ANALYSIS OF POLICIES TO REDUCE OIL CONSUMPTION AND GREENHOUSE-GAS EMISSIONS FROM THE U.S. TRANSPORTATION SECTOR

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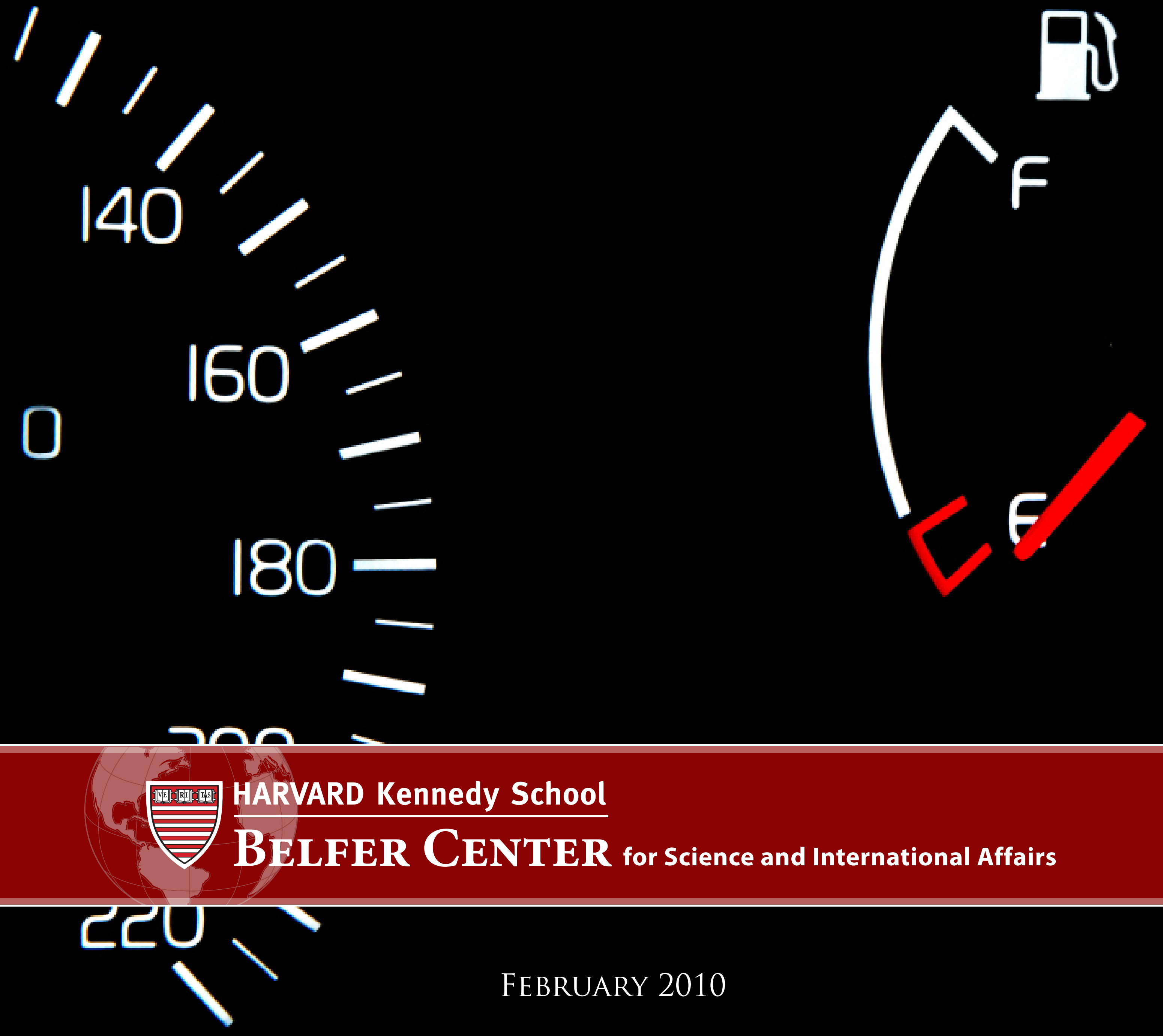

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EXECUTIVE SUMMARY

As the U.S. debates an economy-wide CO_2 cap-and-trade policy, the transportation sector remains a significant oil security and climate change concern. Even though the transportation sector consumes the majority of the U.S.'s imported oil and produces a third of total U.S. Greenhouse-Gas (GHG) emissions, economy-wide CO_2 prices at their currently projected levels will have little impact on this sector. Faced with this reality, the United States has adopted programs such as aggressive new vehicle efficiency standards and the "Cash-for-Clunkers" car scrappage program. Other possible programs include higher gasoline taxes or fees and performance subsidies for low-carbon emitting vehicles, and feebates and incentives for smarter growth.

This study examines the impact of five scenarios. We first study an economy-wide cap and trade program along the lines outlined in the American Clean Energy and Security Act. Then we investigate what happens if, in addition to economy-wide CO_2 prices, Congress also imposed one of several transportation-specific measures: a strong gasoline and diesel tax, continuing to increase the passenger car fuel efficiency standards between 2020 and 2030, and aggressive performance-based tax credits for alternative motor vehicles. In our final scenario, we assume that the United States adopts each of these policies. The 2009 version of the Energy Information Administration's (EIA) National Energy Modeling System (NEMS), an energy-economic equilibrium model of U.S. energy markets, is used to estimate the impacts of these scenarios—both in terms of carbon mitigation and economic costs.

