An Action Plan for Cars

The Policies Needed to Reduce U.S. Petroleum Consumption and Greenhouse Gas Emissions

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Abstract

Reducing petroleum consumption and GHG emissions from cars and light-duty trucks in the United States over the next several decades requires that we implement a clear and coordinated set of policies now. This report describes a portfolio of policies which, in the view of the authors, is needed to put personal vehicle transportation on the road to sustainability in the longer term. To incentivize adoption of more fuel efficient vehicles, we propose coupling existing near-term fuel economy standards with a feebate incentive program and gradual increases in fuel taxes. We further propose driver education initiatives that would give vehicle owners information on how to maximize fuel savings in their purchase and driving decisions. Finally, we underscore the need for a long-term strategy for fuels that evaluates fuels-related programs based on their contribution to reducing life-cycle petroleum consumption and greenhouse gas (GHG) emissions. Together, these policies offer a robust plan of action that will focus and streamline current efforts to achieve these two important national goals. Perhaps most importantly, this plan lays a much-needed foundation for a comprehensive, adaptable long-term policy effort. A more detailed summary of the recommended set of policy measures can be found in Section 2.

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1 Introduction

Light-duty transportation policy in the United States has reached a crossroads. Policymakers are simultaneously grappling with growing dependence on global petroleum markets, the need for greenhouse gas (GHG) emissions controls, and the impact of the recent economic downturn on the auto industry, with little consensus on how to respond. Recently, the Obama administration has called for accelerating the implementation of a much tighter national Corporate Average Fuel Economy (CAFE) standard from 2020 to 2016. While CAFE is a step toward reducing petroleum dependence and GHG emissions, the costs, risks, and benefits of the accelerated implementation schedule are less clear. Furthermore, getting our nation on an appropriate long term trajectory requires looking beyond CAFE to address a broader range of challenges.

This *Action Plan for Cars* lays out a way forward. Based on work at MIT and by others elsewhere, our recommendations offer near term, coordinated policy steps that would immediately begin to put the nation's light-duty fleet on the road to a more sustainable future. Recognizing that there are multiple obstacles to reducing petroleum consumption and GHG emissions, we emphasize the importance of adopting a coordinated policy response to these challenges, rather than seeking a "silver bullet" solution. We underscore the need to act now, especially given the long delays inherent in deploying new technology in the vehicle fleet. We concentrate here on actions that can be started within the next five years to initiate a sustainable, long term transition.

The Action Plan focuses on two closely related goals: 1) reducing reliance on petroleum-based fuels and 2) reducing GHG emissions from automobiles. We consider the solutions to these long-term challenges against the backdrop of the current crisis in the automotive industry, but do not attempt to address the underlying causes of that crisis itself. We recognize that broader changes in response to the crisis may be necessary within the industry, but these are beyond the scope of this study. Our analysis does consider persistent, longer term drivers of fuel consumption and GHG emissions, such as rising demand for vehicle travel.[1]

The first goal, reducing petroleum consumption, is an old issue with a new imperative. An abrupt rise in petroleum prices in the summer of 2008 underscored the nation's vulnerability to price fluctuations in world markets, which can occur much more rapidly than the auto industry or consumers are able to react. A sustained reduction in gasoline consumption would prevent hundreds of billions dollars from leaving the U.S. economy in the event of a similar price shock, given that over half of the petroleum consumed annually in the U.S. is imported. In the long term, production would adjust to a sustained reduction in demand, leaving the U.S. less

[1] Although some of the policies that we recommend would help to address longer-term drivers of fuel consumption and GHG emissions, such as rising demand for vehicle travel, we expect that additional policies may be necessary to create more attractive alternatives to vehicle travel in order to reduce future demand. The fact that such solutions fall outside the scope of this study does not diminish their importance as part of a comprehensive strategy for reducing petroleum dependence and GHG emissions.

exposed to the associated financial and security risks. Reliance on imported petroleum, especially from reserves concentrated in politically unstable regions, runs contrary to U.S. energy security priorities as articulated in recent federal energy legislation (Energy Policy Act of 2005, Energy Independence and Security Act of 2007).[2] The light-duty fleet currently accounts for around 47% of U.S. petroleum consumption, and depends on petroleum for well over 90% of its energy use (Davis, Diegel, & Boundy, 2009). Achieving lower petroleum consumption will require reducing total fuel demand or displacing petroleum with alternative fuels.

The second goal, reducing vehicle GHG emissions, is even more challenging than reducing petroleum consumption. In the near term, the deployment of alternatives to conventional petroleum fuels is likely to be extremely limited, so the only feasible way to reduce GHG emissions is to reduce our current use through improved efficiency. Moreover, many alternative fuels, such as corn ethanol, non-conventional petroleum sources, and fossil-fired electricity, offer substantial petroleum-reduction benefits but little or no GHG reductions. In 2007, tailpipe emissions from cars and light-duty trucks accounted for 16% of total U.S. GHG emissions (U.S. EPA, 2009). The House of Representatives recently passed the American Clean Energy and Security Act of 2009, the first serious attempt to set economy-wide limits on GHG emissions, which includes a cap-and-trade program designed to reduce covered GHG emissions to 83% below 2005 levels by 2050 (ACES, 2009). The resulting price for GHG emissions permits would incentivize emissions reductions based on the relative cost of achieving them. The cost of policy compliance would likely be passed on to consumers and reflected in a moderate increase in gasoline prices at the pump. However, recently policymakers have focused on whether or not additional measures are needed to reduce GHG emissions from light-duty vehicles, and what form those policy measures might take.

Our *Action Plan for Cars* addresses these issues. The report is organized as follows. **Section 2** provides a brief summary of a coordinated set of policy measures aimed at reducing automotive fuel consumption and greenhouse gas emissions. **Section 3** describes vehicle-related measures in detail and discusses their implementation. **Section 4** recommends fuels-related measures required to support this transition in the vehicle fleet. **Section 5** underscores the importance of a coordinated set of policies, identifies several challenges to implementation, and defines criteria for gauging success.

2 Summary of Recommended Policy Portfolio

We recommend a coordinated policy approach that balances reducing the fuel consumption of both new and in-use vehicles, while encouraging the displacement of petroleum by less carbon-intensive, non-petroleum alternatives. Vehicle fuel consumption depends on the combination

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[2] Section 961(a) of the Energy Policy Act of 2005 refers to the motivations of "decreasing the dependence of the United States on foreign energy supplies," and "improving United States energy security," while section 801(a)(2) of the Energy Independence and Security Act of 2007 emphasizes "the national security benefits associated with increased energy efficiency."

of powertrain and fuel used, as well as how the vehicle is driven. We emphasize that this policy portfolio is not a substitute for an economy-wide carbon management policy (such as a carbon tax or cap-and-trade system). Indeed, an economy-wide constraint would ensure that reductions in fuel consumption and GHG emissions are not displaced to sectors not covered under transportation-specific policies. We recognize that policies aimed at creating alternatives to vehicle travel also have an important role to play in reducing petroleum dependence and GHG emissions. However, such solutions are beyond the scope of this study and we do not specifically address them in this report.

In order to reduce the fuel consumption of new vehicles, we recommend a set of three complementary policies:

1. **Clearly defined increases in Corporate Average Fuel Economy (CAFE) standards should continue to be enacted** beyond the 2016 target (34.1 mpg[3]) to ensure a minimum level of progress on fuel consumption, while allowing manufacturers adequate lead time (on the order of 10 years) to fully account for CAFE increases in their product planning cycles.
2. **A "feebate" incentive system should be implemented to encourage consumers to place greater emphasis on fuel consumption in their purchase decisions, by providing rebates on the purchase of lower-consuming vehicles and assessing fees on higher-consuming vehicles.** We recommend that the fee or rebate amount vary by $120 for each 1 gal/1000 mile change in fuel consumption, which would lead to more than 95% of current vehicles incurring between a $2,000 rebate and a $2,000 fee.
3. **Taxes on motor vehicle fuels should be increased by ten cents per gallon each year for at least the next 10 years, in order to reflect more accurately the full cost of fuel use and driving.** This increase would stimulate the purchase of more fuel-efficient vehicles and encourage consumers to consider other transportation choices. We recommend that the revenue generated be returned to consumers through reductions in income or payroll taxes and through financing improvements in transportation infrastructure.

