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Policy Options for Reducing Oil Consumption and Greenhouse-Gas Emissions from the U. S. Transportation Sector

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Discussion Paper

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Introduction

The goal of this discussion paper is to contribute to the current policy debate about how to effectively limit or reduce oil consumption and greenhouse-gas emissions from the U.S. transportation sector. The paper explains what is wrong with the status quo and therefore why new policies are needed. It examines special policy challenges in this domain, and analyzes the pros and cons of individual policy measures. Finally, the paper explores the probable overall effects of several illustrative policy packages. A white paper will be issued in early fall 2007 that will provide a new proposal for addressing oil security and climate change in the U.S. transportation sector, taking into account comments received on the content of this discussion paper.

The status quo and why new policies are needed

Oil security and global climate change are the two largest looming public-policy challenges for the U.S. transportation sector. For the past thirty years, remarkable advances have been made in reducing emissions of "conventional" tailpipe pollutants — hydrocarbons, nitrogen oxides, carbon monoxide, and particulate matter. Less progress has been made on reducing overall oil consumption and emissions of greenhouse gases (GHGs) from the U.S. transportation sector.[2] Highway fuel consumption increased 62 percent between 1973 and 2005,[3] and highway GHG emissions increased nearly 40 percent between 1990 and 2005.[4]

The United States is more dependent on foreign oil than at any time in its history, importing 60 percent of its supplies in 2006.[5] The United States is by far the largest consumer of oil in the world at 20.6 million barrels per day, followed by China at 7.6 million barrels per day and Japan at 5.2 million barrels per day.[6] The transportation sector accounts for two-thirds of U.S. oil consumption, and motor vehicles alone for 44 percent.[7] U.S. oil production peaked in 1970, and, according to the U.S. Energy Information Administration, it is not likely to rise significantly in the future.[8]

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[2] Even though total oil consumption has increased in the transportation sector, the overall oil intensity (thousand barrels oil consumed per day/GDP in 2000$) declined 30 percent between 1985 and 2005 (data from BEA 2007 and EIA 2007). Between 1975 and 2005, the energy intensity (Btu/vehicle-mile) for cars improved 40 percent, and the energy intensity for light trucks improved 27 percent (TEDB 2-15).

[3] In the case of transportation oil consumption, highway usage of gasoline, gasohol, and diesel increased from 110.5 billion gallons in 1973 to 179 billion gallons in 2005 (TEDB 2007, 2-3).

[4] From Table 3-7 of the Inventory of U.S. GHG Emissions and Sinks: 1990-2005 (U.S. EPA April 2007). Includes gasoline and diesel consumption by automobiles, light-duty trucks, other trucks, buses, and motorcycles.

[5] Net oil imports (EIA May 2007).

[6] EIA, World Petroleum Demand, 2002-2006, International Petroleum Monthly, March 2007.

[7] Light vehicles, including cars, light trucks and motorcycles consumed 9.1 million barrels per day of crude oil equivalent in 2005 (TEDB 2007, Table 2.6).

[8] The EIA estimates a 4% growth in U.S. oil production by 2030 (EIA February 2007).

Both the public and government officials are concerned about the perceived economic and security vulnerabilities arising from such high levels of dependence on imported oil. Oil imports have direct security implications through increasing the probability of going to war to protect access to foreign oil supplies, the use of oil revenues to fund the build-up of terrorist forces and the acquisition of weapons of mass destruction by potential adversaries of the United States and its allies, and provision of oil revenues to countries that foment hatred for the United States and train and support terrorists to attack it.[9]

Because the oil market is global in nature, it would be difficult, costly, and of limited effectiveness to focus on restricting imports alone, however. In a global oil market, price spikes equally affect the domestically produced and imported portions of oil used in the United States. Thus, reducing oil dependence overall is the only way to reduce U.S. economic vulnerability to oil-price shocks.[10] While the overall oil intensity[11] of the U.S. economy has declined since the 1970s, rapid price increases still have the ability to shock the economic system and create significant dislocations. Of course, increased domestic production of fuels (e.g., domestic crude, biofuels, coal-to-liquids) can reduce import dependence and the foreign-policy and balance-of-payments liabilities associated with that part of U.S. oil consumption, but some of these approaches would make the climate-change problem worse.

Box A. Terminology

Car – sedan or hatchback

Light truck – sport utility vehicle, pick-up, or van

Passenger vehicle – car and light truck combined (does not include motorcycles, buses, or trains)

Fuel economy – total miles traveled by vehicles divided by total fuel use

Fuel efficiency – energy at wheels divided by the energy in tank – the ***tank- to-wheels*** efficiency

Well-to-tank – the energy use or GHG emissions associated with the production and distribution of oil-derived motor fuels

Field-to-tank – the energy use or GHG emissions associated with the production and distribution of biofuels

Low carbon fuel – fuel that has lower GHG content on a well- or field-to-tank basis, including the GHG emissions associated with fertilizer applications, refining, and distribution.

Global climate change has emerged as a major threat to the United States and countries around the world. It is now clear beyond reasonable doubt that the climate of the Earth is changing at a pace that is highly unusual against the backdrop of natural variations and that the primary driver of this change is the buildup of anthropogenic greenhouse gases (most importantly carbon dioxide) in the atmosphere since the beginning of the Industrial Revolution. As the 2007 assessment of the Intergovernmental Panel on Climate Change (IPCC) states, [12] "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level." The same document gives a "likely" range for the global-average warming to be expected during the 21st century extending

[9] Lugar and Woolsey 1999, and Holdren 2005.
[10] The fraction of oil imported does affect who earns the oil revenue, of course.
[11] Oil consumption per unit of economic output.
[12] IPCC WG1 SFP, p. 5.

from 1.1 to 6.4°C, depending on assumptions about rates of economic growth and technological change.

Even the warming trajectories in the middle of this range would be expected, according to the IPCC, to be associated with a major accentuation of already observed trends toward increased frequency and/or intensity of floods, droughts, tropical storms, heat waves, and wild fires, as well as accelerating sea-level rise. Damage to human well-being around the globe on the higher emissions and warming trajectories could be immense. It is increasingly apparent that the urgency of reducing emissions below mid-range projections is high and the magnitude of the needed reductions is large.

Overall, the U.S. transportation sector accounts for 33 percent of U.S. carbon dioxide emissions and highway fuel consumption for 20 percent.[13] Other greenhouse gases from the transportation sector such as methane, nitrous oxide, and hydrofluorocarbons contribute an estimated 23 million metric tons of carbon equivalent,[14] which is equal to about 5 percent of transportation carbon dioxide emissions.[15] The remaining two thirds of U.S. emissions are attributable mainly to the industry and to industrial and commercial buildings and the energy-using devices they contain; this includes emissions from the generation of electricity, nearly all of which goes to the industrial and buildings sectors. The numbers show that U.S. greenhouse-gas emissions cannot be sufficiently reduced by focusing on motor vehicles alone, but neither can they be sufficiently reduced *without* a significant effort in the transport sector.

The main regulatory mechanism currently in place to address U.S. foreign oil dependence is the Corporate Average Fuel Economy (CAFE) program. Enacted in 1975, it was not designed to address the problem of global climate change -- although in principle approaches of this type could make a contribution to that end -- and neither have any other federal policies been put in place to reduce greenhouse-gas emissions from motor vehicles. It must be added that the CAFE program has not even done what is *was* designed to do -- prevent ever increasing dependence on foreign oil. Overall fuel economy of passenger cars in the United States is no better than it was twenty-five years ago, [16] as illustrated in Chart 1, and U.S. oil-import dependence has increased in both absolute and percentage terms.[17] Whether these shortcomings of motor-vehicle fuel-economy policy to date are best addressed now by strengthening and reforming the CAFE program, or by other approaches, or by a combination of a strengthened CAFE program and other approaches is the question to which we aim to contribute here.

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[13] Motor gasoline and diesel.

[14] Data for 2003. Total U.S. carbon dioxide emissions in that year can be broken down as follows: 29% industry; 18% commercial; 20% residential, 20% motor gasoline, 12% other transportation. Oak Ridge National Laboratory, Transportation Energy Data Book, Edition 25, 2006 (Tables 11.4 and 11.5).

[15] Greene, David and Andreas Schafer, "Reducing GHG Emissions from U.S. Transportation," Pew Center on Global Climate Change, Washington, DC: May 2003.

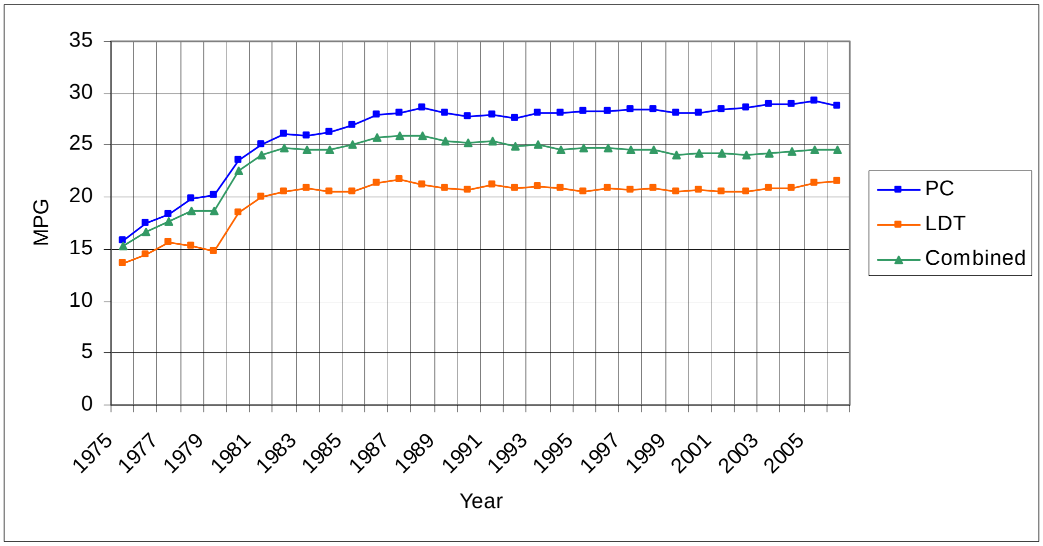
[16] In 1982, the car/light-truck combined CAFE estimate was 25.1 miles per gallon. In 2005, the combined CAFE estimate was 25.2 miles per gallon (Transportation Energy Data Book, 2006, Table 4.17).

[17] Nonetheless, CAFE was estimated in 2002 to have reduced U.S. motor vehicle gasoline consumption below what it otherwise would have been by 2.8 million barrels per day. See NRC 2002.

The CAFE program was adopted as part of the Energy Policy and Conservation Act of 1975. The program—Title 49, Chapter 329 of the United States Code —directs the Secretary of the Department of Transportation (DOT) to establish standards for fuel consumption per mile applicable to passenger automobiles and, contingent upon given criteria, to non-passenger automobiles, or light trucks. DOT delegated authority to the National Highway Traffic Safety Administration (NHTSA) to set fuel economy standards, on which task NHTSA consults with the Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA). EPA is also responsible for new vehicle testing and the estimation of their fuel economy, according to procedures set forth in the Code of Federal Regulations, Title 40, Part 600. The CAFE program can and has been amended by Congress.

The fuel economy standard for passenger vehicles is currently set at 27.5 miles per gallon (mpg) and has been at this level since 1985, when the standard became mandatory. Fuel

Chart 1. Trends in new light-duty vehicle fuel economy



economy standards for light trucks were first established in 1979, at 13.7 mpg. This standard increased to 20.7 mpg by 1996, at which point Congress imposed a multi-year freeze on NHTSA's authority to revise the standard for light trucks. In April 2003, NHTSA set new fuel economy standards for light trucks for model years 2005-2007. For model years 2008-2010, NHTSA raised fuel economy for light trucks to 22.5, 23.1, and 23.5 miles per gallon for 2008, 2009, and 2010, respectively. A modified CAFE program for light trucks will be enforced starting in 2011, setting fuel-economy requirements as a function of vehicle footprint (where footprint is defined as the product of vehicle wheelbase times its average track width).

The current CAFE program also promotes the deployment of vehicles capable of operating on alternative fuels. The fuel economy of such vehicles receives a bonus credit compared to petroleum-fueled vehicles, thus providing automakers with incentives to deploy them as a means to reduce their corporate average fuel economy. These provisions induced domestic manufacturers to commercialize significant volumes of flex-fuel vehicles.

Gasoline and diesel prices have been volatile, leading to weak incentives among vehicle purchasers and drivers to change their behavior. The number of miles driven by Americans continues to increase faster than the increase in the number of cars on the road, and much faster than the rate of population growth.[18] Alternative fuels, while growing rapidly, are still a small fraction of total motor vehicle fuel consumption, with ethanol production capacity in 2006 of 4.8 billion gallons out of a total of 140 billion gallons of gasoline consumption. There are approximately 6 million flexible-fuel vehicles[19] out of a total 232 million passenger cars in the United States.[20]

The automotive and fuels industries are currently handicapped by the lack of a clear long-term policy framework. Without consistent, long-term policies that define the rules of the future, it is difficult for industry to plan, revise product development cycles, or implement changes in their manufacturing operations.

