy of new intermediate passenger cars from 28 mpg to between 39 and 59 mpg over the next 10 to 20 years, resulting in a 30 to 50 percent reduction in fuel consumption for these new vehicles.[xi] Even on existing heavy-duty vehicles, upgrades, such as the EPA SmartWay Upgrade Kits, which include an idling reduction device, tractor and/or trailer aerodynamics, and low rolling resistance duals or single-wide tires, are estimated to improve fuel economy by up to 30 percent.

Since most vehicles' performance, including fuel efficiency, declines slightly over time, manufacturers' efforts to retain original performance through use of superior quality and longer-wear parts, improved on-board diagnostics, and easy-to-follow maintenance schedules can help to maintain efficiency of the in-use vehicle fleet. However, these effects are limited and generally within the range of a few percent.

***Policy Levers*** Policies to spur the development, manufacture, and demand for more fuel-efficient vehicles and technologies include the following:

- Regulatory approaches such as Corporate Average Fuel Economy (CAFE) standards or carbon dioxide ($CO_2$) emission standards;
- Economic incentives such as research and development programs, feebates, registration fees, or fuel price increases; and
- Voluntary/information programs to influence consumer behavior.

The most important policy in achieving fuel economy improvements has been the CAFE standards, which helped result in substantial improvements in the fuel economy of new light-duty vehicles between 1978 and the mid-1980s.[xii] The reported fuel economy of both passenger cars and light-duty trucks has closely mirrored CAFE standards, and these standards ensure that minimum levels of fuel economy are met. However, implementing fuel economy standards can result in side effects, such as the shift in consumer purchasing patterns toward light-duty trucks, which have a lower fuel economy standard.[xiii] Manufacturer mergers may increasingly complicate the selection of which makes and models to include in a firm's average. Consequently, alternative approaches to CAFE have been proposed, including standards based on vehicle class sizes or other factors.

Carbon dioxide emissions standards effectively function as a fuel economy standard. While, in principle, a tailpipe emissions standard could account for varying $CO_2$ emissions per gallon from gasoline, diesel, and alternative fuels, designing a regulatory regime that meaningfully combines fuel choices (made by consumers) with vehicle attributes (chosen by manufacturers) presents significant challenges. For larger trucks or buses, a fuel economy or emissions per ton-mile or per ton-mile capacity could be adapted. Note, however, that such a strategy would tend to encourage oversized vehicles, while emissions are actually minimized by matching the vehicle size to the load to be carried.

Economic incentives also can stimulate the adoption of vehicle fuel-efficiency improvements. Feebates provide a rebate for the purchase of more fuel-efficient vehicles and a tax for the less efficient (the latter already exists as the "gas guzzler" tax). Emission-based registration fees function similarly (and can be implemented jointly with feebates), but one advantage is that they influence drivers' decisions each year, not just at the time of initial purchase. Both feebates and emission-based registration fees can be designed to be revenue neutral, thus making them low-cost economic incentives. Increased fuel prices, such as through higher gas taxes, also can encourage shifts toward purchases of more fuel-efficient vehicles. However, fuel-economy standards, if set appropriately to allow adequate time for manufacturers to change designs without sacrificing consumer attributes, tend to be better accepted by consumers, particularly if the fuel savings largely offset the increased cost of the fuel-economy technology.

Research and development (R&D) investments can help catalyze some technologies and improvements. These investments can represent a sound public policy for obtaining social benefits faster than if left solely to the market. In some cases, private firms may not want to make large R&D investments if they believe their competitors will be able to mimic the technology as "free riders." Public investment in fuel economy campaigns and voluntary program initiatives also can help spur greater awareness among consumers about the financial benefits from fuel efficiency as well as social benefits from energy security and reduced emissions. EPA's SmartWay Transport Partnership is a voluntary program focusing on the freight industry to encourage idle-off and other technologies and practices to reduce freight fuel consumption.

Technology introduction and fleet turnover are important issues for all of the described policy strategies. It often takes 3 to 6 years for a new model with new technologies to be designed, developed, and put into production. Light-duty vehicles typically have a life of about 15 years, with heavy-duty trucks' median lifetime at 28 years.[xiv] Thus, these strategies take a number of years to reach their full productiveness, but for light-duty vehicles in particular, significant advances in fuel economy could occur within a decade. For heavy-duty vehicles, idle-off and other retrofit technologies can also significantly improve fuel economy in the short term.