In addition to these policies aimed at new vehicles, we recommend that a sustained effort be undertaken to provide more information to vehicle purchasers and drivers, on two main fronts:

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[3] The National Highway Traffic Safety Administration and the Environmental Protection Agency have jointly proposed harmonized CAFE and GHG standards. Both proposed rules would create individualized standards for each manufacturer based on the size mix of vehicles that it sells, with larger vehicles held to less stringent standards. Although there is some uncertainty around the precise mix of vehicles that will be sold in future years, it is estimated that the CAFE standards will require an overall sales mix average of 34.1 mpg in 2016, and that the GHG standards would require a sales mix average of 250 g CO_2-equivalent per mile. Using a conversion factor of 8,887 grams CO_2-equivalent per gallon of fuel, they estimate that the GHG standard would be equivalent to 35.5 mpg *if met through fuel economy improvements alone*. However, EPA is allowing manufacturers to earn credits for "off-cycle" vehicle improvements (technological improvements that are not captured by the standard CAFE test cycles, such as changes to the air conditioning system). EPA estimates that the combined GHG reductions from increasing CAFE to 34.1 mpg and manufacturers' expected use of off-cycle improvements will allow them to meet the 250 g/mile standard in 2016 (DOT & EPA, 2009).

1. **Consumer labeling provisions related to fuel consumption should be broadened and updated to reflect the realities of today's car-shopping process. This should include standardizing the presentation of key information on car-buying websites.** These measures would provide more focused and relevant information to aid vehicle purchase decisions.
2. **Driver education programs should be established to provide the public with reliable information on how their driving habits affect in-use fuel consumption, and on the concrete actions they can take to reduce their consumption.**

Finally, a more comprehensive national policy on fuels, including support for non-petroleum fuels, needs to be developed and implemented in a more systematic fashion. Specifically, we recommend the following coordinated actions:

1. **Transportation fuels (both petroleum-based and alternatives) should be included in any comprehensive national carbon management policy. Fuels should be evaluated on the basis of their full life-cycle GHG emissions, which will require additional efforts to improve carbon accounting practices.**
2. **A national strategy for alternative fuels should be developed. This strategy should identify long term objectives and supporting policies for reducing fleet GHG emissions and fuel consumption.** The objective of this national strategy would be to develop a clear set of goals and use them to identify the most promising vehicle powertrain, fuel, and infrastructure options to focus research, development, and demonstration funding, while also identifying appropriate enabling investments in infrastructure in partnership with the private sector.
3. **Any national fuels strategy should include policies that address the need for developing production capacity, distribution infrastructure, and compatible vehicles for the more promising alternative fuels rather than focusing narrowly on one (or even two) of these challenges.** Existing policies for promoting alternative fuels, such as subsidies, mandates, and import tariffs for biofuels, should be revisited to ensure that they align with the new national strategy. Policies should be aimed at integrating efforts across municipal, state, and national levels and clearly defining the roles of the public and private sectors.

3 Detailed Policy Description and Rationale

To achieve significant reductions in petroleum consumption and GHG emissions, policies need to address several related challenges in the market for transportation fuels, and for fuel consumption as a vehicle attribute. Foremost among these challenges is the failure of consumers to consider the broader effects of vehicle fuel consumption on society. The environmental and security costs of fuel consumption are not internalized by consumers in their purchase decisions. More subtly, the market is also affected by information deficiencies. Consumers do not know what the price of fuel will be over the life of their vehicle, they cannot necessarily predict how long they will own the vehicle or its value in the used-car market, and they do not know the fuel consumption that they will realize in real-world driving (Greene, German, & Delucchi, 2009; Turrentine & Kurani, 2007).

To date, the primary policy for addressing these challenges in the U.S. has been the Corporate Average Fuel Economy Standards. A modest effort at improving consumer information has also been made, but is rapidly becoming outdated. Fuel taxes, which could internalize the external costs of fuel consumption, are low and have been decreasing in real terms. To make progress toward reducing both fuel consumption and GHG emissions, we need action on all fronts simultaneously, and in a coordinated fashion, to maximize the benefits of the individual policies at our disposal.

In this section, we present a comprehensive policy portfolio for addressing these failures in the markets for automotive fuels and fuel consumption. Each recommended policy is designed to fulfill a specific purpose, while working synergistically within the broader set of policies. We describe each policy recommendation in detail in the following sections. It is important that these policies be viewed as a single cohesive whole rather than a collection of individual policies, because each policy would not be as effective if implemented in isolation.

3.1 Sustained Progress on Fuel Consumption and Greenhouse Gas Emissions Standards

We recommend that Corporate Average Fuel Economy (CAFE) standards be increased in a steady and predictable fashion on an ongoing basis and beyond the 2016 timeframe, providing ample lead time for manufacturers to incorporate these requirements into their product-planning cycles. Begun in 1975, the CAFE program sets minimum average fuel economy levels that manufacturers must achieve in the mix of new cars and light-duty trucks that they sell each year. After 20 years that saw only minimal changes in the CAFE standards, the Energy Independence and Security Act of 2007 required that the standards be increased such that the combined average for all new cars and light-duty trucks sold in 2020 would reach 35 miles per gallon (mpg). More recently, the Obama administration has proposed coupling more stringent CAFE targets (34.1 mpg by 2016) with newly-established per-mile GHG emissions standards, as part of national efforts to address climate change and fuel consumption jointly (DOT & EPA, 2009).[4] The CAFE program is a familiar fixture of the policy landscape, and has proven effective in reducing automotive fuel demand (Greene, 1997; Schipper, 2009). We see a continued role for CAFE standards as part of a balanced policy portfolio to ensure a minimum rate of fuel consumption improvement, complemented by a purchase incentive program and gradual fuel tax increases.

Policymakers should begin now to define longer term targets for fuel consumption, considering how the lead time for implementation will affect the long term viability of the solutions employed. Increases in the standards should be steady and predictable to allow the automotive

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[4] 34.1 mpg is the fuel economy equivalent of a 250 g CO_2-eq. per mile emissions standard, assuming the GHG target is met through a combination of fuel economy and other improvements. See Footnote 3 on page 3 for a full explanation.

industry time to plan and respond appropriately. In 2007 the Center for Automotive Research reported that developing a single new vehicle program takes at least two years for design, development, and production planning, and that "key vehicle attributes including size, performance, drivetrain, and other major technology options," are set during the first six to 12 months. Moreover, a typical model will remain in production for four to five years between major redesigns, and manufacturers generally budget and plan their complete vehicle portfolios over 10 to 15 years (Hill, Szakaly, & Edwards, 2007). Thus, it is important for the auto industry to know about major CAFE targets a decade in advance, since large increases in average fuel economy will require companies to implement substantial changes across essentially their entire product lines. Companies within the industry do not have the engineering resources to change their full product lines within a time frame of only a few years. Making design changes outside of the normal design cycle would likely lead to higher costs, suboptimal designs, or vehicles that are less desirable to consumers.

The new fuel economy and greenhouse gas (GHG) targets proposed by the Obama administration in September, 2009, would require that the average fuel consumption of new vehicles decrease by approximately 5% per year from 2010 onwards to attain an overall average of 34.1 mpg (29.3 gal/1000 miles) for new vehicles sold in 2016. In general, the costs and benefits of meeting more aggressive targets in the near-term, versus steady, more gradual shifts toward lower fuel consumption levels over the longer term, should be carefully examined. In particular, rushing to meet very aggressive standards in the short term could lead to higher costs, less robust product designs, or overly restricted market choices. Policymakers should be cognizant of this possibility, which has the potential to increase political obstacles to tightening standards in the future.

Policymakers should begin to consider appropriate ways to account for full life-cycle energy use and GHG emissions in setting new standards for automobiles. CAFE standards only address emissions associated with fuel use in the vehicle, employing conversion factors to determine the equivalent fuel economy of electric-only and other alternative fuel vehicles. Current "tank-to-wheel" methods of estimating fuel consumption do not account for the energy intensity of fuel production and distribution. Due to the tiny market share of alternative fuel vehicles, the effect of this approach is currently small. However, it will become increasingly problematic in the event of a broader shift towards alternative transportation fuels, such as biofuels or electricity. Although accurately accounting for upstream fuel use and GHG emissions is a challenging task, this difficulty underscores the importance of establishing a robust framework now, before alternative fuels become more widespread.