Special challenges

Several circumstances conspire to make the policy-making challenge in this domain especially complex. The four most difficult challenges are (1) the combination of low current fleet fuel economy and long vehicle lifetime, (2) the role of consumer choice in driving and purchasing decisions, (3) the various liabilities of all of the alternative fuels, and (4) the limited likely influence on the transportation sector of economy-wide climate-change policies as compared to transportation-sector-specific policies.

Current fleet fuel economy and long vehicle lifetime

The rate of change of the average fuel economy of the on-road fleet of vehicles over time depends on the rate of change of the average fuel economy of each year's new-vehicle fleet, the number of those vehicles sold, the size of the total fleet, and the lifetimes of vehicles on the road. In the United States, the number of relatively inefficient vehicles in the on-road fleet is high in substantial part because of the dramatic rise in sales, during the 1990s, of SUVs, pick-up trucks, and vans intended for use as passenger vehicles but subject to the weaker "light truck" fuel-economy standards. (These light trucks now comprise 41 percent of registered passenger vehicles.[21])

Fuel *efficiency* (see Box A for definition) in most vehicles has improved markedly, but the resulting energy savings generated by installing more fuel-efficient technologies have been used to support increased weight and performance of the vehicles rather than reducing fuel consumption. For the future, even if more fuel-efficient technologies are installed in new passenger vehicles, the rate of improvement of overall U.S. vehicle fuel economy will be limited

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[18] Between 1993 and 2003, the average annual percentage change in the number of vehicle-miles traveled was 2.3%. The average annual growth in the number of vehicles was 2.0%, and the population growth rate was 1.1% (Transportation Energy Data Book, 2006, Table 8.1).

[19] U.S. EPA 2006.

[20] TEDB 2007.

[21] Data for 2005 (TEDB 2007).

by the pace at which the existing fleet of cars is replaced.[22] As new cars are sold whose improved fuel efficiency is dedicated to lowering fuel consumption, and old cars are retired, the fleet-average fuel economy will improve each year.

Consumer choice: driving and purchasing decisions

Consumer decisions about which vehicle to purchase, how much to drive, or which fuel to use hugely influence the intended outcomes of policies in this realm. Americans drive vast distances, and they are driving farther and farther every year. All this motor-vehicle travel increases overall oil consumption. Although there are other factors that affect total oil consumption, including the number of cars on the road, their fuel efficiency, and the use of alternative fuels that displace conventional oil-derived gasoline and diesel, the upward trend of "vehicle-miles traveled" (VMT) in the United States has been difficult to reverse.[23] Between 1995-2005, vehicle-miles traveled by cars grew on average 1.6% each year. SUVs, vans, and light trucks experienced a higher growth rate of 3.0%. The *EIA Annual Energy Outlook 2007* reference case projects a 1.9% average annual growth rate for light-duty vehicles (<8,500 pounds) through 2030.[24] If the EIA's projection is correct, Americans will drive their cars twice as far in 2045 as they drive them today.[25]

There is some recent evidence that drivers are becoming less sensitive to increases in gas prices, which might explain why vehicle-miles traveled is increasing. According to Hughes, Knittel, and Sperling (2008), the price elasticity of demand for gasoline (the relationship between the changes in price of gasoline and changes in the quantity of gasoline purchased) in the short run has fallen from -0.21 to 0.34 in the 1975-1980 time period to -0.034 to -0.077 in the 2001-2006 time period. This indicates that consumers today are less responsive to increases in gasoline prices than they were in the 1970s.

The trend of increasing vehicle-miles traveled is one of the key policy challenges because the projected increase in miles driven by American cars in the future could swamp the gains made through improved fuel efficiency in cars. As can be seen in Chart 2, even if vehicle fuel economy is significantly improved, it is difficult to attain any decrease in total passenger vehicle gasoline consumption (and corresponding GHG emissions) if nothing is done to curb the growth in vehicle-miles traveled.[26] Chart 2 shows that with business-as-usual (BAU) improvements in

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[22] Authors of the NRC study (2001, 114) argued, "Little can be done to improve the fuel economy of the new vehicle fleet for several years because production plans are already in place. The widespread penetration of even existing technologies will probably require 4-8 years. For emerging technologies that require additional research and development, this time lag can be considerably longer."

[23] Taxes on gasoline and diesel are considerably higher in Japan and many European countries, where the taxes range from $2.00-$6.00 per gallon, compared with federal taxes of about 18.4 cents per gallon and average state taxes of approximately 20 cents per gallon in the United States.

[24] Transportation Research Board, "The Fuel Tax and Alternatives for Transportation Funding," Committee for the Study of Fuel Tax Viability and Fuel Taxes for Transportation Finance, Washington, DC 2006.

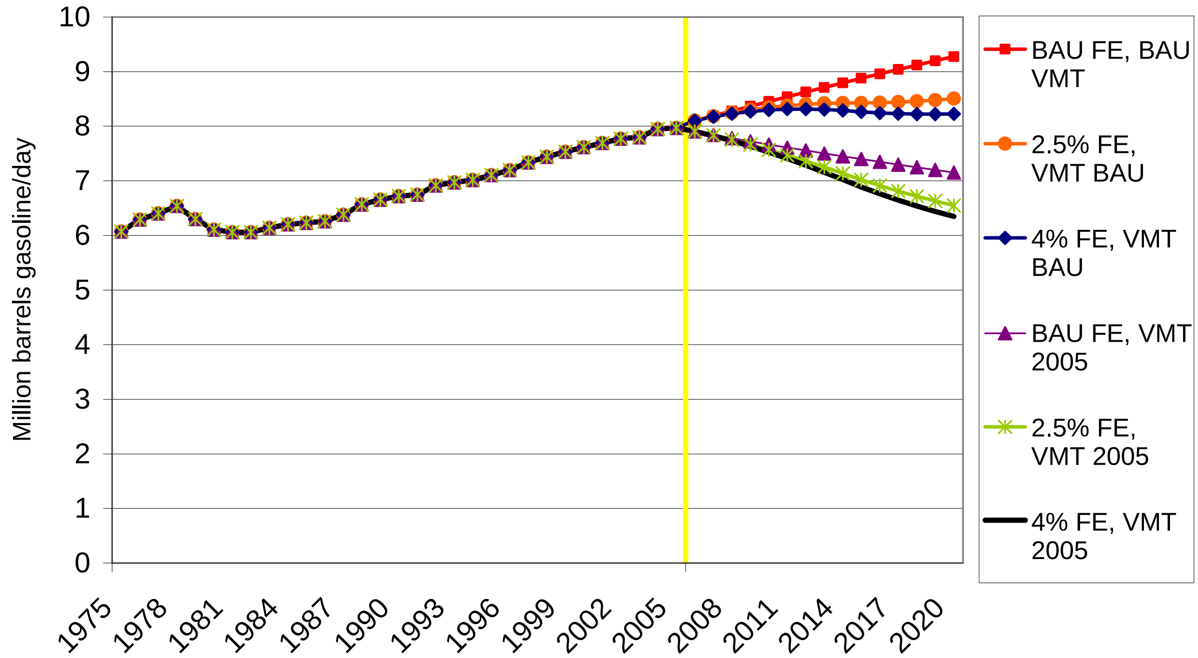
[25] Department of Energy's Energy Information Agency.

[26] The chart assumes Business as Usual (BAU) for fuel efficiency in passenger vehicles is the extrapolation of the historical rate of improvement from 1996 to 2005 and that the BAU path for vehicle-miles traveled for passenger vehicles is the extrapolation of the historical rate of increase from 1996 to 2005. The alternative policy scenarios here are a 2.5% or 4% annual improvement in fuel efficiency in cars and light trucks and holding vehicle-miles traveled steady at their 2005 levels.

fuel economy and business-as-usual increases in VMT, passenger vehicle gasoline consumption would steadily increase through 2020. If VMT is not held constant at 2005 levels, no decrease in passenger-vehicle gasoline consumption can be achieved, regardless of whether the annual improvements in vehicle fuel economy are 2.5 or 4 percent. If VMT is held constant at 2005 levels in combination with either a 2.5 or 4 percent annual improvement in passenger-vehicle fuel economy, a significant reduction of passenger-vehicle gasoline consumption can be achieved.

Americans also strongly influence the automobile market through their choices about which car or truck to buy. Automakers have long argued that U.S. consumers do not value fuel efficiency very highly when deciding which car to buy. If this is true, then one can see why

Chart 2. U.S. passenger vehicle gasoline consumption under different scenarios



automakers are reluctant to produce more efficient vehicles. The surprising success in the U.S. market of the Toyota hybrid, the Prius, for example, somewhat undermines the automakers' claim. Perhaps if more attractive and compelling fuel-efficient vehicles were offered and aggressively marketed by the automobile companies, consumers would want to buy them.

The liabilities of alternative fuels

Despite the recent enthusiasm for biofuels by many analysts and investors, they are not a "silver-bullet" solution to the oil-dependence and climate-change problems. The fossil alternatives to conventional oil in transport applications – natural gas, tar sands, oil shales, and coal-to-liquids technologies – likewise have constraints and liabilities, as does hydrogen no matter how it is produced. In this section we briefly survey the benefits, shortcomings, and uncertainties associated with all of these alternatives.

Due to the recent boost in ethanol production in the United States, some emerging constraints on the amount of domestically-produced ethanol that might displace current U.S. oil supply in the near to medium term have been identified. Even without further government mandates, corn ethanol is projected to increase from 4.9 billion gallons in 2006 to 6.7 billion gallons in 2007 to 12.2 billion in 2009.[27] Corn prices have almost doubled during the past thirty months, reaching $3.77 per bushel in June 2007 and substantially increasing feed costs for livestock and dairy farmers.[28] Due to the recent surge in demand for ethanol, provoked in part by government subsidies and other incentives, U.S. farmers planted 92.9 million acres of corn in 2007, 19 percent more than in 2006. Planted corn acreage in 2007 is the highest since 1944, and state records for planted acreage were set in Illinois, Indiana, Minnesota and North Dakota.[29] Meanwhile, planted area for soybeans fell 15 percent from 2006 levels.

The use of corn-based ethanol may not result in significant net reductions in either greenhouse gases or energy use. Production can be very energy intensive, depending on how the corn is grown and then refined into ethanol (e.g., how much fossil fuel is used to create chemical inputs like pesticides and fertilizer, and whether natural gas or coal is used during the refining process). On a lifecycle basis, however, corn ethanol is estimated to reduce energy consumption by 25 percent on average. Corn ethanol also averages 12 percent lower net greenhouse-gas emissions on a lifecycle basis than gasoline and diesel.[30]

Aside from the greenhouse-gas issue, there are several environmental concerns related to sharply increased production of "first generation" ethanol, including increased pollution from fertilizers and pesticides, soil erosion from over-reliance on one crop, and conversion of natural lands into biofuel production.[31] Second-generation ethanol – so called "cellulosic" ethanol – is still in the R&D stage, and while it offers the promise of greatly expanded potential for ethanol production from a much wider array of feedstocks, the costs are still very high and the biodiversity and ecological implications remain unclear.

Biodiesel requires much less energy to produce, and so its net greenhouse gas reduction as compared to corn ethanol is much better. Production to date, however, has been limited, and much of the biodiesel produced in the United States has been shipped to Europe where prices have been more favorable.

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[27] Production of ethanol in 2006 reached 4.86 billion gallons, an average of 317,000 barrels per day (b/d) or 13.3 million gallons per day. That is an increase of 24.3 percent over 2005 (RFA 2007).
[28] The recent increase in corn prices, for example, provoked huge riots in Mexico City, where corn is a staple, in January 2007, though there were some reports of hoarding and profiteering there (see Malkin 2007).
[29] USDA 2007.
[30] Tilman, et. al (2006) determine that the sum of all energy outputs (including co-products) divided by the sum of all fossil energy inputs results in a net energy balance ratio of 1.25 for corn-grain ethanol. Other estimates (IEA 2004) are somewhat more optimistic, and others more pessimistic. Turner et. al (2007) argue that biofuels processing strongly affects the GHG content of the fuel on a lifecycle basis and that, for example, a new dry mill burning coal produces corn ethanol with no GHG benefits.
[31] The term, "first generation" ethanol refers to the production of ethanol from traditional feedstocks like corn, and using conventional refining methods as well. "Second generation" ethanol usually refers to the production of cellulosic ethanol, which uses a much wider array of feedstocks and refining methods.

Production of heavy oil, tar sands, and coal-to-liquid fuels are either already competitive or close-to-competitive, given current crude oil prices, but production of these fuels is very energy- and GHG-intensive (without carbon capture and storage), as well as ecologically destructive. Oil shale-based liquids are not yet economically competitive.[32]

The limited likely impact of economy-wide policies to reduce GHG emissions as compared with transportation-sector-specific policies

There seems to be an emerging consensus that a mandatory "economy-wide" cap on U.S. GHG emissions is needed because it would provide a foundation for the suite of policies that will be needed to address climate change and the other externalities of the existing energy system (such as high foreign oil dependence or air pollution).[33] Such a cap would be specified in terms of total allowable $CO_{2\text{equivalent (eq.)}}$ emissions per year. Under the cap, a national system of tradable permits could be established, which would create a national price per ton of CO_{2eq}. Likewise, a national carbon tax would create a national price pr ton of CO_{2eq}. But, if either economy-wide system is adopted, it is not likely that such a policy would address the oil security problem, nor is it likely to significantly reduce GHG emissions from the transportation sector.