## Alternative Fuel Strategies

Transportation fuels are dominated by petroleum, with most light-duty vehicles fueled by gasoline and heavy-duty vehicles fueled by diesel in the U.S. Since GHG emissions from transportation are a direct result of petroleum combustion, the use of alternative fuels that are less carbon-intensive is a promising strategy to reduce GHG emissions and the Nation's dependence on petroleum.

Although alternative fuel approaches are similar to other vehicle technology improvements in that they involve changes in the production and sale of new vehicles, they also face a number of additional challenges. One of the most common challenges associated with low-carbon fuels, such as hydrogen, is the lack of existing delivery infrastructure and vehicle designed to run on them. Moreover, in examining the GHG impacts of these fuels, it is necessary to consider the full life-cycle emissions ("well to wheel") to more accurately gauge the GHG performance of a fuel.

This includes not only tailpipe emissions (i.e., emissions resulting from the direct use of the fuel by the consumer) but also the energy associated with extracting the fuel feedstock, refining or producing the fuel, and delivering it to the end user. For instance, corn-based ethanol requires diesel farm equipment and fertilizer inputs just to create the feedstock that must still be converted to ethanol. Electricity, which results in no tailpipe emissions, can be generated from a variety of sources, ranging from a GHG-intensive source—such as coal—to hydropower, a GHG-free source.

***Fuels to Reduce GHGs*** A wide range of alternative fuels may be used to reduce petroleum use, with each providing a different set of advantages, as well as technical and logistical challenges.
Liquefied petroleum gas (LPG) is currently the most widely available alternative fuel in the United States, as more than 350,000 vehicles are serviced by about 4,200 fueling stations. Due to a lower carbon content and life-cycle GHG emissions, some estimates show that LPG vehicles can achieve a roughly 20 percent reduction in GHGs with a total changeover from comparable gasoline vehicles, but these estimates may vary. With an energy density and storage needs similar to gasoline, LPG can provide a comparable range and performance. However, LPG is a relatively minor byproduct of natural gas processing and crude oil refining. Therefore, it cannot replace petroleum on a large scale in the long term. In the near future, it can provide modest GHG reductions, with additional air quality benefits.

Compressed natural gas (CNG) also can reduce GHG emissions by up to 20 percent with a complete changeover compared to gasoline-powered vehicles. Similar caveats to LPG apply to CNG, as well. Large domestic reserves of natural gas and an extensive supply infrastructure can facilitate the market penetration of CNG. However, with a low energy density, CNG is more difficult to handle and requires significantly different on-board storage technology. Additionally, the use of CNG results in much higher methane emissions than gasoline. Methane is another GHG emitted as a byproduct of fossil fuel combustion. Although methane emissions account for a much lower portion of GHGs than carbon dioxide, it is a much more powerful greenhouse gas. Therefore, a small increase in methane emissions may offset the GHG benefit, requiring the installation of a methane catalyst to maintain the benefit.

Biomass-based fuels such as ethanol and biodiesel are particularly promising alternative fuels, in part because they perform and are handled much like petroleum fuels. Ethanol is widely used as a blending agent in reformulated gasoline due to local air quality requirements and Federal tax incentives. Corn-based E85 represents a 25 percent reduction in GHG emissions compared with gasoline-powered vehicles, and researchers anticipate that cellulosic feedstock-based ethanol could reduce life-cycle GHG emissions by nearly 80 percent. Biodiesel (B20) provides a 20–30 percent GHG benefit over gasoline, primarily due to the greater energy density. However, the corn-based ethanol life cycle is petroleum intensive under current practices, and technology for cellulose-based ethanol has not been commercialized yet. Additionally, current production must be greatly increased in order to meet the Nation's transportation fuel demands, but this also represents an important economic opportunity for the Nation's agricultural regions. Hydrogen vehicles have zero tailpipe GHG emissions, while life-cycle emission reductions depend on the feedstock used. Hydrogen infrastructure currently exists, and due to the low energy density of hydrogen gas, on-board fuel storage technology poses significant challenges. However, hydrogen can be used as a fuel in two ways—either in internal combustion engines or in fuel cells. This two-method approach can help the fuel transition into greater use in the future, though technological advances will still be needed before hydrogen is widely available.