Finally, the current CAFE program includes concessions that have undermined its overall effectiveness in improving fuel consumption in a sustained fashion (Evans, 2008). With attribute-based standards that vary with vehicle footprint, and different standards for cars and light-duty trucks, CAFE does not adequately discourage the production and purchase of large, less fuel-efficient vehicles. In addition, manufacturers of flex-fuel vehicles (FFVs – vehicles that can run on either gasoline or ethanol-based fuel) currently receive credits toward meeting CAFE standards, even though the number of these vehicles is small and they are rarely operated on an alternative fuel, a situation that has actually led to increased petroleum consumption. As currently written, the 2016 regulation assumes zero emissions are associated with the electricity use of plug-in hybrid electric and electric-only vehicles, which gravely misrepresents the climate impact of these vehicles, especially in the near term. Whether and how credits are offered to alternative fuel vehicles (such as plug-in hybrid electric vehicles or natural gas-fueled vehicles) should be carefully reviewed to ensure consistency with a new national alternative fuels strategy, which we describe in Section 3.5 of this study.

3.2 A Feebate Program Based on Fuel Consumption

We support the introduction of a "feebate" to provide financial incentives for the purchase of more fuel-efficient new vehicles. A feebate policy combines disincentives (fees) and incentives (rebates) to shift consumers' vehicle purchasing preferences and manufacturers' design decisions towards vehicles with higher fuel economy. Together with an increased gasoline tax (see Section 3.4), the feebate is intended to reinforce the CAFE standard by providing an ongoing incentive for consumers to purchase the higher fuel economy vehicles that manufacturers produce to comply with the CAFE targets. Confident that fuel-saving technologies will be accepted in the market, manufacturers may be less likely to support provisions that would weaken the CAFE targets (as discussed in the previous section). A feebate policy will require careful monitoring and ongoing adjustment as its effects on consumer and manufacturer decisions become clear.

An effective feebate could be structured as follows. Initially, we recommend that a consumer buying a vehicle with an unadjusted laboratory fuel consumption of less than 39 gal/1000 miles (the "pivot point," equivalent to 26 mpg) would be given a rebate on the purchase price that is proportional to the difference between the fuel consumption and the pivot point.[5] Consumers buying vehicles with fuel consumption exceeding 39 gal/1000 miles would pay a fee. We recommend that the amount of the fee or rebate vary by $120 for each 1 gal/1000 miles change in unadjusted laboratory fuel consumption. More specifically, for each 1 gal/1000 miles increase in fuel consumption above the pivot point, the amount of the fee would be increased by $120, while each 1 gal/1000 miles decrease below the pivot point would incur a $120 rebate.

The initial pivot point level of 39 gal/1000 miles would be higher than the model year 2008 average of 37 gal/1000 miles, and would afford rebates to approximately 60% of new vehicle purchasers, based on the model year 2008 mix of vehicles (Ward's, 2008). Under this structure, a vehicle with an unadjusted fuel consumption of 50 gal/1000 miles (roughly equivalent to an on-road fuel economy of 15 mpg) would pay a fee of $1,320.[6] In contrast, a vehicle with an unadjusted fuel consumption of 30 gal/1000 miles (approximately 25 mpg on-road) would receive a rebate of $1,080. Approximately 98% of model year 2008 vehicles would fall somewhere between receiving a $2,000 rebate and paying a $2,000 fee, with the average consumer receiving a $240 rebate.

[5] Fuel economy is based on laboratory-tested, unadjusted, 55/45 city/highway measurements.
[6] On-road adjusted fuel economy numbers are generally 25% lower than test-cycle fuel economy numbers.

The incentive rate contributes to the marginal benefit or cost of decreasing or increasing vehicle fuel consumption. As such, the rate is the key parameter that determines whether manufacturers adopt particular technological improvements and apply them to reducing fuel consumption. Selection of the rate is therefore critical to ensuring that appropriate signals are sent to consumers and manufacturers. A key rationale for adopting a feebate system in concert with a fuel tax is that consumers do not fully value the lifetime fuel expenses associated with a vehicle purchase. Instead, they value fuel consumption over the first three or so years of vehicle ownership (Greene, German, & Delucchi, 2009). As a result, even if fuel taxes are increased, consumers will effectively base their purchase decisions only on the fuel costs incurred over about the first three years, rather than over the life of the vehicle. A feebate system offers consumers a direct incentive to consider at the time of vehicle purchase that portion of fuel taxes that they might otherwise omit from their decisions.

We have recommended an incentive rate of $120 for each 1 gal/1000 miles change in fuel consumption. Currently, the national average gasoline tax is 47 cents per gallon (API, 2009), and as discussed in Section 3.4, we recommend increasing the federal fuel tax by a total of $1.00 per gallon in ten cent increments over 10 years. In making their purchase decisions, consumers are estimated to value the $1.47/gallon gasoline tax at approximately $80 for each 1 gal/1000 miles change in fuel consumption.[7] However, the discounted present value of fuel tax paid over the life of the vehicle is actually $200 for each 1 gal/1000 miles of (laboratory) fuel consumption.[8] Thus, consumers would fail to consider approximately $120 in fuel tax liability for each 1 gal/1000 miles of fuel consumption. Thus, a feebate rate of $120 per 1 gal/1000 miles would correct for this failure by ensuring that the full present value of future fuel taxes incurred over a vehicle's lifetime are considered at the time of purchase.

A feebate rate of $120 per 1 gal/1000 miles is expected to drive reductions in fuel consumption by some 20 to 30% relative to a business-as-usual scenario, over a period of 15 years. Analysis reported by Greene et al. (2005) suggests a reduction in fuel consumption of approximately 23% would result from this rate (2007 dollars), as manufacturers find it cost effective to adopt more advanced technologies. Recent work in our group at MIT has suggested that such a rate might reduce the fuel consumption of the average new car by approximately 30% over a similar time period, as manufacturers redirect their efforts toward lowering fuel consumption rather than continually increasing vehicle power (MacKenzie, 2009).

In 2008, France implemented a feebate program that is similar to what we are recommending, though somewhat more stringent. The French program imposes a feebate based on CO_2 emissions that is equivalent to a rate of approximately $150 per 1 gal/1000 miles, as measured using U.S. testing procedures (MacKenzie, 2009). During the program's first year, the average

[7] Three-year fuel expenses, assuming vehicles are driven 15,600 miles in the first year, decreasing by 4.5% in each subsequent year (NRC, 2002). Also assumes that on-road fuel economy is 25% less than the laboratory test fuel economy, and a 10% discount rate.

[8] Fuel expenses over entire 14 year / 165,000 mile life (NRC, 2002). Assumes that on-road fuel economy is 25% less than the laboratory test fuel economy, and a 10% discount rate is applied to future cash flows.

new vehicle sold in France decreased in length by 2 cm, lost 3% in weight, and 3.5% in power (Navarro, 2009), which was cited by the French environment minister as evidence of the program's success in decreasing average emissions from new cars (Green Car Congress, 2008).

In an overall sense, the feebate scheme can be designed to function as a tax, a subsidy, or to be revenue-neutral, depending on where the pivot point is set relative to the current and future preferences of vehicle buyers. We propose that the pivot point should be set initially such that 60% (more than half) of vehicles receive a rebate, based on current vehicle sales preferences. According to data for model year 2008 (Ward's, 2008), setting the pivot point to 39 gal/1000 miles would achieve this distribution. Our proposed combination of pivot point and feebate rate would effectively constitute a "demand stimulus" of approximately $3.5 billion in the first year, based on the model year 2008 sales mix.

Over time, as consumers and manufacturers respond to the feebate system by reducing the fuel consumption of new vehicles, more vehicles will qualify for rebates and fewer for fees. In order for the government to avoid incurring excessive liabilities for the rebates paid, the pivot point will need to be regularly adjusted downward. In order to keep the system close to revenue-neutral, the pivot point must be adjusted to be reasonably close to the average fuel consumption of the new vehicles sold in a given year. Thus, the government should plan on ramping down the pivot point from its initial level of 39 gal/1000 miles to the expected average of 28 gal/1000 miles over 15 years.