A national policy that resulted in a tradable permit price of $100 per ton carbon equivalent ($27 per ton $CO_{2eq.}$), for example, would translate into an increase in the cost of gasoline of only 25 cents per gallon of gasoline. At $33 per ton of carbon equivalent ($9 per ton CO_{2eq}), the carbon permit price or tax would translate into 8 cents per gallon of gasoline, which would be lost in the noise of day-to-day oil price volatility.[34] An economy-wide CO_2 approach alone will probably not cause oil consumption or GHG emissions from the transportation sector to be significantly reduced unless the price of carbon is set much higher than currently discussed in Washington. (There would be some benefit on the supply side of the vehicle-fuel supply-demand equation, however, insofar as even a modest carbon price would shift the competitive balance among oil substitutes in favor of those that reduce CO_2 emissions or at least do not make them worse.)

As discussed earlier, a key rationale for new policies in the transport sector is that oil use in transport has many externalities in terms of how it affects U.S. economic vulnerability, foreign policy, and national security. From a climate change point of view, some would argue that an economy-wide approach alone is more economically efficient because the cheapest reductions will be made first, and those are likely to be in the power sector since coal has a higher carbon content than oil. But, there are at least two arguments to be made in favor of additional policies to reduce GHG emissions from the transportation sector – policies which would simultaneously address the oil security problem.

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[32] Farrell and Brandt 2006.

[33] See the National Commission on Energy Policy at www.energycommission.org and the U.S. Climate Action Partnership at http://www.us-cap.org/, Bingaman-Specter Senate Bill, for example.

[34] At $100 per ton C: $100/metric ton C * 2.42 kg C/gallon gasoline * 1 metric ton/1000 kg = 25 cents/gallon; At $33 per ton C: $33/metric ton C * 2.42 kg C/gallon gasoline * 1 metric ton/1000 kg = 8 cents/gallon

First, the recent reports from the Intergovernmental Panel on Climate Change and the UN Scientific Expert Group on Climate Change and Sustainable Development have made clear that avoiding the further 1.5 to 2 degrees C of global-average warming likely to precipitate unmanageable climatic disruption would require leveling off global emissions and beginning to reduce them not much later than 2015 to 2020.[35] As a practical matter, this will be very difficult, not least because the UN Framework Convention on Climate Change (ratified by the United States in 1992) specifies that industrialized countries are to take the lead in order to leave room for development in the global South, which means that the United States would have to be leveling off and starting to reduce its emissions even sooner than 2015.

In principle, one could get reductions of the needed magnitudes with a "pure" economy-wide approach (that is, without augmentation with additional policies for the transportation sector), although in practice, such a course is uncertain since politics will make it difficult to set the carbon price high enough in the early years to meet moderate reduction targets.[36] There is the further problem of carbon "lock-in" where more carbon-intensive technologies that are deployed while the carbon price is still too low last for many years and are not pre-maturely retired. This is particularly problematic when one aims to be on a declining emission trajectory on a time scale that is short compared with the lifetime of the technologies (roughly 15 years for cars and 50-75 years for power plants).

Also, there is the economic, technical, and political problem of placing the main burden on the electric power sector in the near term. Since transportation accounts for such a substantial fraction of overall U.S. emissions, it would be politically difficult to effectively place the entire burden on the electric power industry. It will also be difficult economically and technically to achieve rapid reductions from the electric power sector because of large capital investments in plants that are very costly to retrofit for CO_2 capture and slow to turn over. Because the transportation sector has a faster capital-stock turnover rate, the impact of new policies can be felt sooner there.

Finally, by establishing a long-term signal to the transportation industry, companies can begin to plan, alter production cycles, and meet future demand with minimal cost. A worst-case and not unlikely scenario would be that in 2020, it suddenly became clear to policymakers that steep reductions in GHG emissions were needed immediately, and the transportation-related industries were suddenly faced with extremely expensive mandates over a very short time-horizon.

Policy principles and criteria

A number of principles or criteria should guide the formation of new federal policies for the transportation sector to address global climate change and U.S. oil dependence. It is important to note that these criteria can be applied to individual policy measures or to packages

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[35] See http://www.ipcc.ch/ and http://www.unfoundation.org/files/pdf/2007/SEG_ExecSumm.pdf respectively.
[36] According to the National Commission on Energy Policy (2007), a cap-and-trade approach starting in 2012 with a $10-12/ton carbon equivalent price (the "safety valve" price) that escalates at 5 percent per year in real terms, for example, would need supplementary policies in the coal and transportation sectors in order to reduce 15-20 percent below 2006 emissions by 2030.

of measures. Some of the criteria may be highly compatible with each other while others may be in tension (e.g., the need for a clear, long-term signal versus flexibility to change policies in the face of new information, for example). The criteria listed below are approximately listed in order of priority, though all are important.

Individually, or in combination, policies should:

- *Seriously address both the oil- consumption and climate- change challenges*. Certainly policies should not be adopted that make one of the problems worse while trying to solve the other. Committing to do no harm could be considered a "Hippocratic Oath" of energy policy in this domain. In addition, policies should make an *appreciable* difference in addressing one or both problems.
- *Provide a clear, long-term signal to industry and the American public*. Because industry needs time to alter its production cycles, and because consumers need to make purchasing decisions, it is important that the policies provide clear and consistent guidance to the market.
- *Be transparent, verifiable, and enforceable.* Policies should strive to be transparent to the public and industry in order to better provide the clear long-term signal that they need. In addition, they must be verifiable and enforceable.
- *Promote shared responsibility for addressing the problems*. The responsibilities for tackling the climate change and oil security issue should be shared among transportation-related industries, including oil companies, auto manufacturers, and biofuels producers. In addition, the burden should be shared by both producers and consumers.
- *Protect and assist lower-income segments of U.S. society.* Ideally, policies will help lower-income segments of U.S. society, and at worst, they must not harm low-income Americans.
- *Address both fuels and vehicle technologies.* Either individually or in combination, policies should induce change in both fuels and vehicle technologies. Approaches that do this are likely to be more equitable and cost-effective than those that load the whole burden onto one side or the other.
- *Stimulate innovation*. Policies should stimulate innovation (induce technological change) in order to promote the development of new technologies that help address the challenges, and also to reduce costs of existing and new technologies so that they enjoy more widespread success in the marketplace.
- *Be flexible.* Policies should have the capacity to be adjusted in the face of new information and changing circumstances.
- *Be cost effective.* Efforts should be made to design the most cost-effective policies that are consistent with all of the other criteria presented here.
- *Enhance the competitiveness of U.S.-based industry*. To the extent possible, policies should enhance the competitiveness of U.S.-based industry and bolster the U.S. workforce.

There is a large array of policy options for addressing the problems of oil dependence and climate change. Some of these options only offer leverage against one of the two problems, and some offer leverage against both. As the discussion that follows will make clear, however, it is likely that only a portfolio of complementary measures selected from the array – as opposed to any one measure alone – will be able to meet a high proportion of the criteria just outlined.

Individual policy options: pros and cons

A number of individual policy options are defined and explained in this section, with elaboration of advantages and disadvantages of each. It is not our intention to comprehensively analyze all the possible policy options here (though most are contained in Appendix A), but rather to clarify the main pros and cons of the most frequently-discussed approaches. A suitable strategy is likely to entail a portfolio of approaches and policies constructed so that its elements address different parts of the problem, different paths to achieving the aim, and/or different time frames. In addition, the portfolio approach allows employment of policies that offset each other's weaknesses and to achieve redundancy where the importance of the aim is deemed to justify paying for this. Later in this paper, three policy packages are outlined for illustrative purposes to show how individual policy measures are likely to interact with each other to achieve different outcomes.

Fuel-economy standards

This policy mechanism specifies, through a regulatory or political process, the average per-mile fuel consumption of new vehicles sold in a given year. Fuel-economy standards – such as the U.S. Corporate Average Fuel Economy (CAFE) standard – are intended to induce innovation in vehicle technologies to curb or reduce oil consumption. Corporate average fuel-economy standards for passenger vehicles have been in place in the United States since 1975 (enforcement started in 1978), and standards for light-duty trucks were adopted a few years later. Both standards have remained fairly stagnant for the last 25 years. Fuel-economy standards can be implemented in numerous ways. Different options include using a corporate average, fleet average, weight-based, sized-based, or vehicle footprint-based standard.[37]

The advantages of fuel-economy standards are specified below. Fuel-economy standards:

- Are attractive politically. Fuel-economy standards direct auto manufacturers to adopt fuel saving technologies and thus offset the impact, on consumers, of any increases in fuel prices, although the standards may cause the price of cars to increase. They do not have any direct effect on the oil industry.
- Address potential market failures. Some evidence indicates that consumers are not very rational at incorporating fuel savings into their purchasing decisions.[38] Their willingness to pay for fuel economy does not correspond well with the fuel savings that could be obtained during the lifetime of the vehicle. (In principle, CAFE standards can achieve, through government edict, an economic balance point between increased first cost and

[37] The mandatory Japanese and Chinese vehicle fuel-economy standards use a weight-based system, with different standards issued for each weight-class. Japanese fuel economy standards are approximately equivalent to 46 mpg, and the Chinese standards are approximately equivalent to 36 mpg. The voluntary European standards are assessed on a CO_2 equivalent basis, and translate into approximately 43 mpg (An and Sauer 2004).
[38] See, for example, Turrentine and Kurani (2005).

lifetime fuel-cost savings that it may not be in the automaker's interest to figure out and that most consumers are not equipped to figure out.

- Place a market value on a public good. Energy security is a public good and is not properly valued by free markets. One manifestation of energy insecurity is the excessive importation of oil (where "excessive" can be economically or politically defined). Fuel-economy standards are one way in which government can limit oil consumption in passenger vehicles.
- Create certainty about the minimum fuel efficiency of new motor vehicles. Because automakers must meet the standards, they provide a minimum floor for technical fuel efficiency.
- Induce innovation. All performance standards induce innovation in industry to meet the standards, unless the standard is easy for industry to meet.

Fuel-economy standards have some drawbacks as well. They:

- May increase vehicle-miles traveled. The policy problem that fuel-economy standards intend to address is the consumption of petroleum by motor vehicles. Because fuel economy standards instead reduce per-mile fuel consumption and because no clear targets are specified for total fuel consumption by vehicles, there is no guarantee that setting a standard will limit or reduce overall oil consumption. In fact, total U.S. motor-vehicle fuel consumption has increased 60 percent since the CAFE program was enacted, in large part to the increase in the number of cars on the road (see 'scale effect' next) and the increase in vehicle-miles traveled (see 'special challenges' earlier). Also, because fuel-economy standards provide consumers with more efficient vehicles, thereby lowering the per-mile cost of driving, they may actually stimulate *more* driving – the so-called "rebound" effect.[39]
- Do not address the scale effect. Fuel-economy standards are not intended to discourage sales of new automobiles. An increase in the number of passenger vehicles on the road can offset the gains achieved through the per-mile fuel consumption standard.
- Neglect the climate change mitigation goal. CAFE was not designed to address GHG emissions from motor vehicles. By improving vehicle fuel efficiency, fuel-economy standards inherently reduce carbon dioxide emissions because less fuel is burned, but they do not provide direct incentives to reduce the carbon content of vehicle fuel or the emissions of other greenhouse gases such as hydrofluorocarbons.
- Have stagnated. Fuel-economy standards for passenger vehicles have not been significantly raised in the past 25 years in the United States. Such stagnation is clearly not the result of technological or economic infeasibility, but rather the result of political inertia or grid-lock.
- Fail to encourage technological innovation beyond the standard. Like every performance standard, fuel-economy standards induce technological innovation to the point of meeting the standard, unless there is some other incentive for the firm to go beyond compliance.
- Are complex to implement. The burden of determining the optimal standard is placed on the regulator. Because of inherent asymmetries of information between regulator and

[39] The "rebound" effect for personal transportation has been estimated to be about a 10% increase in the short-run and a 20-30% increase in the long-run in fuel consumption for a 100% increase in fuel efficiency standards (Greening, Green, and Difiglio 2000).

regulated industry, among other factors, it is unlikely that the regulator will find the true optimal standard. Another source of complexity is the difficulty of measuring fuel economy. Historically, fuel economy has been defined as the distance traveled per unit volume of fuel under standardized driving conditions. It has long been suspected – and recent EPA findings prove – that the driving cycles used to measure fuel economy are not representative of contemporary driving patterns.