Electricity offers many of the same advantages and disadvantages as hydrogen—there are no tailpipe emissions, and life-cycle emissions depend on the fuel used to generate electricity. Based on the average national electricity profile, lifetime GHG emissions are 27 percent lower than gasoline, but electricity from GHG-free sources such as hydro and nuclear power would result in zero GHG emissions. Although electric vehicles may take advantage of the existing energy infrastructure, on-board storage options are currently limited. Heavy batteries made with existing technology provide a limited travel range.

***Policy Levers*** Policy actions, such as alternative fuel vehicle (AFV) mandates, direct or indirect support of R&D of fuels and AFVs, and carbon taxes or other forms of fuel-specific taxes, can encourage the development and adoption of alternative fuel markets. One form of AFV mandate requires vehicle purchasers such as government agencies and large fleet owners to purchase a minimum percentage of AFV vehicles. Another form requires the minimum sales of AFVs by vehicle producers. In both cases, the intent is to generate demand for AFVs and encourage market development. Such policies may be useful in creating market niches, but adoption in these niches does not always translate to success in the broader market. Support for R&D, either through direct funding or indirect methods such as tax credits, aims to stimulate alternative fuel technology research so that it advances faster than it would otherwise. The benefits of R&D incentives are likely to be long term, though well-targeted research could provide progress toward short-term goals.

A carbon tax is tied directly to the carbon content of the fuel, thereby increasing fossil fuel prices. Alternatively, a system of fuel taxes could be implemented that taxes alternative fuels at a lower rate. In both cases, the differential tax rates provide an incentive for consumers to switch to AFVs. Additionally, the increased cost of fuel would also encourage the manufacture of more efficient vehicles and a reduction in vehicle travel. The effectiveness of such a strategy would depend on the level of the tax and the elasticity of consumer response. By pricing a negative externality (carbon emissions), broad-based carbon taxes could lead to greater economic efficiency overall, but at a risk of slowing economic activity due to the increased cost of energy.

## Travel Activity/Behavioral & System Changes

***Behavioral Changes That Reduce GHGs*** Several behavioral mechanisms can reduce transportation GHGs. Motorists can reduce the absolute number of vehicle miles traveled (VMT), for example, by combining trips, taking shorter trips, telecommuting, or carpooling. Alternatively, consumers could choose to switch to less GHG-intensive modes, such as from low-occupancy personal vehicles to transit, and businesses could switch from trucking to rail or waterway. Or motorists can improve fuel efficiency, such as through slower/smoother acceleration, slower speeds, avoiding driving during congested periods, and improved maintenance practices. Although vehicle technologies and alternative fuel options may be addressed on the national level, behavioral and system changes are best implemented through the local and regional transportation planning processes.

***Travel Strategies*** Policies to reduce vehicle travel include increased investments in transit, bicycle, and pedestrian facilities; ridesharing facilities and programs (such as high-occupancy vehicle lanes and park-and-ride lots); land use policies (such as transit-oriented development); demand management programs (such as programs designed to encourage employers to reduce employee trip making through telecommuting, transit, and ridesharing); and pricing (such as parking pricing, road pricing, and increased fuel taxes).

Traditional transportation demand management strategies have proven to be of limited effectiveness as a means to reduce urban air pollution, and modest impacts are expected in terms of reductions in GHG emissions. Although carpooling and transit play a key role in reducing traffic congestion in many markets, investments and programs to encourage greater use of them—through high-occupancy vehicle (HOV) lanes, park-and-ride facilities, and transit rail and bus service enhancements—are often quite expensive in terms of cost per ton of emissions reduced (though cost effectiveness can improve significantly when travel time savings are factored in). While demand management programs, such as rideshare matching and employer-based programs, are often cost effective, their overall application has become of minor significance, as commuting during regular business hours represents a decreasing share of total VMT. If these measures were to be implemented aggressively as a comprehensive package across an entire metropolitan region, it would maximize their synergies and could result in a 6 percent reduction in urban commute VMT (a 1.7 percent reduction in urban VMT or 1.1 percent reduction in total light-duty VMT).[xv] Investments in transit, ridesharing, and other demand management programs would likely have to be substantial and combined with supportive land use policies to have more notable effects in reducing the demand for vehicle travel. Thus, realistic levels of transportation demand management (TDM) implementation are unlikely to yield significant GHG savings.