Management of the scheme must balance the needs of vehicle manufacturers with the government's objectives. In order to incorporate appropriate fuel-saving technologies in vehicles, manufacturers would need clarity on the details of the feebate scheme well in advance, ideally about ten years ahead of time. However, the magnitude of the response to the feebate cannot be predicted precisely, so the relative amounts of rebates that will be paid out and fees collected will not be known in advance. As such, the government requires some flexibility to regularly adjust the scheme to ensure that it functions within federal budget constraints. We suggest that a useful compromise may be to commit to future time frames within which the feebate pivot point will apply. This would provide manufacturers confidence as to the minimum rebate more fuel-efficient vehicles would receive, while allowing the government the flexibility it needs to manage costs. For example, the government could set an expected pivot point of 28 gal/1000 mi, as noted above, but retain the flexibility to set the pivot point to anywhere in the range of 25 to 30 gal/1000 miles. Over time, as the industry response to the feebate program becomes clear, it should become easier to more accurately predict the future response, and the government will be able to set the pivot point with greater certainty.

3.3 Vehicle Scrappage Incentives

In the summer of 2009, the U.S. implemented a vehicle replacement incentive program known informally as "Cash for Clunkers." So-called clunkers are known to produce high levels of particulate air pollutant emissions, and in general larger, older vehicles have higher fuel consumption. Permanently removing these vehicles from the fleet and recycling the materials has the effect of decreasing the average fuel consumption of the national vehicle fleet. Cash for

Clunkers offered a purchase incentive of \$3,500 or \$4,500 for a new vehicle if an existing vehicle with high fuel consumption was scrapped at the same time.

Analyses of the Cash for Clunkers program have found it to be an expensive GHG mitigation strategy. For example, Knittel (2009) estimated that the cost was at least \$240, and possibly more than \$500, per ton of avoided CO_2 emissions.

Cash for Clunkers served as a short term government economic stimulus measure, due to its high cost and limited applicability (as the pool of vehicles eligible for scrappage is depleted). Instead of funding similar vehicle scrappage programs at significant expense, we recommend the implementation of a feebate program that applies to all new vehicles, provides a uniform signal to all vehicle purchasers and manufacturers, and is sustained over a decade or more, so that manufacturers can adjust their product portfolios to take full advantage of the program.

3.4 Increased Fuel Taxes

We recommend increasing the tax rate on transportation fuels by ten cents per gallon each year for at least a decade, and returning the revenues to taxpayers through income or payroll tax reductions and by funding improvements in transportation infrastructure. The purpose of taxing fuels is to reduce consumption by including in the fuel's price the environmental and other social costs associated with fuel use. In response to a sustained increase in fuel taxes, consumers would be expected to drive less, shift to alternative (relatively less expensive) fuels, and purchase vehicles that consume less fuel per mile of travel.

The rationale for taxing transportation fuels is to ensure that the societal costs associated with vehicle travel and fuel use are appropriately included in the costs of operating vehicles. These costs include global warming impacts, local air pollution, road congestion, increased traffic accidents, and—in the case of conventional petroleum-based fuels—dependence on imported supplies. By including these costs in the price of fuel, consumers are expected to reduce their consumption, assuming that they have access to full information and rationally evaluate fuel costs. Parry and Small (2005) have estimated that the optimal gasoline tax for the United States is approximately \$1.01 per gallon in 2000 dollars when accounting for these externalities. Assuming 2% annual inflation, this tax would be approximately \$1.50 per gallon in 2020 dollars. The inclusion of transportation fuels under an economy-wide carbon management policy, such as cap-and-trade or a carbon tax, would effectively add a modest additional charge to the price of these fuels.

We recommend increasing the fuel tax rate by ten cents per gallon each year, for at least ten years. The current average fuel tax rate is 47 cents per gallon, including both state and federal taxes (API, 2009). Annual increases of ten cents per gallon, if begun in 2010 and sustained over 10 years, would bring the tax rate in line with the optimal level estimated by Parry and Small (2005), adjusted for inflation, by 2020. After 10 years, we recommend that the appropriate level of fuel taxation be reassessed before a decision is made to maintain the tax rates or continue increasing them.

Policymakers may wish to consider differentiated taxation for non-petroleum fuels as a temporary measure to increase the attractiveness of alternative fuels. Exempting alternative fuels from some or the entire tax burden associated with the federal fuel tax would make these fuels more attractive to consumers relative to petroleum-based fuels. Any such differentiated taxation should be carefully coordinated with a national alternative fuels strategy, as discussed in Section 4.

The political ramifications of a substantial fuel tax increase are not to be underestimated, but we believe that these can be mitigated by ensuring that 100% of new revenues collected through the fuel tax are returned to taxpayers through reductions in income or payroll tax rates and expenditures for improvements in transportation infrastructure. Tax reductions should proportionately favor low-income households, given that they are likely to end up paying higher fuel taxes relative to their income. In addition, any policy proposal advocating an increase in federal or state fuel taxes should clearly outline how the revenues generated from the taxes will be used to benefit consumers. To address the concerns over the fairness and political feasibility of increasing fuel taxes, we recommend returning half of the money through tax credits to lower-income households and using the other half for transportation system improvements. Finally, spreading the fuel tax increase over several years will permit taxpayers to more readily adjust to the price change.

Directing revenues from fuel tax increases to offsetting cuts in income taxes or payroll taxes can reduce the taxpayer burden. Supporters of this approach have pointed out that larger tax cuts (or even tax credits) could be offered to select groups that would be hit harder by the fuel tax increases, such as taxi drivers, truckers, or farmers. The only limitation on how such rebates could be allocated is that they must not be tied directly to an individual taxpayer's fuel consumption, since doing so would remove the incentive for those taxpayers to seek cost-effective reductions in fuel use (Levine & Roe, 2009).

Our surface transportation system is in critical need of additional funding. The Highway Trust Fund, formed in 1954 to cover federal highway expenses, is quickly being depleted and is projected to carry a negative balance beginning this year (FHA, 2009; CBO, 2007). Fuel taxes have failed to keep up with inflation, yet roads carry more goods and passengers than they did a few decades ago. The net effect is that the fuel tax today is far lower than it was in the past, when measured in terms of real dollars per mile of driving (Knigge & Görlach, 2005). Our recommended tax increases of ten cents per gallon annually for the next decade would provide for revenue growth of approximately $14 billion annually. By comparison, the current Highway Trust Fund balance stands at just $5.8 billion. The National Surface Transportation Policy and Revenue Commission panel has recommended an immediate increase in the federal fuel tax of 25 to 40 cents per gallon between 2008 and 2013, which is roughly consistent with our recommended tax increases over the same period.

Increasing fuel taxes would be expected to elicit two distinct responses from consumers, and the magnitudes of these responses would be expected to increase over time. First, implementing a higher fuel tax would induce behavioral changes in driving patterns, as consumers reduced the amount they travel in response to an increase in the cost of driving. The tax would encourage people to use public transit more frequently, consolidate trips, carpool, cycle, walk, or telecommute, or some combination of these responses. It is estimated that for a

10% increase in the fuel cost of travel, consumers will decrease their vehicle travel by 0.3% in the short term and 1% over the longer term (in other words, the elasticity of vehicle travel with respect to the fuel cost of travel is assumed to be -0.03 in the short term and -0.10 over the longer term) (CBO, 2008; Small & Van Dender, 2007). If the $1.00 per gallon increase in fuel taxes through 2020 amounted to a 35% increase in price, demand for vehicle travel would be expected to decrease by about 3% over the ten-year period in question, relative to business-as-usual.[9] The second key response to fuel taxes is that consumers would be expected to modify their vehicle purchase decisions, replacing their vehicles over time with ones that consume less fuel. Reacting to this shift in customer preferences, manufacturers would deploy more advanced vehicle technologies and place greater emphasis on reducing fuel consumption, rather than increasing vehicle performance and size. It is estimated that a 10% increase in fuel prices would elicit a 0.3% reduction in average fuel consumption in the short term (an elasticity of -0.03), and 3.3% in the longer term (an elasticity of -0.33) (Evans, 2008). We therefore estimate that a 35% increase in the price of gasoline would decrease the fuel consumption of the average new vehicle by about 10% over a decade or so.