- Place unequal burdens on consumers and industry. The cost of new technology adopted by industry to meet the standard translates into higher vehicle prices. Higher prices will be paid by all consumers, regardless of the amount of driving they do. In other words, consumers do not pay for the external cost of their driving, but rather for a *proxy* of it. Thus, on average, consumers who drive less will subsidize consumers who drive more. In addition, fuel-economy standards place the entire regulatory burden on the automobile industry, and none on the fuels providers.[40]

GHG performance standards for vehicles

GHG performance standards for vehicles can be defined in terms of the tailpipe emissions resulting from the combustion of fuel or in terms of the per-mile emission of all greenhouse gases coming from the vehicle. Under the first definition, GHG standards are similar to fuel economy standards in that they are based on the mass of $CO_{2eqivalent}$ per distance traveled (e.g., $gCO_{2eq.}$/mile) basis for new passenger vehicles.[41] As such, GHG performance standards share many of the same pros and cons of fuel-economy standards. This discussion, therefore, will only elaborate additional pros and cons related to GHG performance standards.

The main advantage to GHG performance standards as opposed to fuel-economy standards is that they create incentives to reduce all greenhouse gases coming from motor vehicles (not just carbon dioxide), while maintaining a positive incentive to reduce oil consumption. As previously noted, the main greenhouse gases emitted by passenger cars are carbon dioxide, methane, and nitrous oxide. (Black carbon – soot – emitted by cars is another heat-trapping substance of concern, although not a greenhouse gas.) Not including black carbon, the non-CO_2 greenhouse gases are estimated to account for 5-6 percent of a typical U.S. passenger vehicle's GHG emissions.[42] By regulating all greenhouse gases and not just carbon dioxide, greater GHG mitigation can be achieved, and automobile manufacturers can have more flexibility in terms of how they choose to reduce emissions than they do with fuel economy standards. GHG performance standards also provide certainty to the government and public about the GHG efficiency of the motor vehicles. They also induce the automotive industry to innovate at least enough to meet the standard.

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[40] There is an indirect incentive in the CAFE program for alternative fuels due to the flex-fuel credits that can be accrued by automobile manufacturers for selling flex-fuel vehicles. Consumers may be reluctant to purchase flex-fuel vehicles unless alternative fuels are available, which puts some market demand on fuels providers to offer alternative fuels.

[41] The European standard is assessed on a gram/kilometer basis. The current voluntary standard for each automobile manufacturer is 140 grams CO_2 per kilometer by 2008 and 120 grams CO_2 per kilometer by 2012. The 1995 level was 186 g/km. The European Commission is currently considering a mandatory CO_2 target since automobile manufacturers are likely to fail to meet the voluntary target in 2008.

[42] This includes an estimate of vehicle-miles driven. See EPA 2005.

On the other hand, politically, labeling the standards with the GHG-emissions stamp might appear to weaken the emphasis on energy security, even though the GHG standards would have the same energy security benefits as fuel economy standards.

GHG performance standards for fuels

GHG performance standards for fuels are a relatively new notion, and many aspects of their actual definition and implementation are not yet completely understood or standardized. In general, a GHG performance standard on fuels would require that all fuels meet a standard which specifies the number of grams of $CO_{2eq.}$ per unit of fuel produced (e.g., gCO_{2eq}./gallon)[43] Most frequently discussed is the low-carbon fuel standard (LCFS), which has been adopted in principle in California but has yet to be implemented. With a LCFS, the carbon content or carbon intensity of the fuel can be interpreted in various ways. Possible interpretations of carbon intensity include:

- The total GHG emissions from fuel production through fuel consumption per unit of fuel volume or energy content;
- The carbon contained in a unit of volume or energy of the particular fuel; and
- The total GHG emissions from fuel production through fuel consumption per unit of usable energy delivered to power the vehicle (commonly referred to lifecycle or well-to-wheels emissions)

Fuel carbon intensity can also be measured at the firm level or at the industry level. In its broadest form, a LCFS would account for all the climate impacts of fuel production and consumption, including those derived from water consumption and land-use changes.

There are several advantages to a low carbon fuel standard (LCFS). First, a LCFS provides a strong incentive to invest in low-carbon fuel technologies. Most importantly, a LCFS provides a minimum level certainty about the amount of low-carbon fuel that must be provided to the marketplace that would not be guaranteed with price-incentive mechanisms like carbon taxes. Also, because it is not a tax, a LCFS is more attractive politically.

A LCFS places a burden for reducing GHG emissions on fuels providers (namely oil companies), unlike fuel economy standards or GHG performance standards for vehicles. It also creates the possibility of comprehensively managing carbon emissions by implementing a well-to-wheels approach.

From an oil security point of view, the LCFS provides a direct mandate for alternative fuels while providing an incentive to produce fuels which emit the least amount of greenhouse gases during production and use. Often, policy proposals aimed at increasing the availability and use of alternative fuels fail to provide safeguards to prevent alternative fuels from resulting in a net increase in GHG emissions. Use of coal-to-liquids without carbon sequestration, for example, would displace oil consumption, but would cause a big net increase in GHG emissions.

[43] Any metric is possible, such as pounds per barrel, grams per gasoline, grams per liter.

There are drawbacks to a LCFS as well. Typically, a LCFS is specified as a percentage reduction in fuel carbon intensity relative to baseline fuel. Thus, like vehicle fuel economy or GHG performance standards, it does not control the total carbon in fuels delivered and so total GHG emissions will depend on the volume of fuel consumed. If a greater number of vehicles drive greater distances then the actual emissions may not be significantly reduced. This is a key difference between a per-unit standard and other policies aimed at curbing emissions at target levels (e.g., cap-and-trade).

Because the LCFS sets deadlines for compliance, it poses the risk of forcing in the market fuels and production technologies that are not optimal in the longer term. Such risk is particularly high whenever there is only one fuel alternative that can realistically meet the standard at the enforcing deadline. As a specific example, if implementation and enforcement timelines are chosen such that ethanol from starch crops is the only economically-feasible alternative to meet the standard, investment would heavily move in this direction. In a world of zero transaction costs, this would not be a problem. It is clear, however, that once industry makes investment decisions in one direction, switching to different one can be costly. Therefore, early targets may result in inefficient investment and hinder the market introduction of better technologies currently under development.

Standards encourage technological innovation only to the point of meeting the standard—industry has little incentive to pursue innovation to reduce fuel carbon intensity beyond that point. More precisely, industry may seek ways to meet the standard at lower costs but is not likely to seek ways to reduce carbon intensity beyond the level set by the standard.

Depending on how the LCFS is implemented, measuring and monitoring the fuel's carbon intensity will be difficult. This problem will be complicated still further when the standards are applied to imported fuel products.

Finally, if an economy-wide climate policy such as a carbon tax or tradable permits for carbon is implemented, a LCFS that includes upstream emissions may result in double counting of such emissions. Further, it may be difficult to identify what part of the GHG emissions should be attributed to fuel production as opposed to other products or end uses, such as products derived from petrochemicals.

Volumetric requirements for biofuels

A volumetric requirement for biofuels mandates that a certain quantity of biofuels fuels be sold. The Energy Policy Act of 2005 called for EPA to publish standards requiring that 4.5 billion gallons of renewable fuels, almost exclusively corn-based ethanol, must be purchased in 2007, increasing to 7.5 billion gallons by 2012. Projected ethanol production in the United States for 2007 will far exceed this goal and will be close to the 2012 target by year's end. Using this same mechanism, Congress is now considering dramatically increasing the targets. The Senate bill – The Biofuels for Energy Security and Transportation Act of 2007 – would mandate 8.5 billion gallons by 2008 and 36 billion gallons by 2022. It would also establish targets for "advanced biofuels" (defined as renewable fuels not made from corn),which would increase steadily each year reaching a level of 21 billion gallons in 2022. The Senate legislation also caps the amount of "conventional biofuels" (corn-based ethanol) sold as no more than 15 billion gallons in any year after 2022.

There are two main issues surrounding volumetric requirements—the use of mandates to accelerate the market penetration of biofuels and the size of the mandates. Advocates argue that given the urgency of the dual threats of climate change and energy security, the nation cannot afford the luxury of allowing the market to gradually adjust to market signals. Further, states, such as Minnesota, Hawaii, Louisiana, Missouri, and New Mexico have already taken unilateral action, and without strong federal preemption the industry will confront a chaotic mix of requirements that would be inefficient and costly.

On the other hand, by requiring the industry to purchase a set volume of biofuels, government could limit the oil industry's ability to reduce carbon intensity in the most cost effective manner. Further, there are concerns about the potential impact on food prices, use of ecologically vulnerable land areas (including wetlands), soil erosion, and the absence of an existing infrastructure to transport and manage a rapid increase in biofuels.

These concerns are exacerbated by the size of the target. The larger the volumes and the shorter the time period, the greater will be these externality impacts. Further, both the President's target of 35 billion gallons and the Senate's target of 36 billion are heavily dependent on the development of second-generation biofuels, most of which are still in the R&D stage.

Carbon tax on transportation fuels

Carbon taxes can be assessed on any fuel, and they are generally understood to encompass not just carbon dioxide but all greenhouse gases, so they would be assessed on a CO_2-equivalent basis. Carbon taxes are a policy measure that could be used to reduce greenhouse gases for the entire economy, and also more specifically to reduce emissions from transportation fuels.[44] As discussed under 'special challenges' above, an economy-wide carbon tax would result in a relatively weak tax on transportation fuels since they are generally less carbon intensive than coal.

The focus of this paper is the transportation sector, so in the case of a carbon tax for transportation fuels, the tax would be assessed as $X per ton of CO_2- equivalent per unit of fuel. The tax could be assessed once and held constant, or it could increase gradually by a certain percentage each year in nominal or real terms. A carbon tax could be levied on a lifecycle basis or it could simply be levied in terms of a fuel's carbon content. A methodology for assessing, monitoring, and verifying the greenhouse-gas content of the fuels would need to be developed by a regulatory agency.[45] To induce changes in consumer behavior, a carbon tax would have to be sufficiently high, and it is not clear how high it would have to be. But, even if the optimal tax level is not achieved initially, the tax rate could be adjusted over time in response to new information.[46]

[44] Many in the business community have endorsed carbon taxes, and many economists have long-favored this approach.
[45] The Environmental Protection Agency is logical.
[46] Pearce 1991.

There are a number of advantages to a carbon tax. The biggest one is that it provides absolute carbon-price certainty, which in turn allows investors to calculate very precisely the costs and returns on energy investments. In contrast, as is explained later, the permit price in cap-and-trade systems will fluctuate, creating some market uncertainty.[47] As Pizer (1997) drawing on Weitzman (1974) notes, taxes fix the marginal costs of abatement at the specified tax level, and cap-and-trade systems precisely limit emissions but create uncertainty about the costs of abatement. In the case of a carbon tax, consumers and private industry will know exactly what they will pay (or save) depending on the decisions that they make.[48] Most of the other advantages flow from this certainty characteristic of taxes.

Depending on its level, a carbon tax could induce sustained innovation in the transportation-related industries.[49] The more fossil fuels industries are able to reduce the carbon content of the fuels, the less taxes they will have to pay or pass on to the consumer. Because the price of carbon-intensive fuel will be higher, the consumer will be more likely to purchase lower-carbon fuel and vehicles. This, in turn, will motivate the automobile industry to produce more carbon-efficient vehicles to meet the increased demand for low-carbon passenger cars.

A carbon tax could also dampen the growth in vehicle-miles traveled. Since the cost-per-mile driven would increase, drivers would begin to make more careful choices about how much to drive. If the carbon tax was assessed at a high enough level, the historical growth in vehicle-miles traveled in the United States could be slowed or even reversed, reducing oil consumption and greenhouse-gas emissions.

Other advantages related to the revenues from carbon taxes are that they could be used to create political capital and that they help to reduce the costs of the overall policy. Goulder (1995) showed that when carbon tax revenues are used to finance costs in distortionary taxes (such as income taxes), the overall policy costs are significantly reduced. Carbon tax revenues could be used to provide income tax relief to the American tax payer, to buttress social welfare programs such as social security, to help U.S.-based industry and workers to make the transition to a lower-carbon industry, to support research, development, demonstration, and deployment of low-carbon technologies, and to support public transportation. The allocation of tax revenues is, of course, ultimately Congress's decision. The potential tax revenue would be dependent on the level of the tax imposed, but for illustrative purposes, a 50 cent tax on gasoline and diesel would generate approximately $90 billion in the first year.[50]

A tax also has the advantage of being relatively transparent, as compared with cap-and-trade programs. The tax is easily understood by consumers as a fee placed on the carbon content of fuel. Compared with cap-and-trade programs, it is relatively simple to administer because there are fewer monitoring and enforcement requirements.

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[47] Nordhaus 2007.
[48] This assumes, of course, that the level of the tax is not frequently changed by Congress.
[49] Pearce 1991.
[50] Assuming the GHG content of the fuel was constant (which would not be the case). In 2005, highway usage of gasoline, gasohol, and diesel was 179.1 billion gallons (TEDB 2005).

Of course, there are disadvantages to carbon taxes as well. As already noted, the first drawback is that while a carbon tax provides price or cost certainty, it does not provide certainty about the exact quantity of oil or greenhouse gas emissions that will be reduced.