However, modeling suggests that a combination of strong land use policies (focusing on transit-oriented development and mixed-use, pedestrian-friendly design), combined with transit investments and bicycle and pedestrian facilities, can play an important supporting role in reducing GHG emissions, while achieving benefits in terms of reduced criteria air pollutant emissions, reduced traveler delay, and more sustainable communities. For instance, Portland, Oregon's, regional vision for 2040 includes transit-oriented development, mixed-use centers, transit system improvements, and market strategies (a daily parking charge for commuters who drive alone and free transit passes, at least partially funded by parking revenues). Modeling revealed that this vision could result in an 8 percent reduction in motor vehicle fuel consumption and carbon dioxide emissions compared to a more auto-oriented growth pattern.[xvi]

Pricing strategies take a number of forms and are generally quite effective, at least in the limited real-world examples in place. However, pricing strategies are often initially unpopular with the public, although recent experience with road pricing suggests that drivers are willing to pay higher prices to travel if benefits, such as free-flow conditions, are associated with the increased charges. Increasing fuel taxes could be an effective strategy since it not only encourages reduced vehicle travel but also sends a price signal that encourages sales of more fuel-efficient vehicles, thereby having both a VMT and fuel economy impact. Contrary to earlier research, recent studies suggest, however, that light-duty vehicle fuel consumption is less responsive to fuel price increases.[xvii] Parking pricing, whether an increase in existing prices (including meters or municipal parking) or pricing free spots (including mandatory parking cash-out and on some residential or street parking) can shift mode choice and/or lead to combining trips (park once). Road pricing in the form of congestion pricing mainly enhance capacity by balancing traffic flow but also encourages carpools and other mode shifts. Pay-as-you-drive insurance would make this fixed cost into a marginal one; elasticity-based estimates indicate a VMT reduction as high as 10 percent if there were full implementation. VMT-based registration fees have not been implemented (although per mile charges are being tested in Oregon) but would apply a less immediate and thus less effective means of shifting behavior. Thus, pricing measures already being implemented show substantial promise from VMT reductions relative to traditional behavioral strategies.

Strategies to influence driving behavior can also have a significant effect on fuel consumption. Lowering speed limits and increasing enforcement on highways to a maximum of 55 mph would reduce fuel consumption. Greater driver awareness of fuel savings through efficient gear-shifting and acceleration/deceleration patterns also are quite effective. Programs, mostly through consumer awareness campaigns, to encourage vehicle maintenance (e.g., through use of low-viscosity motor oil, ensuring proper tire pressure, and improved tire quality) may reduce full consumption by 2 percent or more with a high (50 percent) penetration rate.[xviii]

Traffic flow improvements, including intelligent transportation systems and traveler information, can reroute traffic from congested areas where fuel economy suffers. Traffic signal improvements and efficient incident management can smooth traffic flow and clear road blockages more quickly, also improving fuel economy. Mode shifts from trucking to rail and especially to water can improve fuel efficiency where feasible and economically viable; however, there are limited cases where this applies. Freight logistics also can be improved to reduce fuel consumption, as many shipping firms already include fuel costs in their prices. However, there are opportunities for logistics to be extended between firms, especially for urban distribution and deliveries. Europe has already introduced public programs to encourage this.

***Policy Levers*** Although vehicle technology and alternative fuel options are typically addressed through Federal policy, behavioral and transportation system changes rely more heavily on local and regional implementation and may have important implications on State and metropolitan transportation planning. Effective transportation planning, especially strategic planning that incorporates emission reductions as one of the objectives rather than merely a constraint to other objectives, is critical to success in achieving effective behavioral changes which may have multiple benefits. Several States, including Massachusetts, New York, and Vermont, now require that transportation plans examine energy use and GHG emissions. These types of requirements in the transportation planning process can spur additional emphasis on travel demand management, transit, and system operational efficiency strategies.