3.5 Improved Consumer Education and Information

We recommend several new programs to improve the quantity and quality of information available to vehicle purchasers and drivers. These polices would address market inefficiencies due to incomplete information about how individual actions affect vehicle petroleum consumption and GHG emissions. Specifically, our recommendations are designed with two goals in mind:

1. Increasing access to fuel consumption information at the time of vehicle purchase
2. Increasing awareness of a “high fuel economy” driving style and vehicle use

Currently, U.S. fuel consumption information and education policy comprises mandatory fuel economy labels on new vehicles and a government website dedicated to fuel economy information (www.fueleconomy.gov). EPA fuel economy certification and labeling allow buyers to contrast the fuel economy of comparable vehicles using a common baseline. However, this information could be much more accessible and relevant if slight changes were made in how and when it is presented to buyers. In addition, although the role of driving style and vehicle maintenance has received increased media coverage in the last few years, useful information about how individuals can apply these techniques is not readily available. In order to achieve the greatest potential, information and education programs must address both vehicle purchasers and drivers, provide credible, meaningful, and persuasive information, and come from a wide range of stakeholders and sources.

[9] Linear approximations of the response are commonly used for small changes in the fuel cost of travel. However, for larger changes in the fuel cost of travel, constant elasticity implies a nonlinear response in travel. Evans (2008) provides a thorough summary of the underlying calculations.

3.5.1 Purchaser education

The new vehicle labeling scheme created in the 1970s, which forms the backbone of the U.S. fuel economy program, should be extended to accommodate increased reliance on television advertisements and internet research in making vehicle purchase decisions. Three new efforts are needed to provide appropriate information earlier in the purchase process:

1. Standardizing the way fuel economy is presented in vehicle advertisements
2. Creating an online fuel economy label
3. Upgrading the fueleconomy.gov website

Current Federal Trade Commission (FTC) regulations require that EPA-estimated fuel economy values need to be included in vehicle advertisements only if the advertiser chooses to disclose fuel economy figures (FTC, 1995). Although fuel economy estimates are based on standardized procedures, they are not consistently or prominently displayed in television and print advertisements. The subtleties of the regulations mean that advertisers can choose to present only the highest (usually highway) fuel economy value, rather than both the city and highway or the combined value. We recommend requiring all vehicle advertisements (television, radio, newspaper, internet, and billboards) to include prominently both city and highway fuel economy, in order to encourage customers to place greater emphasis on fuel consumption and ensure that they have the necessary information to make comparisons. The FTC has proposed changes to its rules governing fuel economy advertising, but the modifications do not address the issues raised here (FTC, 2009).

Over half of all automobile purchasers use the Internet as a primary source for researching vehicle purchases, particularly manufacturer websites (eMarketer, 2007a; eMarketer, 2007b). This reliance on online research will likely grow in the future. For example, GM has already begun testing a program to sell new cars on eBay (Van Praet, 2009). Despite the importance of Internet information, fuel economy values are often difficult to find on manufacturer websites and are not presented in a standardized format. We therefore recommend an online labeling scheme that requires city and highway fuel economy estimates to be displayed in a standardized format, along with a link to the fueleconomy.gov website. Essentially, this would be the online equivalent of the well-established requirements for window stickers and fuel economy guides. Such an approach is not unprecedented; New Zealand has already implemented an online labeling requirement for all vehicle traders and sellers (EECA, 2009).

Because of the increased use of the Internet, the fueleconomy.gov website provides a valuable tool for encouraging purchasers to think more thoroughly about fuel consumption. Although most buyers start with automobile manufacturer websites, the best source for automotive information (according to Internet market users) is neutral web sites (eMarketer, 2007b). We recommend that the fueleconomy.gov website be revamped to emphasize fuel consumption (for example, by focusing on annual fuel cost or gallons per 1000 miles instead of miles per gallon) and to encourage comparisons across as well as within vehicle classes. The use of fuel economy (miles per gallon) has been shown to create the illusion of more fuel savings than is often the case (Larrick & Soll, 2008). And although the fueleconomy.gov website provides a useful resource to compare vehicles of a specific class, it does not do enough to emphasize the full range of vehicles and fuel economies available. For more discussion, see DeCicco (2006).

3.5.2 Driver Education

After the point of vehicle purchase, drivers can significantly reduce their own fuel consumption through choices about travel distance, driving style, and vehicle maintenance. Driving just five miles less each day would save close to 90 gallons of petroleum per year for the average vehicle. This could be achieved through route planning, trip-chaining, or car-sharing. Even driving style ("eco-driving") has the potential to reduce fuel consumption by 10 to 20% while reducing accidents by up to 35% and increasing driving comfort (Hennig, 2008). Keeping a vehicle properly maintained, particularly in the case of older vehicles, provides additional fuel savings. Together these behaviors represent the spectrum of "high fuel economy behaviors." Ironically, while there is a general understanding that these behaviors do impact fuel consumption, there is no reliable and consistent source of this information. As a result, drivers have many misconceptions (Carrico et al., 2009; Elliott et al., 2005) and are unsure of how to apply these more measurable behaviors. To address these gaps, we recommend three specific measures:

1. Including high fuel economy behaviors in driver education classes and certification tests
2. Certifying classes and programs that teach these behaviors
3. Funding public information campaigns to emphasize the potential fuel savings

We recommend that state driver's tests and new driver classes should incorporate information about the impact of vehicle fuel economy, travel distance, vehicle maintenance, and driving style on fuel use by 2013. Germany first implemented such a policy in 1999, with Finland, Sweden, the Netherlands, and others following soon thereafter (OECD, 2008). Fuel and cost savings can be used to motivate more efficient and safer driving practices such as using less aggressive acceleration and braking and anticipating speed changes.

Individualized instruction and feedback have demonstrated some of the largest long-term changes in driver behavior, particularly when coupled with in-vehicle feedback or fuel economy read-outs. An example is Denver's Driving Change program. Participants in this program saw their fuel economy improve by an average of 10% between May and November, 2008 (Jaffe, 2009). We recommend that a program be created immediately to certify people and organizations to teach and promote high fuel economy driving behaviors.

Public information campaigns have a role in driver education as well. The eco-driving literature has repeatedly noted that the medium is just as important, if not more so, than the message. For example, the Dutch eco-driving program (www.hetnieuwerijden.nl) employs characters from "The Dukes of Hazzard" and their iconic car, the General Lee. A more blunt approach is to publicize fuel and cost savings achieved by implementing fuel-saving techniques by both fleets and individuals, such as the 3 million gallons of gasoline UPS saved in 2007 (Lovell, 2007), or the fact that fuel conservation has become a key determinant in NASCAR victories (Livingstone, 2009). We recommend that these efforts be led by EPA and DOE, in partnership with industry, non-profits, local governments, and other stakeholders. In this way, the messages can be tailored to specific audiences, who will be hearing it from a familiar source.

The most important aspects of these driver education programs are that all three high fuel economy behaviors (travel distance, driving style, and maintenance) be taught together and that they be taught repetitively starting with initial driver's education. Increasing awareness of only one behavior could cause people to focus exclusively on that behavior while increasing consumption due to the others (Weiss & Tschirhart, 1994). In addition, when this information comes from a wide range of sources and at all stages of driving, it adds to the credibility of the information and allows high fuel economy behaviors to become habit. Finally, public information campaigns should promote the link between vehicle fuel economy and environmental and climate factors to motivate both purchasers and drivers (DeCicco 2006).

3.5.3 Effectiveness

Purchaser and driver education programs have the potential to be highly cost effective, although their cost effectiveness depends significantly on the behavioral change that they are able to motivate and sustain. The Denver Driving Change program was underwritten by a $400,000 grant and has already demonstrated significant savings (Jaffe, 2009). The Dutch eco-driving program, comprising an extensive public information and driver training program (including even water travel), will cost an estimated €35 million ($50 million) in total, but in 2006 alone saved 0.3 million tons of CO_2. If the Dutch government meets its goal of saving 1.5 million tons of CO_2 annually by 2010, the cost will be less than €10 ($15) per ton of CO_2 (OECD, 2008).

For purchasers and drivers already concerned about and motivated by fuel use, more information will enable them to make informed decisions about which vehicle to purchase and when and how to drive and maintain that vehicle, with the potential for significant fuel savings. For the rest of the population, the link between information and behavior change is less well defined. Consumers and drivers must have both the ability and the desire to change their vehicle purchasing, use, and driving behavior (Elliott et al., 2005). This is why purchaser and driver education alone cannot supplant fuel tax increases and the creation of a feebate program, policies which generate a direct economic motivation for all purchasers to reduce fuel consumption.