Politically, conventional wisdom holds that it is unwise to impose new taxes. But, this may be changing. A New York Times/CBS News Poll last year found that 55 percent of Americans polled said they would favor an increased tax on gasoline if the increased tax would reduce the United States's dependence on foreign oil, and 59 percent stated they would favor an increased tax on gasoline if the increased tax would cut down on energy consumption and reduce global warming.[51]

There are policy integration issues as well. If the an economy-wide cap-and-trade system is chosen as the preferred instrument for managing greenhouse gas emissions, it might be preferable to create a cap-and-trade system for transportation fuels as well so that they could be linked. On the other hand, if a national carbon tax is chosen as the preferred instrument for managing greenhouse gas emissions, then a somewhat higher tax might be useful for transportation fuels.

Finally, as with all taxes, there are distributional equity issues that would need to be addressed. Placing a new tax on transportation fuels would make it more expensive to drive, and this could be hard on lower-income segments of society if other transportation options are not available. These regressive aspects of a carbon tax can be offset depending on how revenue from carbon tax is distributed. Lower-income families, for example, could receive larger income tax rebates.

Economy-wide GHG cap-and-trade program

The notion of marketable emission permits, initially proposed in Dales (1968), is centered on the determination of property rights for an environmental good and the creation of a market for such rights. In a climate-policy context, a cap-and-trade program would start with government establishing a limit (cap) on the total emissions of greenhouse gases allowed in a given period (typically a year or a quarter) and dividing that total amount into marketable units or permits (typically a metric ton of carbon dioxide equivalent, $CO_{2eq.}$). In any given period, each emitter would be allowed to emit a quantity equivalent to the permits that it owns. An emitter can gain ownership of an emission permit in several ways, depending on the design of the program. Under one approach, permits can be directly allocated by the government to the emitters, according to a given distribution rule, at the beginning of each period. If based on historical emissions, such an approach is known as "grandfathering" of permits. Under a second approach, emission permits would be sold by the government in an auction at the beginning of each period. In an auction, emitters would try to purchase as many emission permits as they need for the price that they are willing to pay. Other approaches include combinations of grandfathering and auctioning, commonly referred as hybrid allocation systems.[52] Regardless of the approach used for the initial distribution of permits, emitters are able to buy and sell permits from and to other emitters in an open permit market (in other words, trade).

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[51] See http://www.nytimes.com/packages/pdf/national/20060228_poll_results.pdf from February 28, 2006.
[52] Tietenberg 2006.

As the market for GHG emission permits matures, a uniform permit price would emerge. The ability of emitters to trade permits among themselves would result in the homogenization of marginal cost of abatement across trading emitters. Every emitter could choose to reduce its emissions to the point where its abatement marginal cost equals the permit price and then buy any additional needed permits from the market. Otherwise, emitters for whom the marginal cost of reducing emissions is high are able to buy emission permits at a lower cost (the market-clearing permit price) from emitters whose marginal cost of abatement is low rather than actually reducing emissions themselves. It is important to notice that an economy-wide cap-and-trade program does not allow any sector of the economy to dispense with contributing to meeting the emissions cap—if a sector or emitter chooses to buy permits instead of engaging in actual GHG abatement, the corresponding emission reductions will be achieved nevertheless by the sector or emitter that sells the permits in question.

Because it enables all emitters to seek an emissions-abatement cost equal to the permit market-clearing price, a cap-and-trade has the theoretical potential to achieve the necessary total emissions reductions at a minimum total cost. In this sense, a system of marketable permits is comparable to an effluent (or, carbon) fee—both systems are capable of meeting the emissions goal cost-effectively. The two systems have, however, important differences.[53]

Market imperfections and suboptimal implementation choices, however, will likely preclude a cap-and-trade program from actually attaining the theoretical minimum cost. Factors that veer a program away from cost effectiveness include transaction costs, market power, deficient enforcement, and administrative costs. Non-zero transactions costs (the costs of trading a set of permits) results in fewer trading operations and affect the market equilibrium.[54]

Regardless of the potential advantages that a system of marketable permits may have, particularly relative to command-and-control approaches, the relatively-scant experience accumulated with this approach casts some uncertainty as to the extent to which real-world factors may prevent such advantages to fully materialize. The most notable example, the European Union's Emission Trading System (ETS), has demonstrated that the price of emission permits can be volatile, thus rendering return on investments uncertain. The ETS experience adds some empirical evidence to the studies suggesting that auctioning permits may be a better approach than grandfathering.[55]

Cap-and-trade systems also are expected to stimulate technological innovation. The dynamics of innovation motivated by a tradable permits market are, however, not always obvious and they depend on a variety of factors.[56] Industry may have both direct and strategic incentives to innovate. Direct incentives are those that affect the economics of the innovating industry, such as the reduction in carbon abatement costs. Strategic incentives are those that relate to the effects of technological innovation on the other industries or businesses. Strategic incentives are the result of one important difference between marketable permit systems and

[53] Baumol and Oates 1988.
[54] Stavins 1995.
[55] Ackerman et al. 1998; Cramton and Kerr 2002.
[56] Bruneau 2004.

emission standards: Because technological innovation reduces the abatement cost, and because reductions in abatement costs results in reductions in permit price,[57] technological innovation by one industry or business can also impact the abatement cost of other industries or businesses.

Technological innovation also depends on the method of permit allocation. Studies have shown that auctioning permits provides greater incentives for innovation than grandfathering permits.[58] The total emissions cap may also have an effect on technical change. Some evidence indicates that more stringent caps lead to greater technological adoption.[59] Competitive behavior, either short- or long-term focused, should lead industry to innovate in order to reduce abatement costs over time. Because the expenditure in emission permits will translate into higher product prices and because of the competitive nature of these industries, they will be pushed by market forces to innovate.

Experience shows that the most difficult step toward the implementation of a tradable permit program is permit allocation. While in theory the allocation scheme has no significant impact on cost effectiveness, in practice the chosen scheme will have a tangible effect on not only cost effectiveness but also on equity.[60] Broadly, initial permit allocation can be classified into free distribution, auctioning, and hybrid systems. Under free distribution, emission allowances are typically distributed based on the historic emissions of each source and on some fairness rule—an approach known as grandfathering. Previous programs relied on administrative allocation methods primarily because they were more politically attractive. This is a natural consequence of the bigger financial burden on emitters posed by an auction than a free distribution system. There may be, however, equity issues associated with permit auctioning if the financial burden varies significantly across emitters. Grandfathering may have negative consequences. One such negative effect is strategic behavior on the part of the emitter, who has incentives to cheat and report inflated historic emissions in order to obtain a larger number of allowances. Hybrid allocation schemes that combine the efficiency features of auctioning with the capability of free-distribution to deal with equity issues may be, therefore, a good alternative.

Finally, just as regulators may not know where exactly to set the level of a carbon tax to achieve their desired outcome, they will not know where exactly to set the cap on carbon to achieve the optimal outcome. If the cap is set too high, there will be weak demand for permits, but if it is set too low, the demand could increase, putting upward pressure on permit prices.[61] One tool for handling this potential problem is to set a price cap on the permits, meaning that if they reach a certain level the government can sell additional permits at that price. This essentially converts the approach into a carbon tax at that level.

[57] This is so because the clearing price of the permit equals the marginal abatement cost.
[58] Jung et al., 1996.
[59] Kerr and Newell 2003; Taylor et al. 2005.
[60] Tietenberg 2006
[61] As explained by Weitzman (1974), "The main thing to note here is that generally speaking it is neither easier nor harder to name the right prices than the right quantities because in principle exactly the *same* information is needed to correctly specify either. It is true that in a situation with many independent producers of an identical commodity, only a single uniform price as to be named by the center, whereas in a command mode, separate quantities must be specified for each producer" (pg. 478).

Transportation sector cap-and-trade program

Within an economy-wide cap-and-trade program, the transportation sector could be carved out and a special cap-and-trade program devised for it alone. In this case, total emissions from the transportation sector would be capped, and then permits to emit allocated under the cap. Trading would be allowed within the sector, and could be allowed to a limited extent outside of it so that the program could be linked to a larger, economy-wide cap-and-trade program.

The transportation sector as a whole presents a special challenge for cap-and-trade programs because there are millions of different emissions sources – each car, truck, bus, train, and airplane is a source, as well as the factories that produce cars and the facilities that produce and refine fuels. Creating a permit system so that each and every vehicle owner could buy and sell permits, while theoretically desirable, is impractical. Monitoring and verifying each vehicle's emissions, the amount of driving by each vehicle, and the GHG intensity of the fuel consumed by each vehicle would be a huge undertaking.

There have been several proposals on how to artificially estimate emissions in order create a transportation-sector specific cap-and-trade program. One idea developed by Ellerman, Jacoby, and Zimmerman (2006) is to establish a "lifetime carbon burden" (LCB) for light duty vehicles. This would entail multiplying the carbon efficiency of each new vehicle by an estimate of the total miles driven by the car over its lifetime, by an estimate of the GHG intensity of the fuel. Manufacturers would then aggregate the LCBs of all the vehicles they sell, and be able to trade permits under a cap. It is not clear how flexible-fuel vehicles would fit into this proposal, but presumably they would have a lower LCB. This type of program provides manufacturers with the flexibility of trading permits, and potentially participating in an economy-wide cap-and-trade program if this is allowed. The disadvantages are that there are no direct incentives for consumers to limit driving, to purchase more climate-friendly vehicles, or to purchase lower-GHG fuel. There are also no incentives for the fuels industry to produce lower GHG fuel. By merely estimating vehicle-miles traveled and the carbon intensity of the fuel, the incentives for innovation in the fuels industries and changes in consumer behavior are removed, and the likelihood that vehicle-miles traveled will be reduced diminishes.

Another option would be to establish separate GHG performance standards for vehicles and GHG standards for fuels, and then to create a cap-and-trade system based on the standards. Permits would be allocated to both automobile manufacturers and fuels producers, who would then be allowed to trade these permits across the two industries. Devising an equitable and effective allocation formula that would survive the legislative process would be a challenge. This system would create greater flexibility than a cap-and-trade program that only included one of the two industries, but it is likely that the fuels industry would need to purchase many credits from the auto industry. As with the Ellerman *et al.* proposal, the main disadvantage is the absence of direct incentives to limit driving or purchase more climate-friendly vehicles. The incentive for each industry to produce lower-carbon fuels or vehicles that emit less carbon, however, is preserved.

Transportation *fuels* *cap-and-trade program*

A cap-and-trade program for transportation *fuels*, is a third option for employing the cap-and-trade policy mechanism. In this case, all suppliers of transportation fuels would have their emissions capped. The cap could be imposed "upstream" at the location where the fuel is produced, or it could be imposed "downstream" at the point of sale. The upstream approach is easier to monitor since there would be fewer sources. The cap could be imposed on a lifecycle basis, capturing both the GHG content of the fuel and the greenhouse-gas emissions associated with the production of the fuel (e.g., crude oil extraction and transportation or growth of biofuel feedstock).

A cap-and-trade system for transportation fuels would work like a carbon tax by creating a permit price based on the GHG content of the fuel, and thus it shares most of the advantages and disadvantages of the carbon tax.

There are two additional benefits. First, although it acts like a tax, a cap-and-trade system for transportation fuels is not tax, and this may be politically helpful. Second, the program could be designed so that it could easily be integrated into an economy-wide cap-and-trade program. The principal downside this option is that it is somewhat more complicated to implement and enforce as compared with a carbon tax.

Feebates

Feebates combine rebates on vehicles with higher fuel economy with fees on vehicles with lower fuel economy. The fee or rebate can be collected at the point of vehicle purchase or annually, similar to how local jurisdictions collect excise taxes. The impact of a feebate system directly depends on the chosen rate. A feebate system is characterized by a "pivot point" and a fee-rebate rate. The pivot point is the fuel efficiency level that divides vehicles into high and low fuel efficiency types. The rate defines how the fee and the rebate increase as the fuel economy of the vehicle in question moves away from the pivot point. From this general structure, a feebate system can include additional elements such as vehicle categories and caps in fee-rebate levels. Because there is a pivot point, the policy should be revenue neutral.

Traditionally, feebates have been thought of in terms of vehicle fuel efficiency. However, the same notion could be used as a climate policy instrument. Instead of fuel efficiency, fees and rebates could be applied to vehicle per-mile emissions of $CO_{2eq.}$[62] In principle, feebates could also be applied to fuels, incentivizing the purchase of lower-carbon fuels and discouraging that of higher-carbon fuels.

Feebates are not a new policy notion. However, there have been virtually no implementation experiences in the United States. The DRIVE+ program passed the California legislature in 1990, but was eventually vetoed by the Governor. The state of Maryland passed a feebate law in 1991, but it was never actually implemented.[63]

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[62] See Davis et al., 1995; Koopman 1995; McManus 2007.
[63] Langer 2005.

The main advantage of feebates is that they may induce changes in consumer choices when they purchase a vehicle. As the cost of new vehicles increases proportionally to their fuel or GHG efficiency, consumers are likely to respond by purchasing vehicles that are more fuel efficient. This is a short-term, demand-side effect of feebates. This effect, however, has been found to be responsible only for a small fraction of any increases in overall fuel economy achieved by a feebate system when modeled.[64] Feebates also provide assistance to lower-income purchasers of fuel-efficient vehicles.