## Conclusions

The most effective strategies for reducing $CO_2$ are likely to be those that influence the vehicle fleet through new vehicle technologies and fuels. As described in the corresponding sections above, per mile $CO_2$ reductions on the order of 50 percent for fuel economy and 80 percent for alternative fuels for appropriately equipped vehicles are possible in the 25-year timeframe. Vehicle technology changes show the greatest short-term potential, with substantial fuel savings and GHG benefits available within 10 years if policies are aggressively pursued. Alternative fuels have great longer-term potential but need to overcome technological and economic-viability barriers, address full fuel cycle emissions, and face fuel distribution transition issues—all of which greatly slow penetration rates.

Travel demand management and operational improvement strategies are more likely to be supporting strategies that result in modest reductions in vehicle fuel consumption. Investments in transit and high-occupancy vehicle facilities can be expensive, and land use measures that are necessary to support broader scale reductions in vehicle travel require a relatively long time horizon to have regional impacts.

In theory, pricing through increased fuel taxes or a "carbon tax" would be the most economically efficient means to reduce GHG emissions from transportation, since this type of price signal supports multiple strategies. Specifically, increased fuel taxes can encourage consumers to purchase more fuel-efficient vehicles, switch to low-carbon fuels, and reduce vehicle travel. However, increasing fuel prices to the extent that they would be a significant price signal is unpopular with the public and may have substantial adverse impacts on the economy. Regulatory approaches, such as fuel economy requirements, if timed properly and implemented in a way that industry can meet them, are more likely to be accepted by consumers and offer the potential for substantial GHG emissions reductions. Voluntary programs to encourage reduced fuel consumption can also be a win-win for consumers and the environment.

Many of these strategies—notably most vehicle technology and fuels strategies—have limited implications on the future development of transportation infrastructure. The largest implication will likely be on transportation system revenues, given that the current system for funding highways relies on fuel taxes, and the need for additional highway funding sources continues to grow. However, policies that require transportation planning to account for GHG emissions could have implications for State and metropolitan transportation decision-making, resulting in increased emphasis on integrating land use and transportation needs, transit and non-motorized transportation, and pricing. Moreover, reducing GHG emissions may have multiple benefits by saving consumers and the freight industry money on fuel costs, reducing dependence on foreign oil, and helping to reduce urban air pollution problems.

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[i] U.S. Environmental Protection Agency, "Greenhouse Gas Emissions from the U.S. Transportation Sector:1990-2003" (EPA420-R-06-003, March 2006). With updates by ICF International.

[ii] Sales-weighted fuel economy of new light-duty vehicles peaked at 22.1 mpg in 1988. The relatively flat fuel economy is due primarily to two factors: (1) only moderate improvements in fuel economy for passenger cars and light-duty trucks; and (2) increased market share for light-duty trucks, which tend to be less fuel efficient than passenger cars.

[iii] See, for example, Gillespie, T.D., 1992, *Fundamentals of Vehicle Dynamics*, Society of Automotive Engineers, Warrendale, Pennsylvania.

[iv] Context-specific versions also address speed, acceleration, traffic, inclines, and road conditions.

[v] Calculations from www.fueleconomy.gov/feg/hybrid_sbs.shtml and www.fueleconomy.gov/feg/findacar.htm. Estimates have some uncertainty due to differences between test and real-world fuel economy.

[vi] U.S. DOT, FHWA, *Highway Statistics 2005*, Table VM-1.

[vii] Calculations from www.fueleconomy.gov/feg/hybrid_sbs.shtml, www.fueleconomy.gov/feg/findacar.htm, and U.S. DOT, FHWA, *Highway Statistics 2005*, Table VM-1.

[viii] This increase was a market reaction to high fuel prices in an environment of accommodating emission standards for "clean diesel," rather than the result of a regulatory initiative.