4 Coordinating Action on Automotive Fuels

A new, clearly conceived approach to automotive fuels policy is needed to reduce the petroleum use and GHG emissions of the U.S. light-duty vehicle fleet. A more comprehensive strategic approach is essential because of the interdependencies between a fuel's characteristics and its production, distribution, use in vehicle systems, and its impacts. In particular, the strategy should consider both the capability of existing fuel infrastructure to distribute the alternative fuel and of the existing vehicle fleet to use it. Current alternative fuels policy does not adequately address these realities, nor is its relationship to broader security and environmental goals clear. For example, under the Energy Independence and Security Act of

2007, a renewable fuels standard requires that substantial volumes of biofuels be used, but the mandated levels will soon exceed the capacity of the vehicle fleet to utilize these quantities.[10] Moreover, the GHG emissions benefits of such a policy are questionable. Today, alternative fuel deployment efforts focus largely on specific fuel and infrastructure options (see, for example, Morrow et al., 2008; NCEP, 2009) and lack coordination across sectors and levels of government. Given the scale of the transition and the diversity of potential sectors involved, national coordination will be particularly important.

4.1 Potential Alternatives to Conventional Petroleum-based Fuels

In the hundred-plus years since spark-ignition and diesel internal combustion engines were first developed, petroleum-based fuels—due in large part to their high energy densities, comparatively low prices, and ease of production and delivery—have been the dominant source of energy for vehicle propulsion. Petroleum dependence persists, despite numerous attempts to introduce alternative fuels. During the last few decades, governments and private stakeholders have spent hundreds of billions of dollars worldwide on research, development, demonstration, and commercialization of alternative fuels that were expected to be cheaper, environmentally more benign, or more secure in supply than petroleum-based fuels. The more prominent potential alternative fuels are discussed in the following sections.

Heavy Oils and Tar Sands are chemically similar to conventional petroleum but are more technically difficult, and thus costly, to extract. In the Western Hemisphere there are two large deposits of concentrated fossil hydrocarbons that are being recovered as raw materials for fuels. One is the Canadian tar sands and the other is the very heavy oils of the Orinoco Oil Belt in eastern Venezuela. Canada has been producing about one million barrels of oil per day from the tar sands and Venezuela was producing about half a million barrels per day before recent political changes in oil field control. The actual oils produced from both locations are similar in chemical and physical properties. They are thick, tar-like materials, highly aromatic, with high concentrations of sulfur and other elements that must be removed during refining. The oils have high viscosities, and must be heated or diluted to flow at necessary rates. Considerable energy is expended during the recovery of the oils from these deposits, significantly increasing life-cycle GHG emissions. In addition, considerably greater energy consumption and GHG emissions result from refining these oils to the specifications required for transportation fuels, when compared with petroleum refining. A major advantage of these fuels is that they can be readily distributed in the existing infrastructure and used in existing vehicles. Currently, fuels produced from heavy oils and tar sands are among the more successful alternative fuels, comprising about 5% of transportation demand, an amount that is expected to increase. The increased GHG emissions and other environmental challenges of using these resources create a tension between the environmental and energy security goals of alternative fuel use.

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[10] This statement assumes technical blend limits do not increase, for instance, through the use of miscible biofuels or other alternatives to today's ethanol and biodiesel.

Coal and Oil Shale can be converted into liquid fuels compatible with today's internal combustion engine vehicles. Their appeal derives chiefly from the fact that the U.S. has the world's largest reserves of coal and the largest potentially recoverable oil shale resource, promising a secure future supply of fuel. However, both coal- and shale-derived fuels have significantly higher life-cycle GHG emissions than conventional petroleum-based fuels. Today, there is no commercial production of liquid fuels from either raw material in the U.S., due to several challenges. In the case of coal, these challenges include a lack of experience with commercial-scale coal-to-liquids processes, high plant costs, water use and other environmental impacts, and the fact that the process (Fischer-Tropsch) yields excellent diesel and jet fuel, but a low quantity and quality of gasoline. In the case of oil shale, interest centers mainly on an *in situ* process that would use advanced recovery technology to heat the rock and unlock immobilized reserves. Key issues facing this process include high capital costs, challenges in preventing hydrocarbons and heavy metals from migrating into neighboring groundwater supplies as the shale is heated, and uncertainty over how much energy (and GHG emissions) will be required to heat the rock and to accommodate other features of the process.

Biofuels have been used in American cars since the very beginnings of the U.S. automobile industry, but have never supplied more than a few percent of the total fuel consumed by road vehicles. Interest in biofuels as substitutes for petroleum fuels has grown in recent years for three main reasons. First, biofuels can be produced from domestic sources of biomass, offering security benefits. Second, depending on feedstocks and land-use effects, biofuels may have lower lifecycle GHG emissions than petroleum-based fuels. Finally, biofuels are seen as a lucrative market for American farmers, an influential political constituency.

Current biofuels are made from plant materials otherwise used for food or feed. Also, land use changes involved in producing biomass for fuel can release substantial GHG emissions (Searchinger, 2009). Two recent comprehensive studies conclude that biofuels can become at least a partial replacement for petroleum fuels but to do so, they must shift from food and feed crops (e.g. corn grain and vegetable oils) to other plant materials like grasses, wood waste, and possibly algae, which can be converted to biofuels by new technologies under development. These reports concluded that current, first-generation biofuels (such as corn-based ethanol) have limited potential to displace petroleum beyond about 10%, or to reduce GHG emissions. Some second-generation biofuels offer much greater potential, perhaps up to 25%, but are still under development (OECD & IEA, 2008; NAS, 2009).

Electricity stored in on-board batteries could be used to power vehicles either alone or in combination with an internal combustion engine. Electricity offers many advantages, including low energy cost per mile, no tailpipe emissions, quieter operation, and home recharging for many households. The existing electric grid could support moderate numbers of such plug-in hybrid and electric-only vehicles without expanding our electricity generating capacity, assuming most vehicles are recharged at night.

To realize the advantages of electricity, a number of challenges must still be overcome. These challenges include the high cost of batteries, and the usage constraints for electric-only vehicles imposed by limited battery range and long recharge times. Novel business models involve providing the battery and vehicle separately, and spreading the cost of the battery over the lifetime of the vehicle. Advances in battery technology may help to bring costs down and improve performance, but the pace and extent of these advances is uncertain. To address the climate change problem, the GHG emissions from electric power production would need to be substantially reduced, given that more than half of today's U.S. electricity generation relies on coal. How to balance recharging convenience and daily cyclical demands on the power system remains unclear. Various demand-side management programs such as dynamic pricing have been proposed, although the consumer response is uncertain. Consumers are also likely to demand convenient access to recharging, which will require the installation of distributed charge points. It is likely to be a decade or more before further technological progress and business model innovation enable electricity to play a significant role in the light-duty vehicle fleet. However, policymakers interested in enabling the use of electricity as a transportation fuel should begin now to address the issues outlined above, since they have a unique opportunity in the early stages of deployment to establish standards and practices aimed at reducing longer-term barriers to adoption and maximizing the environmental and other benefits of the technology.

Natural gas and Liquid Petroleum Gas (LPG) have been available to car owners since the 1930s, but the impact of these fuels has to date been limited. Natural gas releases somewhat fewer GHG emissions than petroleum combustion for the same amount of energy. However, this advantage can be offset by leakage of just a few percent in the fuel infrastructure or in the vehicle itself, because methane is a much more potent GHG than CO_2. Today, U.S. light-duty vehicles obtain about one-quarter of one percent of their energy needs from LPG, and essentially none from natural gas (Davis, Diegel, & Boundy, 2009). Although natural gas and LPG offer the potential to diversify energy supply, any energy security benefits will depend on the origins and relative price volatility of each fuel. In addition to leakage and potential security concerns, there are several other barriers to large-scale adoption, including reduced trunk space due to fuel tank volume, longer refueling time, reduced range between refueling, limited numbers of refueling stations, and restrictions (e.g. in tunnels) for hazardous materials transport. Recent discoveries of significant natural gas in shale deposits in the U.S. suggest it could in the mid-term be a relatively low cost source of energy, but the inconvenience of using gaseous fuels in transportation as opposed to other sectors remains a major disadvantage.