Studies show that the principal mechanism triggered by fuel-efficiency feebates is the adoption by manufacturers of fuel-efficiency technology (e.g., Davis et al., 1995). This is the long-term, supply-side effect of feebates. Whenever adopting a technology is cheaper than the corresponding feebate, manufacturers will tend to proceed this way rather than changing their product mix. Feebates also provide continuous incentives for technology adoption. Contrary to static fuel economy standards, feebates provide incentives for continuous reductions in vehicle fuel (or GHG) intensity.

There are several drawbacks to feebates as well. The regulator must determine the correct rate in the face of uncertainty about how the consumer will respond. The optimal feebate rate depends on variables that are not fully understood, such as consumer valuation of fuel savings. Thus, predicting the results of a given feebate rate in terms of new-vehicle fuel economy and total fuel savings is difficult. Ideally, an acceptable feebate rate would be approximated iteratively, in a trial-and-error fashion. However, such approach would present industry with a moving target, which industry will likely resist.

Also, depending on how the feebate system is designed, it could favor manufacturers that focus on market segments characterized by lower average fuel economy (e.g., bigger vehicles). Such inequity effects can be tempered by applying different feebate structures to different vehicle categories.

Depending on how they are designed, feebates should reward the purchasing of vehicles with higher fuel efficiency and punish the purchasing of vehicles with lower fuel efficiency, regardless of the amount of driving that individual consumers do. Thus, feebates may provide no incentives for consumers to reduce their driving. Further, because consumers do not pay the full price of the fuel-efficiency technology they purchase, the free reduction in their per-mile driving cost may incentivize them to increase their driving. This problem could be rectified if the feebate is assessed on an annual basis, annual mileage information is collected, and the mileage is incorporated into the annual feebate rate.

A final downside is that a feebate system could be perceived as a tax, which could make it less politically unpalatable. This effect could be avoided or tempered by designing a revenue-neutral system, in which the dollar value of the rebates equaled the revenue collected.[65]

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[64] Davis et al. 1995; Greene, et al. 2005.
[65] Greene et al. 2005.

Tariffs on imported fuels and vehicles

A tariff is a duty imposed on imported goods. In this context, it is a duty imposed on imported fuels and vehicles. At present, the United States does not impose tariffs on motor vehicles based on their fuel efficiency or GHG efficiency. It does, however, impose a 54 cent tariff on imported ethanol. Most of the ethanol that is traded on the world market comes from Brazil, which produces it from sugar cane. The production process for sugar-cane-based ethanol emits far less carbon than corn-based production, and it requires fewer energy inputs. Further, Brazil has the capacity to significantly increase its production and could provide the United States with upwards of 4 billion gallons of ethanol within two or three years.

Reducing or eliminating these tariffs could provide U.S. consumers with access to lower cost ethanol and would reduce the global contribution of carbon from the production of ethanol. However, in a marketplace in which the government requires the petroleum industry to purchase ever larger percentages of ethanol, the U.S. consumer may not be able to capture the benefits of low-cost Brazilian supplies. In a scenario characterized by ever stronger government-imposed volumetric standards, Brazilian ethanol would provide a portion of the incremental supply. The market price would be set by corn-based ethanol producers because they are the marginal producers. Brazilian farmers, land owners, biorefiners and shippers (and perhaps the government) would fight for their portion of the incremental rents, which could be quite significant.

Aside from the tariff protection, U.S. farmers also enjoy a production subsidy of 51 cents per gallon, the guarantee of a minimum national price of corn per bushel, and the indirect subsidy of the large mandated volumes of renewable fuel that must be produced under U.S. law.

Research, development, and demonstration in advanced transportation technologies

Studies have shown that there are many technologies available today that could be used to improve fuel efficiency or reduce greenhouse gas emissions in the transportation sector.[66] Investments in research, development, and demonstration (RD&D) of advanced transportation technologies will improve the menu of technological options for the future, and potentially help to bring down their costs. Government support for RD&D can be direct or indirect. Direct support is mostly provided through the DOE, although some is appropriated to other agencies such as the U.S. Department of Agriculture (USDA). Indirect support is given to the private sector through sub-contracts and tax credits for private RD&D investments. Most of DOE's RD&D programs related to transportation in the United States have private sector partnership components.

U.S. government investment in transportation efficiency RD&D peaked in 2001 at $251 million, and then declined to a low of $161 million in 2005 before beginning to rebound in 2006 at $178 million.[67] Most of the funding was devoted to the Partnership for a New Generation of Vehicles (PNGV) and subsequent FreedomCar programs, which were focused on hybrid-electric

[66] See, for example, NRC 2002 and GAO 2000.
[67] In 2000 real dollars (Gallagher et. al 2007).

and fuel-cell vehicles respectively. But there are many other RD&D programs that complement the FreedomCar program today.

With respect to biomass and biofuels RD&D, U.S. government investments first peaked in 1999 at $99 million, and their funding had not recovered by the last fiscal year appropriated, which was in 2006. The President's budget request for FY08 was $179 million, however, so it is likely that government investments for biofuels will nearly double from their FY06 levels of $90 million.[68]

There are several criticisms of the U.S. energy transportation-related RD&D programs in the United States. First, they often appear to have lagged private-sector innovation, as was the case when Honda and Toyota brought hybrid-electric vehicles to market before the PNGV program had concluded. The FreedomCar program has been criticized for being overly focused on fuel-cell vehicles, thereby starving other important research needs, such as how to improve batteries for electric and hybrid-electric vehicles. In addition, there have been large Congressional earmarks for the biomass/biofuels programs, resulting in the Department of Energy not being able to proceed with the other RD&D programs as planned. Some have argued that government energy RD&D is not well managed, but this criticism has been waning in recent years, in part because of new procedures and mechanisms at the Department of Energy to improve management and overall performance (NRC 2001).

Tax incentives and government purchasing

Tax incentives and government purchasing are two policy instruments that allow the government to help spur early deployment of advanced energy technologies, although there are many others such as labeling programs and public education. By providing tax incentives (deductions or credits), the government encourages consumers to buy more efficient or lower GHG products. By purchasing climate-friendly or energy-efficient products, the government provides a steady source of demand to innovative companies, and helps to create economies of scale for producers, which should help bring down the costs of the technologies so they will enjoy greater success in the marketplace.

Examples of some of the tax incentives currently in place are the tax credit (formerly a deduction) for the purchase of a hybrid-electric vehicle, and tax credits for industry-sponsored RD&D. Until 2006, a federal tax deduction was offered for qualifying hybrid vehicles in the year of purchase, but starting in 2006, the deduction was converted into a full tax credit as part of the Energy Policy Act of 2005. The tax credit is clearly more generous than the previous tax deduction and varies by model, depending on the emissions and fuel economy.[69] In addition, the credit begins to expire for a particular model after sixty thousand units are sold. Some states have also established tax deductions or credits for hybrid vehicles.

The federal government has already imposed procurement requirements for itself through its Federal Energy Management Program, which is noteworthy because the U.S. federal

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[68] Ibid.

[69] Although the tax credit is more generous than the tax deduction for most individuals, the tax credit has no effect on a filer's tax owed under the Alternative Minimum Tax.

government is the largest purchaser of energy products in the world. Federal buyers are now required by the Energy Policy Act of 2005 to purchase products that are ENERGY STAR®-qualified, for example.[70] In addition, many state and local governments also have made commitments to purchase low carbon or energy-efficient products. Portland, Oregon, for example, replaced all red and green traffic signal incandescent light bulbs with energy saving light emitting diode modules (LEDs). These LEDs reduce energy use about 85 percent over standard light bulbs and greatly reduce yearly maintenance. By installing 14,000 LED lamps, the City reports that it is saving approximately 5.25 million kWh each year – enough to power over 400 homes there.[71]

The impact and effectiveness of these government programs is hard to measure and evaluate. The tax credits have the advantage of providing additional incentives for consumers to purchase more efficient vehicles, but it is not clear that they have had a noticeable impact. Evidence is beginning to accumulate that other measures, including increases in gasoline prices, access to high-occupancy vehicle lanes, environmental values or philosophies, and states with high average vehicle-miles traveled, have had stronger influences on consumer decision-making than the hybrid-vehicle tax credits.[72]

The effects of illustrative packages

Here, individual policy instruments are combined together to create illustrative packages and then assessed using the criteria set forth earlier. We wish to underline that these are not proposals on our part, but rather straightforward combinations that allow us to illustrate the range of the likely interactive effects of combining different policy instruments. In any case, their cumulative impact will strongly depend on the precise details of the actual policies. An effective package must provide incentives that affect both investment and production decisions on the part of auto manufacturers and fuel producers on the one hand, and vehicle purchase and driving decisions on the part of consumers on the other.

Package 1: Reformed CAFE standards with volumetric requirements for alternative fuels

The benefits and costs of this package would obviously depend on the choices for the respective standards. Fuel economy standards are limited by technological and economic factors, as well as by timelines for new-vehicle development. Presently, fuel economy standards are mainly designed to apply to petroleum-fueled vehicles, with limits on the credits that can be added with the production of flex-fuel vehicles. The increase of ethanol blending required by a renewable fuel standard (RFS) may have direct implications on the actual fuel economy of vehicles, as the energy density of the fuel decreases. As volumetric ethanol blending moves beyond E10, standard vehicles become less capable of running on this fuel, and the auto industry would need to respond by deploying new vehicles with increasing alternative-fuel capabilities. Thus, fuel economy standards would need to be designed so as to accommodate the characteristics of the new fuels.

[70] According to the FEMP website, http://www1.eere.energy.gov/femp/procurement/.
[71] See City of Portland Office of Sustainable Development website: http://www.portlandonline.com/osd/index.cfm?c=41460
[72] Turrentine and Kurani 2007, Kahn 2006, Gallagher and Muehlegger 2007.

The market certainty provided by the RFS would induce investment in ethanol (and other renewable fuels) refining.[73] Because of the lower energy content of ethanol relative to gasoline, the volume of gasoline displaced would be smaller than the amount of ethanol required by the volumetric standard on renewable fuel. Ethanol is generally less carbon intensive than gasoline on a lifecycle basis per unit of fuel energy and therefore overall greenhouse gas emissions from light-duty vehicles would decrease. To the extent that renewable fuels are produced in the United States, however, all emissions during fuel production become domestic.

Both fuel economy and renewable fuel standards are instruments designed to reduce the consumption of petroleum fuels in transportation and as such, this package would result in enhanced domestic oil security. This policy package would place no direct incentive on consumers to limit driving or purchase more energy-efficient products. Indirectly, if the price of unit of fuel energy increases as a result of the RFS, consumers may respond by buying less. However, as fuel economy standards reduce the per-mile cost of driving, consumers would find incentives to increase their amount of driving. The balance of these contradictory impacts depends on the choice of the respective standards.

Package 2: GHG performance standards for fuels and vehicles

This package contains instruments that are each designed to reduce the carbon intensity of road transportation. While a standard on vehicle tailpipe per-mile CO_2 emissions is similar to a fuel economy standard, it would more naturally incorporate the benefits of alternative fuels. It would also open the spectrum of technological alternatives by inducing industry consideration of non-mainstream vehicle power trains.

The actual benefits achieved by this package are directly dependent not only on the levels of the standards but also on consumer behavior. There is significant uncertainty as to how consumers will choose to operate dual-fueled vehicles such as flex-fueled vehicles and plug-in hybrid electric vehicles. The per-mile carbon intensity attributed by regulation to such vehicle platforms would have to be based on assumptions about consumer choices, and therefore actual effects of tailpipe standards on GHG emissions from vehicle travel will be better estimated as consumer behavior becomes better understood.

The effects and implications of the low-carbon fuel standard (LCFS) are strongly related to implementation choices. One such choice is how to measure fuel carbon intensity. If the carbon intensity is measured on a well-to-wheels basis, this policy package may lead to double counting of GHG emissions. If double counting is avoided, for example by measuring fuel carbon intensity as the carbon content per unit of fuel volume, this package provides an effective systemic approach to reduce GHG from road vehicles. It is not certain how the two instruments would interactively induce technology innovation. In a hypothetical scenario, auto manufacturers and fuel providers may find incompatible lowest-cost strategies to meet their respective standards.

[73] At least initially, an overinvestment followed the RFS in the Energy Policy Act of 2005.

Package 3: GHG performance standards for fuels and vehicles, feebates, and a carbon tax on transportation fuels with income tax rebates

This package differs from the other two mainly in that it is the only one that introduces policies aimed directly at consumers. This package incorporates greenhouse-gas performance standards on both fuels and vehicles, imposes a feebate system, and adds a carbon tax as well with the revenues used for income tax rebates. One could argue that a carbon tax would be sufficient to achieve the policy goals without the performance standards, but it is not likely that a sufficiently high carbon tax would be imposed for political reasons, so the performance standards are still necessary. Without specifying the levels of the standards or the carbon tax, it is obviously impossible to predict exactly what would happen. But assume that the GHG standards are somewhat more stringent than the current equivalent levels of the CAFE program, and that the carbon tax is noticeable, but not very large. Assume that the performance standards are progressively strengthened and that the carbon tax is increased by a small percentage every year in real terms. Assume that the feebate is set at the point of purchase of a new vehicle, and that the program is managed at the federal level.