[ix] European Commission, 2002, "Implementing the Community Strategy to Reduce $CO_2$ Emissions from Cars — Third annual report on the effectiveness of the strategy," European Commission, 2002 (http://europa.eu.int/eur-lex/en/com/pdf/2002/com2002_0693en01.pdf).

[x] U.S. Environmental Protection Agency, SmartWay Transport Partnership materials. Available online at

http://www.epa.gov/SmartwayLogistics/basic-information/index.htm

[xi] K.G. Duleep, "Evolutionary and Revolutionary Technologies for Improving Automotive Fuel Economy," 1997. In *Transportation, Energy, and Environment: How Far Can Technology Take Us?*, edited by John DeCicco and Mark Delucchi.

[xii] CAFE standards initially required a fleet average of at least 18 mpg for new passenger cars, increasing annually until 1990, when it reached 27.5 mpg; light-duty truck fuel economy requirements increased from 17.5 mpg in 1982 to 20.7 mpg in 1996.

[xiii] Similarly, the differentiation between cars and trucks can result in some interesting results (such as the PT Cruiser, Subaru Forester, and other relatively small vehicles being classed as trucks), as can the exclusion of certain very large personal vehicles as they are not considered light-duty trucks.

[xiv] 1990 Truck Survival Rate, U.S. DOE, (2003) Available at http://cta.ornl.gov/data/tedb25/Edition25_Chapter03.pdf.

[xv] Authors' calculations based on Transportation Research Board, 2005, *TCRP Report 107 - Analyzing the Effectiveness of Commuter Benefits Programs* and : 1.7 percent commute VMT reduction from employer programs using parking cash-out, ride-matching, vanpools, transit benefits, etc.; 1.0 percent commute VMT reduction from regional ride-matching and park-and-ride lots; 3.7 percent net commute VMT reduction from extensive telecommuting and compressed work week adoption (adjusted to account for 50 percent offset by increased discretionary trips).

[xvi] For documentation of this study and other examples, see: U.S. Environmental Protection Agency, *Our Built and Natural Environments: A Technical Review of the Interactions between Land Use, Transportation, and Environmental Quality*. EPA 231-R-01-002, January 2001.

[xvii] According to an analysis of long-run fuel price elasticities conducted by the U.S. Department of Energy (U.S. Department of Energy, Office of Policy and International Affairs, *Policies and Measures for Reducing Energy Related Greenhouse Gas Emissions: Lessons from Recent Literature*. DOE/PO-0047, July 1996), pre-1986 estimates generally showed an average -0.807 elasticity, suggesting that a 10 percent increase in fuel cost equates to a 8.1 percent reduction in light-duty fuel consumption in the long-term; however, post-1986 studies showed an elasticity of -0.376. A more recent study suggests that current gasoline demand is even more inelastic than in the past: in 1975–1980, gasoline demand fell 2.1 to 3.4 percent for every 10 percent increase in price, yet in 2001–2006, gasoline purchases fell by just 0.34 to 0.77 percent for every 10 percent increase in price. Source: Hughes, J., Knittel, C., and Sperling, D. 2006. "Evidence of a Shift in the Short-Run Price Elasticity of Gasoline." Revisions requested from *The Energy Journal*.

[xviii] International Energy Agency, 2005, *Saving Oil in a Hurry* and International Energy Agency, 2001, *Saving Oil and Reducing $CO_2$ Emissions in Transport*.

## CONSOLIDATED COMMENTS FROM MEMBERS OF THE BLUE RIBBON PANEL OF TRANSPORTATION EXPERTS - PAPER 4D-03

One reviewer commented as follows:

This paper is focused overwhelmingly on highway transportation. This reviewer would suggest that it could put more emphasis on the role of railroads (because railroads are three or more times more fuel efficient than trucks, diverting freight from truck to rail would have positive GHG ramifications) and the role of technologies (idle reduction systems, more fuel efficient locomotives, more sophisticated trip planning procedures to reduce travel distances and efficiency, and so on) that railroads are employing today that reduce GHG emissions.

Also, on page 2, the paper states: "In 2004, ...3 percent of GHG emissions were from rail." According to the EPA (*Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2004*), railroads account for well under 1% of total greenhouse gas emissions from all sources. Freight rail accounts for 2% of total GHG emissions from transportation.