Hydrogen has also been proposed as a low carbon substitute for petroleum-based fuels in vehicles. At present, hydrogen has many limitations that make it an unlikely near term solution. First, hydrogen is a gas and carries with it the inconvenience of transporting, storing, and using a gaseous fuel. Second, it is an energy carrier and must be produced from primary fuel sources, the least expensive of which are fossil sources. Third, although fuel cells are desirable for their high efficiencies, they are also at present far too expensive. The other alternative, burning hydrogen in an internal combustion engine, is less efficient. Fourth, an infrastructure that delivers hydrogen or its precursors does not exist and would need to be constructed. In our view, these limitations place hydrogen in a category apart from the other options discussed here, although hydrogen's potential as a transportation fuel in the longer term should not be ignored.

4.2 The Need for a Strategic Approach to Automotive Fuels

The primary conclusion to be drawn from examining the fuels opportunities today is that history has not revealed any clearly superior alternative fuels. Each potential alternative has its own set of strengths and weaknesses, as well as its supporters and detractors. Even within a particular fuel type, the energy and emissions footprint can vary widely, depending on the choice of feedstock, processing or blending requirements, or the availability of related enabling technologies such as long-range batteries or carbon capture and storage. Moreover, certain fuels may help address one of the problems of petroleum-based fuels, while exacerbating others. For instance, in the case of oil sands and coal-to-liquids, reduced reliance on petroleum imports trades off against GHG emissions, since these domestic fuel sources have a higher emissions footprint per barrel of fuel produced.

Despite policy efforts over the past several decades, all alternative fuels combined displaced only about 10% of total gasoline demand in 2008.[11] Several challenges have prevented wider adoption. The lower cost of petroleum compared with alternatives and petroleum's favorable properties from a technical standpoint have combined to deter production of alternative fuels. Notwithstanding the serious environmental impacts and security issues associated with their use, petroleum-based fuels have proven superior to alternatives in almost every way. With respect to fuel use, many of the potential alternative fuels face several challenges related to their incompatibility with the existing fuel distribution infrastructure or with existing vehicles. However, there are significant barriers to increasing system flexibility. First, the upfront costs of developing a new refueling infrastructure are high and concentrated among early investors, but once the infrastructure is in place, the benefits fall disproportionately to late entrants, weakening or negating private investment incentives. Second, the long lead times for refueling system construction and turnover of the vehicle fleet will limit the pace of any transition. Third, consumers are more likely to purchase vehicles if they can refuel them conveniently, but the business proposition for alternative fuel stations is unattractive until there is already an established base of customers who need the alternative fuel.

The combined effect of these factors is that those alternative fuels that can be distributed using the existing fueling infrastructure and consumed in existing vehicles, such as ethanol and biodiesel which can be blended with petroleum based fuels, will have a significant advantage compared with much less compatible alternatives. It is unclear whether or not private parties will make investments in new refueling infrastructure even if the price is right, given the

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[11] U.S. ethanol consumption was approximately 9.6 billion gallons in 2008, and displaced approximately 6.5 billion gallons of gasoline (due to ethanol's lower energy content relative to gasoline) (AFDC, 2009). Tar sands accounted for approximately 1.3 million barrels per day, or 38%, of Canada's total oil production of 3.4 million barrels per day in 2008 (CERA, 2009). U.S. imports of petroleum from Canada totaled 38 billion gallons in 2008 (EIA, 2009). Assuming that 38% of these imports were derived from tar sands, 15 billion gallons of tar sands-derived fuels were imported from Canada. Gasoline accounted for 46% of U.S. petroleum consumption in 2008 (EIA, 2009). Assuming that 46% of imported tar sands based fuels were used in gasoline, the estimated volume of tar sands-based fuels in U.S. gasoline in 2008 is 6.8 billion gallons. Thus we estimate that ethanol and tar sands combined displaced approximately 13 billion gallons of gasoline in 2008, out of a total of 138 billion gallons consumed.

uncertain returns to early movers. The appropriate role of government in supporting alternative fuels development and then deployment in its early stages remains unclear. Policy makers could help to raise investor confidence, for instance by establishing vehicle and fuel compatibility standards at the national level. The challenge, however, is determining under what conditions such intervention might be warranted, given significant uncertainty surrounding the rate of development and associated cost of future vehicle and fuel technologies.

4.3 Recommendations

Our recommendations related to fuels are stated and explained in the paragraphs below:

1. Transportation fuels (both petroleum-based and alternatives) should be included in any comprehensive carbon management policy. Fuels should be evaluated on the basis of their full lifecycle GHG emissions, which will require additional efforts to improve carbon accounting practices.

Motor vehicle fuels and electricity should be included from the outset in any comprehensive carbon management policy that the United States adopts. It is critical that the inclusion of transportation fuels under a carbon management system be based on the full lifecycle emissions associated with the production, distribution, and use of the feedstock and fuel. This is especially significant for many alternative fuels, for which a large portion of the emissions can occur upstream. For example, liquid fuel production from coal can produce as much emissions upstream as it does during the actual combustion of the fuel in the vehicle, and would potentially require carbon capture and storage technology (Mantripragada & Rubina, 2009). In the case of biofuels, a significant fraction of the emissions also occurs upstream, during the growing, fertilizing, and harvesting of feedstocks and any land-use changes that occur. The magnitude of these upstream emissions is uncertain, but they contribute significantly to the overall emissions associated with many biofuels (CARB, 2009). Despite this uncertainty, it is important to use the best possible assessments and to update them over time. At the same time, we recommend continuing efforts to develop ever more robust methodologies for greenhouse gas accounting. Electricity used in transportation should also be subject to this type of assessment.

2. A national strategy for alternative fuels should be developed. This strategy should identify long term objectives and targets, and supporting policies for reducing fleet GHG emissions and fuel consumption. Efforts should be focused on developing the fuel options which have the potential for significant reductions in petroleum consumption and GHG emissions. The objective of this national strategy would be to develop a clear set of goals and use them to identify a subset of the more promising vehicle powertrain, fuel, and infrastructure options to focus research, development, and demonstration funding, while also identifying appropriate enabling investments in infrastructure in partnership with the private sector.

The current patchwork of fuels policies does not adequately address the related issues of rising petroleum consumption and GHG emissions. To ensure internal consistency and clear metrics for progress, a national-level strategy on alternative fuels should be developed that clearly identifies long-term petroleum and GHG emissions reduction goals. A timetable should also be set for revising and updating the strategy as new information, for instance, about technology costs or policy effectiveness, becomes available.

The national strategy would not necessarily overturn existing policies, but rather would force policymakers to review the merits of existing policies to determine whether or not they were consistent with the new national strategy. Any related policies, such as those proposed as part of the policy package described here, should similarly be designed to align with the national strategy. For example, the extension of the proposed increase in the gasoline tax to non-petroleum fuels should be carefully considered, balancing potential lost revenues against the desire to encourage low-carbon or non-petroleum fuel sources, at least in the short term.

3. Any national fuels strategy should include policies that address the need for developing production capacity, distribution infrastructure, and compatible vehicles for the most promising alternative fuels, rather than focusing narrowly on one (or even two) of these challenges. Existing policies for promoting alternative fuels, such as subsidies, mandates, and import tariffs for ethanol, should be revisited to ensure that they align with the new national strategy. Policies should be aimed at integrating efforts across municipal, state, and national levels and clearly defining the roles of the public and private sectors.

We recommend that specific alternative fuels policies be developed in a more deliberate and coordinated manner than has been employed in the recent past, as part of the national strategy mentioned in the second recommendation above. In particular, greater attention should be paid to the challenges of integrating a new fuel into the existing system. Policies should be designed to favor fuels that maximize cost-effective reductions in fuel consumption and GHG emissions, while acknowledging the substantial advantages of fuels that are compatible with existing vehicles and the refueling infrastructure. This approach requires strengthening our analytical capabilities for comparing across potential fuels pathways, rather than conducting focused assessments of single solutions, which may be subject to the bias of technology advocates or other stakeholders. Instead, both technological and policy solutions should be vetted in a forum that represents the diversity of knowledge and views about the viability of particular options. An organization that includes government, academic, industry, and non-industry experts should mediate these exchanges.

The government also has a critical coordinating role to play in surveying state-level policy and experience to inform action at the national level, as well as developing technology standards to support compatibility in the fueling system across state lines. Reconciling policies at the national level reduces or eliminates the difficulty of meeting diverse regulatory requirements, while standardization raises developers' confidence that individual technologies will be widely adopted. For example, the standardization of the electrical system interfaces for plug-in hybrid and electric-only vehicles would instill confidence in potential manufacturers that compatible designs would be accepted. Furthermore, ideas and lessons from state experiences could be evaluated in a centralized manner and possibly adopted. For instance, the rationale for and lessons from the Low Carbon Fuel Standard in California could inform debate on the role of a similar policy at the federal level under the national fuels strategy. In general, policies that allocate public funds for refueling infrastructure deployment should be carefully considered to ensure that they will encourage private investment and will address specific barriers to market entry, rather than propping up an uncompetitive alternative.