Intuitively, one would expect that the new carbon tax would immediately get the attention of drivers. Because the carbon tax would increase by a small percentage every year, then drivers would know that the cost of gasoline is only going to increase in the future. This certainty may have some influence when they decide to purchase their next vehicle, persuading them to purchase a more fuel-efficient or climate-friendly vehicle, all else being equal. The tax would probably have a stronger effect on the amount that people drive. People become more conscious about how much they drive, combining trips, or choosing to take alternative forms of transportation if it is available. The carbon tax will also minimize the so-called “rebound” effect where consumers drive more because they have bought fuel-efficient cars. Similarly, the carbon tax would create a disincentive for alternative fuels such as coal-to-liquids to be developed without carbon capture and storage.

The revenues from the carbon tax are, in this scenario, used to provide income tax rebates to all Americans, scaled to their income tax bracket so that lower-income Americans receive bigger rebates. This could prove to be quite popular politically.

While the carbon tax is not likely to strongly affect which cars people decide to purchase, the feebate would cause people to re-think their vehicle purchase decisions. If the fee or rebate is sizeable, a person who is in the showroom deciding between two similar models might be induced to purchase the lower-carbon vehicle because they would receive a rebate.

Because of the new consumer interest, auto manufacturers would be more motivated through the market to develop, offer, and market attractive climate-friendly passenger vehicles. If they were not induced to do this because of the carbon tax, they would be required to do so anyway through the greenhouse-gas performance standards on vehicles. This provides certainty about the minimum GHG efficiency of the vehicles (though not about maximum levels of future oil consumption or GHG emissions because we don’t know how many cars there are or how far they will be driven). It is possible, even quite likely, that the carbon tax and feebates will provide sufficient incentives for consumers to change their purchasing behavior enough to render the standards unnecessary, but the performance standards provide a guarantee.

Oil companies and other fuels providers would have a clear economic incentive from the carbon tax to develop, blend, and offer lower-carbon fuels. The less greenhouse-gas intensive the product, the cheaper it could be offered. Oil companies might even decide that it is worth differentiating their product more clearly so that they offered a "low-carbon" fuel at the pump to make it more obvious to consumers. Consumers would likely to gravitate to the cheaper, lower carbon fuels, as they have in Europe and Brazil where diesel and ethanol were respectively taxed less stringently than gasoline to encourage drivers to buy the alternative fuels.[74]

This policy package creates a more certain marketplace for industry and consumers alike. Both the automotive and fuels industries will have market-driven incentives to develop and manufacture cleaner and more efficient products.

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[74] Sugarcane ethanol was sold in Brazil at the pump for 59 percent of the price of gasoline. The Brazilian government set the gasoline price relative to the price of ethanol (Moreira and Goldemberg 1999). In Germany, gasoline prices including taxes as of 7/9/07 were $7.01/gallon and diesel prices (including taxes) were $5.86/gallon. This is a difference of $1.15 (Lou 2007). For reference, U.S. gasoline prices including taxes as of 7/8/07 were $3.18.

Bibliography

Ackerman, F., B. Biewald, D. White, T. Woolf, and W. Moomaw 1998, "Grandfathering and Coal Plant Emissions: The Cost of Cleaning up the Clean Air Act," *Energy Policy*, 27: 929-940.

An, Feng, and Amanda Sauer 2004, "Comparison of Passenger Vehicle Fuel Economy and Greenhouse Gas Emission Standards Around the World," Pew Center on Global Climate Change, Arlington, VA, December.

Austin, David and Terry Dinan 2005, "Clearing the Air: The Costs and Consequences of Higher CAFE Standards and Increased Gasoline Taxes. *Journal of Environmental Economics and Management*, 50: 562-582.

Baumol, W. and W. Oates 1988, <u>The Theory of Environmental Policy</u>. Second ed. Cambridge, UK: The Cambridge University Press.

BEA 2007, "Current-Dollar and "Real" Gross Domestic Product," Bureau of Economic Analysis, Washington, DC, June 18 (available at: www.bea.gov/national/xls/gdplev/xls).

Brännlund, Runar, Tarek Ghalwash, and Jonas Nordström 2005, "Increased Energy Efficiency and the Rebound Effect: Effects on Consumption and Emissions. *Energy Economics*, 29, 1-17.

Bruneau, J. 2004, "A Note on Permits, Standards, and Technological Innovation," *Journal of Environmental Economics and Management*, 48(3), 1192-1199.

Bush 2007, "Twenty In Ten: Strengthening America's Energy Security," President George W. Bush State of the Union 2007 Address, available at: http://www.whitehouse.gov/stateoftheunion/2007/initiatives/energy.html

Collantes, G. 2007, "The Corporate Average Fuel Economy Program: Seeking Common Ground for the Way Forward," Unpublished white paper. *Energy Technology Innovation Policy, Belfer Center for Science and International Affairs*, Kennedy School of Government, Harvard University.

Cramton, P. and S. Kerr 2002, "Tradable Carbon Permit Auctions: How and Why to Auction Not Grandfather. *Energy Policy*, 30, 333-345.

Dales, J. 1968, <u>Pollution, Property and Prices,</u> Toronto: University of Toronto Press.

Davis, Stacy C. and Susan W. Diegel 2007, <u>Transportation Energy Data Book</u>, Edition 26, Oak Ridge National Laboratory, Tennessee.

Davis, W., M. Levine, K. Train, and K. Duleep (1995) *Effects of Feebates on Vehicle Fuel Economy, Carbon Dioxide Emissions, and Consumer Surplus*. U.S. Department of Energy, Office of Policy. DOE/PO-0031.

EIA February 2007, “Annual Energy Outlook with Projections to 2030”, Energy Information Administration, U.S. Department of Energy, Washington, DC, February.

EIA April 2007, “World Petroleum Consumption, Most Recent Annual Estimates 1980-2006,” Energy Information Administration, U.S. Department of Energy, Washington, DC, April 20 (available at: www.eia.doe.gov/emeu/international/RecentPetroleumConsumptionBarrelsperDay.xls).

EIA May 2007, “International Petroleum Monthly” Energy Information Administration, U.S. Department of Energy, Washington, DC, May (available at: http://www.eia.doe.gov/emeu/ipsr/t21.xls)

Ellerman, A. Denny, Jacoby, Henry D., and Martin B. Zimmerman 2006, “Bringing Transportation into a Cap and Trade Regime,” *MIT Joint Program on the Science and Policy of Global Change*, Report No. 136, June.

Farrell, Alexander E. and Adam R. Brandt 2006, “Risks of the Oil Transition,” *Environmental Research Letters*, 1(1).

Gallagher, Kelly S. and Erich Muehlegger 2007, “Is it Easy Being Green? The Effects of Hybrid-Electric Vehicle Consumer Incentives,” John F. Kennedy School of Government, *working paper under development*.

Gallagher, Kelly S., Sagar, Ambuj, Segal, Diane, de Sa, Paul, and John P. Holdren, "DOE Budget Authority for Energy Research, Development, and Demonstration Database," *Energy Technology Innovation Policy*, John F. Kennedy School of Government, Harvard University, 2007.

Goldberg, Pinelopi K. 1996, “The Effect of the Corporate Average Fuel Efficiency Standards,” *National Bureau of Economic Research*, NBER Working Paper 5673.

Goulder, Lawrence 1995, “The Effects of Carbon Taxes in an Economy With Prior Tax Distortions: An Intertemporal General Equilibrium Analysis,” *Journal of Environmental Economics and Management*, Vol. 29, 271-297.

Greene, David L. 1998, “Why CAFE Worked,” *Energy Policy*, 26(8), 595-613.

Greene, David L., James R. Kahn, and Robert C. Gibson 1999, “Fuel Economy Rebound Effect for U.S. household Vehicles. *The Energy Journal*, 20(3), 1-29.

Greene, David, Philip Patterson, Margaret Singh, and Jia Li (2005) Feebates, rebates and gas-guzzler taxes: a study of incentives for increased fuel economy. *Energy Policy*, 33: 757-775.

Greening, Lorna A., Greene, David L., and Carmen Difiglio 2000, "Energy Efficiency and Consumption – the Rebound Effect, - a Survey," *Energy Policy*, 28, 389-401.

Federal Register 2006, "Fuel Economy Labeling of Motor Vehicles: Revisions to Improve Calculation of Fuel Economy Estimates; Final Rule," 40 CFR, Parts 86 and 600. Wednesday, December 27. Available on the World Wide Web at www.regulations.gov.

Holdren, John P. 2005, "Commentary on Part IV: A New Energy Security Strategy," in Kalicki, Jan H. and David L. Goldwyn (eds.) Energy and Security: Toward a New Foreign Policy Strategy, Woodrow Wilson Center Press, Washington, DC.

Hughes, Jonathan E., Knittel, Christopher R. and Sperling, Daniel 2008, "Evidence of a Shift in the Short-Run Price Elasticity of Gasoline Demand" *The Energy Journal*, 29(1), January.

IEA 2004, Biofuels for Transport: An International Perspective, International Energy Agency, Paris.

IPCC 2007, "Summary for Policymakers," Working Group I, Intergovernmental Panel on Climate Change, Geneva (available at http://ipcc-wg1.ucar.edu/wg1/wg1-report.html)

Jung, C. 1996, "Incentives for Advanced Pollution Abatement Technology at the Industry Level: An evaluation of Policy Alternatives. *Journal of Environmental Economics and Management*, 30(1), 95-111.

Kerr, S. and R. Newell 2003, "Policy-Induced Technology Adoption: Evidence from the U.S. Lead Phasedown," *Journal of Industrial Economics*, 51, 317-343.

Kahn, Matthew E. 2006, "Do Greens Drive Hummers Or Hybrids? Environmental Ideology as a Determinant of Consumer Choice and the Aggregate Ecological Footprint", October. Available at SSRN: http://ssrn.com/abstract=940033.

Koopman, G. (1995) Policies to reduce CO2 emissions from cars in Europe: a partial equilibrium analysis. *Journal of Transport Economics and Policy*, 30(1): 53-70.

Langer, Therese (2005) Vehicle Efficiency Incentives: *An Update on Feebates for States. American Council for an Energy-Efficient Economy*. Report number T051.

Leiby, Paul and Jonathan Rubin 2000, "The Alternative Fuel Transition: Results from the TAFV Model of Alternative Fuel Use in Light-Duty Vehicles 1996-2010." Technical report ORNL/TM2000/168. Oak Ridge, TN: Oak Ridge National Laboratory.

Lou, Joel 2007, "Weekly Retail Diesel and Gasoline Prices (Including Taxes," Energy Information Administration, U.S Department of Energy, available at http://www.eia.doe.gov/emeu/international/prices.html#Motor.

Lugar, Richard G. and R. James Woolsey, "The New Petroleum," *Foreign Affairs*, January/February 1999.

Malkin, Elizabeth 2007, "Thousands in Mexico Protest Rising Food Prices," *International Herald Tribune*, February 1.

McManus, Walter (2007) *Economic Analysis of Feebates to Reduce Greenhouse Gas Emissions From Light Vehicles for California*. Transportation Research Institute, University of Michigan. Report UMTRI-2007-19-2.

Moreira, Jose R. and Jose Goldemberg 1999, "The Alcohol Program," *Energy Policy*, 27, 229-245.

National Highway Traffic Safety Administration (NHTSA) 2001, "Automotive Fuel Economy Manufacturing Incentives for Alternative Fueled Vehicles. Final Rule." Docket Number 2001-10774, RIN 2127-AI41.

NHTSA 2006, "Summary of Fuel Economy Performance," NHTSA 2006-24437-2, National Highway and Traffic Safety Administration, Washington, DC.

NHTSA 2006a, "Average Fuel Economy Standards for Light Trucks Model Years 2008-2011. Final Rule," Docket Number 2006-24306, RIN 2127-AJ61.

NHTSA 2007, "CAFE Overview: Frequently Asked Questions", National Highway and Traffic Safety Administration, U.S. Department of Transportation, Washington, DC, available at http://www.nhtsa.dot.gov/cars/rules/cafe/overview.htm.

National Research Council (NRC) 2001, "Energy Research at DOE: Was It Worth It? Energy Efficiency and Fossil Energy Research 1978 to 2000," National Academies Press, Washington, DC.

National Research Council (NRC) 2002, "Effectiveness and Impact of Corporate Average Fuel Economy Standards," National Academies Press, Washington, DC.

RFA 2007, "2006 Ethanol Production up Nearly 25 Percent Over 2005," Renewable Fuels Association Press Release, http://www.ethanolrfa.org/media/press/rfa/view.php?id=964

Nordhaus, William D. 2007, "To Tax or Not to Tax: Alternative Approaches to Slowing Global Warming," *Review of Environmental Economics and Policy*, Vol. 1, 26-77.

Pearce, David 1991, "The Role of Carbon Taxes in Adjusting to Global Warming," *The Economic Journal*, Vol. 101, 938-948.

Pizer, William A. 2002, "Combining Price and Quantity Controls to Mitigate Global Climate Change," *Journal of Public Economics*, Vol. 85, No. 3, 409-434.

Small, Kenneth A. and Kurt Van Dender 2005, "The Effect of Improved Fuel Economy on Vehicle Miles Traveled: Estimating the Rebound Effect Using U.S. State Data, 1966-2001, Paper EPE-014, University of California Energy Institute.

Stavins, R. 1995, "Transaction Costs and Tradable Permits," *Journal of Environmental Economics and Management*, 29(2), 133-148.

Taylor, M., E. Rubin, and D. Hounshell 2005, "Regulation as the Mother of Invention: The Case of SO2 Control," *Law & Policy*, 27(2), 348-378.

Tietenberg, T. 2006, <u>Emissions Trading: Principles and Practice</u>. Second ed. Washington, DC: Resources for the Future.

Tilman, David, Hill, Jason, and Clarence Lehman 2006, "Carbon Negative Biofuels from Low-Input High Diversity Grassland Biomass," Science, Vol. 314, 8 December.

Turner, Brian, Plevin, Richard, O'Hare, Michael, and Alexander Farrell 2007, "Creating Markets for Green Biofuels: Measuring and Improving Environmental Performance," Institute of Transportation Sustainability Research Center, University of California, Berkeley.

Turrentine, Thomas S. and Kurani, Kenneth S. 2007, "Car Buyers and Fuel Economy," *Energy Policy,* Vol. 35, 1213-1223.

USDA 2007, "Acreage," U.S. Department of Agriculture, Washington, DC, June 29, available at http://www.usda.gov/nass/PUBS/TODAYRPT/acrg0607.txt.

University of California 2007, *A Low-Carbon Fuel Standard for California. Part 1: Technical Analysis*. May 29.

U.S. DoT, U.S. DoE, and U.S. EPA 2002, "Effects of the Alternative Motor Fuel Act CAFE Incentives Policy," Report to Congress, March.

U.S. EPA 2005, "GHG Emissions from a Typical Passenger Vehicle," *U.S. Environmental Protection Agency*, EPA420-F-05-004, February.

U.S. EPA 2006, "E85 and Flex Fuel Vehicles," EPA420-F-06-047, October 2006, available at: http://www.epa.gov/smartway/growandgo/documents/factsheet-e85.htm

U.S. EPA 2007, "Inventory of U.S. GHG Emissions and Sinks: 1990-2005," *U.S. Environmental Protection Agency*, April.

Weitzman Martin 1974, "Prices vs. Quantities," *Review of Economic Studies*, October.

Glossary

BAU – business as usual

GHG – greenhouse gas(es)

CH_4 – methane

CO_2 – carbon dioxide

CO_2 equivalent – the carbon dioxide equivalent of all GHG including N_2O, SF_6, PFCs, CH_4, and CO_2

N_2O – nitrous oxide

PFC – perfluorocarbon

SF_6 – sulfur hexafluoride

VMT – vehicle-miles traveled

Appendix A: Matrix of Policy Options

Policy	Pros	Cons	Reduce Oil?	Reduce GHGs?	Cost-effective and flexible?	Stimulate innovation in transport techs?	Easily to enforce?	Enhance competitive-ness of US-based industry?	Consumer incentive?	Equity problems?
Set floor for domestic oil prices	- Provides consistent signal to market regarding minimum possible oil price, encouraging development of fuel alternatives and use of more efficient vehicles	- Could encourage development of biofuels, coal-to-liquids, and oil shale without regard to the resulting GHG emissions; - lack of certainty about oil consumption and emission reduction	Yes	Maybe	Not clear	Yes	Yes	Maybe	Yes	Maybe
Carbon tax on transportation fuels	- Raises price of transportation fuels; - gives transparent signal to market to encourage low-carbon fuels and technologies; - provides revenue to government that can be used to ease transition, offset other taxes, fund public transportation, or fund R&D; - favored approach by many economists	- Possible aversion to use of taxes as a policy instrument; - lack of certainty about oil cons. and emission reduction	Yes	Yes	Yes	Yes	Yes	Maybe	Yes	Maybe
Upstream cap-and-trade system for transportation fuels	- Raises price of transportation fuels; - provides revenue to government that can be used to ease transition, offset other taxes, fund public transportation, or fund R&D; - conventional wisdom says that "market-based mechanisms" like cap-and-trade are	- Gives less transparent signal to market to encourage low-carbon fuels and technologies; - More administratively complex	Yes	Yes	Yes	Yes	No	Maybe	Yes	Maybe

	politically palatable - Certainty about the cap on emissions									
Economy-wide cap and trade program	- Psychological signal for consumers that U.S. is committed to reducing GHG emissions that may affect purchasing decisions in cars and fuels	-Very weak price signal to transportation fuels, depending on carbon price (e.g., \$100/tonCO_2 = 26 cents/gallon gasoline) so unlikely to reduce GHGs or reduce oil consumption	No (negligible)	No (negligible)	Yes	No	No	Maybe	No	Maybe
Economy-wide carbon tax	Same	Same	No (negligible)	No (negligible)	Yes	No	Yes	Maybe	No	Maybe
Transportation cap-and-trade (cap-and-trade emissions from autos and fuels together)	- Lots of flexibility - Reduces oil consumption and GHGs - Shared responsibility	- Oil companies bear most of the burden cost-wise - Complex administratively - Not simple or clear - Consumer incentive hidden	Yes	Yes	Maybe	Yes	No	Maybe	Maybe	Maybe
Production tax credit for any domestically-produced petroleum alternatives (e.g., ethanol, CTL, oil shale, CNG)	- Reduces oil consumption - Supports U.S.-based jobs and industry	- Costly - Could dramatically increase GHG emissions	Yes	Maybe	No	Yes	Yes	Yes	No	Yes
Renewable fuels standard	- Creates mandate for renewable fuels - Supports U.S.-based jobs and industry - Reduces oil consumption	- May not reduce GHG emissions depending on how the renewable fuels are produced - Could have adverse effects on ecosystem and water supplies - Could cause competition with food on agricultural lands	Yes	Maybe	Maybe	Yes	No	Yes	Yes	Yes
Alternative fuels standard	- Reduces oil consumption	- Could dramatically increase GHG emissions	Yes	Maybe	Yes	Yes	Yes	Yes	Yes	No

	- Supports U.S.-based jobs and industry - Less costly to government than PTC									
More stringent corporate average fuel economy standard	- Reduces oil consumption and GHG emissions	- Complex policy - Costly burden entirely on auto industry - No consumer incentives	Yes	Yes	No	Yes	No	No	No	No
“Reformed” and strengthened CAFE standard that is “attribute” based	- Reduces oil consumption and GHG emissions	- Complex policy - Costly burden entirely on auto industry - No consumer incentives - Perverse incentive to increase footprint or weight of vehicle	Yes	Yes	No	Yes	No	No	No	No
Strengthened CAFE with credit trading	- More flexibility - Reduces oil consumption and GHG emissions	- Very complex - No consumer incentive - Burden borne by auto companies alone	Yes	Yes	No	Yes	No	No	No	No
GHG performance standard for passenger cars	- Significant reduction in GHGs and oil consumption - Stimulates innovation in vehicle technologies - Simple, clear policy - No “technology picking” - Same approach as Europe and Japan, just mandatory, so products can be exported to those markets	- Burden borne by auto companies alone - No consumer incentive	Yes	Yes	Yes	Yes	No	No	No	No
RD&D into cleaner vehicles and fuels	- Provides better technology options in the future - Reduces costs of existing technologies	- Some cost to RD&D (but some return)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Government purchasing of advanced vehicles and/or fuels	- Guaranteed niche market - Helps to bring down costs of technologies in early stages of deployment	- Limited government market (though fairly large)	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Government investment in alternative fuel infrastructure (e.g., railways, E85 pumps, etc.)	- Creates enabling infrastructure for alternative fuels - Helps to overcome major barrier to alternative fuels	- Costly (how costly?) - Picking winners for fuels? - Possible stranded assets	Yes	Maybe	Maybe	Maybe	No	Yes	No	No
Remove tariffs on imported ethanol	- Helps to diversify supplies of foreign fuel - Reduces oil consumption - Reduces GHG emissions (since likely to be Brazilian ethanol)	- Puts some competitive pressure on U.S. ethanol production	Yes	Yes	Yes	Yes	Yes	Maybe	No	Yes
Expansion of tax credits for hybrid vehicles	- Increases consumer interest in hybrid vehicles -	- Not clear that they have worked	Yes	Yes	No	Yes	Yes	Maybe	Yes	No
Road or congestion pricing	- Encourages use of mass transit - Reduces congestion, which reduces oil consumption		Yes	Yes	Yes	No	No	Maybe	Yes	Yes
Gas guzzler taxes	- Taxes on most in-efficient vehicles	- For luxury vehicle buyers, these have had no impact on purchase decisions	Yes	Yes	n/a	No	Yes	No	Yes	Yes
Feebate	- Fees for inefficient or GHG-intensive vehicles, and rebates for very efficient, more intensive fuels	- Creates incentives to purchase more efficient and climate-friendly vehicles.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Smart growth policies	- Reduces the need to drive as much, reduces VMT	- Difficult policy instrument for federal government because authority resides at local level	Yes	Yes	Yes	Yes	No	Maybe	Yes	Maybe

Protecting oil transit lanes to bring crude to U.S. market; protecting U.S. infrastructure to deliver refined fuels to market	- Enhances energy security	- Costly, but necessary	No	No	No	No	No	No	No	No

Appendix B: Side-by-Side Comparison of Current and Proposed Policies

	Fuel Economy Standards for Vehicles	GHG Standards for Vehicles	Fuels Policies
Corporate Average Fuel Economy Standard	Passenger car standard (fleet average) is 27.5 mpg; new light truck standards (size-based) is 22.2 mpg; extra credits for flex-fuel and alternative-fueled vehicles; light trucks that exceed 8,500 lbs gross vehicle weight rating are exempted.[75]	None	None, though there are indirect incentives for alternative fuels
Bush Administration	Proposes that Congress should authorize the Secretary of Transportation to apply the attribute-based method to passenger cars; Secretary of Transportation should be given the authority to set the fuel standard, based on cost/benefit analysis, using sound science, and without impacting safety	none	Set a new alternative fuel standard at 35 billion gallons of renewable and alternative fuels by 2017[76]
Senate Energy Bill[77]	Raises the average fuel economy standard for cars and light trucks to 35 miles per gallon by 2020 (40% improvement over current levels).	none	Mandates the production of 36 billion gallons of renewable fuels by 2022 with 15 billion to come from corn-derived ethanol. Maintains 51 cent per gallon subsidy for ethanol used in fuel.
California Standards	none	30% average reduction in GHG emissions for cars and light trucks by 2016 starting in 2009, which is approximately 4% per year.[78]	Low Carbon Fuel Standard (LCFS) for transportation fuels sold in California, with initial goal of reducing the carbon intensity of California's passenger vehicle fuels by at least 10 percent by 2020.
Ellerman, Jacoby and Zimmerman (2006)		Create "lifetime carbon burden" (LCB) for light duty vehicles by capping emissions from light duty vehicles; LCB is calculated by multiplying carbon efficiency of new vehicle by an estimate of the total miles that will be driven by the car over its lifetime and estimating the fuel blend. Allow manufacturers to trade credits under cap.	

[75] NHTSA 2007.
[76] This definition would permit alternative fuels such as coal-to-liquids that would result in a large net increase in GHG emissions, depending on whether or not carbon sequestration is employed. Bush 2007.
[77] http://thomas.loc.gov/cgi-bin/bdquery/z?d110:S.1419:
[78] http://www.arb.ca.gov/newsrel/nr092404.htm

A wide range of policies, programs and investments implemented since 2016 under Canadaâ€™s climate plan, and the Pan-Canadian Framework on Clean Growth and Climate Change, have led to the biggest improvement to the countryâ€™s emissions outlook since reporting began.Â However, we do know they can deliver important greenhouse gas reductions. For example, Canadaâ€™s 2019 greenhouse gas projections indicate that a faster-than-anticipated uptake of a set of clean technologies could reduce emissions by 13 million tonnes in 2030.Â Introduced new regulations to reduce methane emissions from the oil and gas sector, reduce greenhouse gas emissions from heavy-duty vehicles, and accelerate the phase-out of coal-fired electricity In the United States, most of the emissions of human-caused (anthropogenic) greenhouse gases (GHG) come primarily from burning fossil fuelsâ€"coal, hydrocarbon gas liquids, natural gas, and petroleumâ€"for energy use. Economic growth (with short-term fluctuations in growth rate) and weather patterns that affect heating and cooling needs are the main factors that drive the amount of energy consumed. Energy prices and government policies can also affect the sources or types of energy consumed. Carbon dioxide.Â Carbon dioxide emissions from other anthropogenic sources and activities were about 5% of total GHG emissions and about 6% of total CO_2 emissions.1. Other greenhouse gases. Greenhouse gas emission statistics - emission inventories. 3. Figure 3: Greenhouse gas emissions, by source sector, EU-28, 1990 and 2017(percentage of total) Source: Eurostat (env_air_gge), European Environment Agency.Â Substantial amounts of human-induced greenhouse gas emissions have come from the increased use of fossil fuels burned to power new machines, generate electricity and propel transport vehicles. The amount of emis-sions has accelerated in the last 200 years, reecting increases in the worldâ€™s population, economic development, and increased production and consumption in a globalized economy. Greenhouse gas emission statistics - emission inventories. 5.