Overall, this set of fuels policies complements the policy proposals focused on vehicles. These recommendations are designed to add coherence, logic, and a broader vision within which to reconsider and potentially realign existing alternative fuels policies, without passing judgment on existing policies *per se*. The challenge before us is how to stimulate the evolution of a sustainable fuel system, not just a single fuel or vehicle technology. Only with a national strategy and corresponding policies that consider the interrelated components of the system simultaneously will we be able to make significant progress toward our broader security and environmental goals.

5 The Importance of Coordinated Policies

The potential for reducing light-duty vehicle fuel consumption over the next 25 years is substantial. By improving the efficiency of internal combustion engines (gasoline and diesel), increasing the efficiency of transmissions, improving hybrids and expanding their sales volumes significantly, introducing electricity into transportation by starting to build-up production volumes of plug-in hybrid and electric-only vehicles, reducing vehicle weight, and moderating expectations of ever increasing vehicle performance, the average fuel economy of the new U.S. vehicle sales mix could be steadily improved. Recent studies (Bandivadekar et al., 2008; NRC, 2009) indicate that average new vehicle fuel consumption could decrease by up to 30% over the next 10 years and 50% over 25 years (fuel economy increases of 40% and 100%, respectively). However, these reductions in the use of petroleum-based fuels, and corresponding reductions in greenhouse gas emissions, are unlikely to be realized in a market without clear policy signals. As we have explained, an effective set of policies will be required to achieve these potential improvements in practice.

Purposeful, coordinated action is required now to lay the foundation for more sustainable personal vehicle transportation in the United States. Reducing petroleum consumption and GHG emissions are two important policy goals that bear on the evolution of our vehicle transport system, which encompasses the vehicle, fuel production and delivery infrastructure, and the user. The policies we recommend are designed to address distinct parts of the system as well as the interactions among them. Poorly designed policies could interact with each other in unexpected ways to reduce or negate their effectiveness. Here we summarize how the elements of our proposal address the different aspects of the problem while avoiding redundant or counterproductive outcomes.

We have designed our package of policies to address, in a coordinated fashion, the distinct challenges to reducing fuel consumption and GHG emissions in the purchase and use of personal vehicles in the United States. In the case of the environmental and security impacts of fuel consumption, an increase in the fuel tax would internalize the costs of petroleum reliance, and including vehicle transportation within a national climate policy would ensure consistency with GHG emissions reduction goals. However, these pricing measures alone are unlikely to be fully effective, given that consumers have been shown to undervalue the fuel savings over the vehicle lifetime for reasons described previously. The fact that consumer vehicle purchases are partly insulated from the costs of fuel taxation indicates that additional measures are needed.

Our proposal advocates a continuation of CAFE standards beyond 2016 and the implementation of feebates that mandate or incentivize improvements in vehicle fuel consumption. By combining them with a fuel tax increase, these measures ensure that consumers will more fully internalize the environmental and national security costs of driving. The fuel tax can be set at a level designed to offset any rebound effect associated with lower driving costs, which are enabled by higher fuel economy. Meanwhile, the feebate level captures the additional cost or savings associated with fuel consumption over the lifetime of the vehicle that a consumer might not otherwise value. With a fuel tax increase, consumers would also place greater value on vehicles with higher fuel economy. Higher fuel taxes would provide consumers with the motivation both to purchase vehicles that consume less fuel and to drive them more conservatively. Simultaneously, new efforts on consumer information and driver education would empower them to translate these motivations into action. At least one critic has claimed that fuel taxes and incentives can only work if the CAFE program is abandoned (Reynolds, 2009). However, our analysis indicates that over the medium to long term, modest increases in gasoline taxes can offset the costs imposed on manufacturers by CAFE standards, by increasing consumer demand for the more fuel-efficient vehicles that CAFE requires (MacKenzie, 2009). Moreover, the required gasoline taxes would not be nearly as high as they would need to be if taxes were the only policy driving lower fuel consumption (MacKenzie, 2009). Thus we submit that combining a higher fuel tax with a CAFE standard and feebate policy would be more effective than a fuel tax alone.

Low carbon fuels currently play a limited role in displacing petroleum and reducing GHG emissions, but could contribute significantly if use were expanded. This expansion is constrained by a number of challenges described in Section 4 on fuels. Here we emphasize the importance of developing a national strategy for alternative fuels, which will allow closer evaluation of the merits and drawbacks of existing and proposed fuels and policy initiatives intended to promote them. We emphasize that this strategy should focus on the ultimate goals of reducing fuel consumption and GHG emissions, rather than promoting specific fuel choices. Within this framework, such fuels and their accompanying technologies should be evaluated on the basis of their full life-cycle GHG emissions to ensure emissions are reduced, and not just displaced upstream or to other sectors.

The policies summarized above address vehicle and fuel purchasing behavior, but do not account for contributions from on-the-road driving behavior, which also affects fuel consumption and GHG emissions. We thus include driver education efforts as necessary to fully realize the benefits of vehicles with a higher rated fuel economy, as well as to reduce fuel consumption in the existing fleet.

A carefully coordinated policy approach is especially important in light of the current economic crisis and the challenges it has imposed on the automotive industry. If maintaining a healthy automotive manufacturing industry is seen as a desirable policy outcome, then care must be taken to balance the goals of reducing petroleum demand and GHG emissions with the capability of the automotive industry to reduce vehicle fuel consumption and install alternative-fueled powertrains at reasonable costs. Just as important as the question of whether technologies are available to reduce fuel consumption is the question of how much consumers are willing to pay for those reductions. With two of the three Detroit manufacturers having declared bankruptcy this year, it is important to recognize that imposing additional costs through mandates could be problematic. At the same time, it is important to view our policy recommendations in a broader and longer term context. We recommend making changes step by step, and sustaining them over an extended period of time. Thus, many of the effects of our recommended policies will not be felt for several years, perhaps long after the current economic crisis has subsided.

Just as the complex interactions between vehicles, drivers, fuels, and infrastructure call for coordinated policy action, they also require careful evaluation to determine the success of policy initiatives. With respect to measuring the success of policies, we make several recommendations. First, the success of a policy should be judged based on its contribution to meeting the overarching goals of reduced GHG emissions and petroleum consumption. There may be a temptation to focus too narrowly on “intermediate variables” that are easily measured but are ultimately of lesser importance. For example, the success of CAFE should be judged not according to the average fuel economy of new vehicles or even the fleet as a whole, but by the program’s effect on total fuel consumption and GHG emissions. Similarly, the success of an alternative fuels policy should be judged not by the total quantity of alternative fuel delivered, but by the amount of petroleum and GHG emissions saved, compared with a no-policy scenario. Second, sufficient time must be allowed for policies to have their intended effect. For example, it is thought that the elasticity of vehicle travel with respect to fuel cost per mile increases over time. Care must be taken when evaluating a fuel tax policy based on only a few years of data. A feebate policy can only have its full effect once manufacturers have had time to adjust their product planning and development to the new market conditions. Third, policy analysts should attempt as much as possible to disentangle the effects of policies from one another and from underlying drivers such as growth in population and GDP. Measuring how petroleum use and GHG emissions change over time relative to a careful chosen baseline may be an appropriate metric of the impact of the policy portfolio as a whole. However, when it comes to judging the effectiveness of individual component policies, careful comparisons must be made against scenarios in which other conditions are held appropriately constant.

Finally, an ongoing monitoring effort and institutionalized process for revisiting policy design based on newly available data will be critical to identifying successes as well as unintended consequences. Although experience with the CAFE Program has been gained over many decades, a number of the measures proposed are novel to the United States. An expert task force that is insulated as much as possible from the political process should be charged with the periodic review of data from a variety of sources on the costs and benefits of the policies proposed here. As such, the policy portfolio presented in this report should be considered as laying the foundation for an adaptive, ongoing, and ultimately robust policy effort that will help to address the environmental and security challenges in personal vehicle transportation.

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Introduction

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