Several results stand out.

First, all the policy scenarios modeled fail to meet the Obama administration's goal of reducing total U.S. GHG emissions 14% below 2005 levels by 2020. If there is a strict cap on emissions that must be met either with emissions reductions from covered sources or through purchases of offsets, our results imply that large purchases of offsets will be required. Sector-specific programs in sectors other than transportation are not included in our analysis and may help meet the Obama administration's goals.

Second, the largest reductions in GHG emissions from transportation are obtained by increasing the cost of driving with fuel taxes. While CO_2 prices are equivalent to fuel taxes, CO_2 prices at their projected levels are far too small to create a significant incentive to drive less. Fuel prices above $8/gallon may be needed to significantly reduce U.S. GHG emissions and oil imports. At such prices, CO_2 emissions from the transportation sector alone are reduced to 14% below 2005 levels and net crude oil and petroleum product imports decrease by 5.7 million barrels per day, relative to 2008 levels. Efficiency policies such as performance standards and purchase tax credits, while politically palatable, do not address growth in Vehicle Miles Traveled (VMT), an important root cause of GHG emissions from transportation.

Third, purchase tax credits are an expensive way to reduce oil consumption and GHG emissions from transportation. We observe that artificially increasing the popularity of alternative motor vehicles through tax credits has the unintended effect of decreasing new conventional vehicle fuel economy as compared with implementing Corporate Average Fuel Economy (CAFE) standards without the credits. Furthermore, aggressively subsidizing alternative motor vehicle purchase is a very expensive proposition, costing the government roughly $22-37 billion per year. Reducing this figure through appropriations limits would limit the influence of the subsidy program.

Finally, the macroeconomic impacts of reducing GHG emissions are small, even with our relatively aggressive policy scenarios. Losses in annual Gross Domestic Product (GDP), relative to business-as-usual are less than 1%, and GDP is projected to grow at 2-4% per year through 2030 under all scenarios. Similar results hold for other macroeconomic indicators. This result clearly illustrates that aggressive climate change policy need not bring the economy to a halt.

All of our conclusions rely on the NEMS model that, like all models, has its flaws. We caution against embracing the absolute numbers resulting from our analysis. These results should, instead, serve as an indicator of the nature of impacts that would be observed in various transportation policy scenarios. The overarching conclusion of this report is that reducing GHG emissions and fuel consumption in the transportation sector will be an enormous challenge that requires stronger policy initiatives than are currently being discussed by policy makers.

1. INTRODUCTION[1]

In a significant step towards addressing the threat of global climate change, the U.S. House of Representatives passed the American Clean Energy and Security Act (ACES)—also referred to as the Waxman-Markey bill—that will establish an economy-wide cap-and-trade program for CO_2 emissions, the most prominent of the Greenhouse Gases (GHGs) in June 2009. In their Fiscal Year 2010 budget proposal (OMB, 2009), the Obama administration assumed such a program would be in place and promised to work towards[2]

> "an emissions reduction program to reduce greenhouse gas emission approximately 14% below 2005 levels by 2020." (OMB, 2009, pg. 21)

ACES adopts the slightly stronger goal of a 17% reduction in CO_2 emissions from "large" sources, relative to 2005 levels, by 2020 (CEC, 2009). The EPA equates this target to a 15.4% reduction in economy-wide CO_2 emissions (EPA, 2009a). While ACES represents an important accomplishment for GHG policy in the United States, the measures it adopts may not result in the desired reductions in economy-wide GHG emissions. Further, it will have a minimal effect on gasoline consumption and thus meeting the goal of reducing U.S. imports of foreign oil (EIA, 2009b). This study focuses on the impacts of transportation–specific policies intended to reduce both oil consumption and GHG emissions, in addition to economy-wide CO_2 prices.

Energy security and global climate change present particularly tough challenges for transportation policy. While the United States has made remarkable advances in reducing emissions of tailpipe pollutants known to directly cause adverse public health effects, much less progress has been made on reducing overall oil consumption and GHG emissions from transportation. Annual U.S. highway fuel consumption, almost all from petroleum-based fuels, increased 59% between 1973 and 2007, from 110.5 to 176 billion gallons (Davis et al., 2009, Table 2.11). U.S. crude oil and petroleum product imports have increased from 6 million barrels per day in 1981 to 12.9 million barrels per day in 2008 (EIA, 2009); see Fig. 1. Net imports of crude oil as a share of total U.S. consumption increased from 36% in 1975 to 57% in 2008 (Davis et al., 2009, Table 1.12). Largely due to this fossil fuel-intensive energy supply, the U.S. transportation sector now accounts for 28% of U.S. GHG emissions, and this

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[1] This report draws from Morrow, W. Ross, Gallagher, Kelly Sims, Collantes, Gustavo, and Henry Lee (2010). "Analysis of Policies to Reduce Oil Consumption and Greenhouse-Gas Emissions from the U.S. Transportation Sector." *Energy Policy*, Vol. 38, No. 3, March: 1305-1320.

[2] This goal has not been without criticism (Kantor, 2009). Dr. Rajendra Pachauri, chairman of the IPCC, has stated that "reducing emissions to 1990 levels by 2020 falls short of the response needed by world leaders to meet the challenge of reducing emissions to levels that will actually spare us the worst effects of climate change." (WI, 2009)

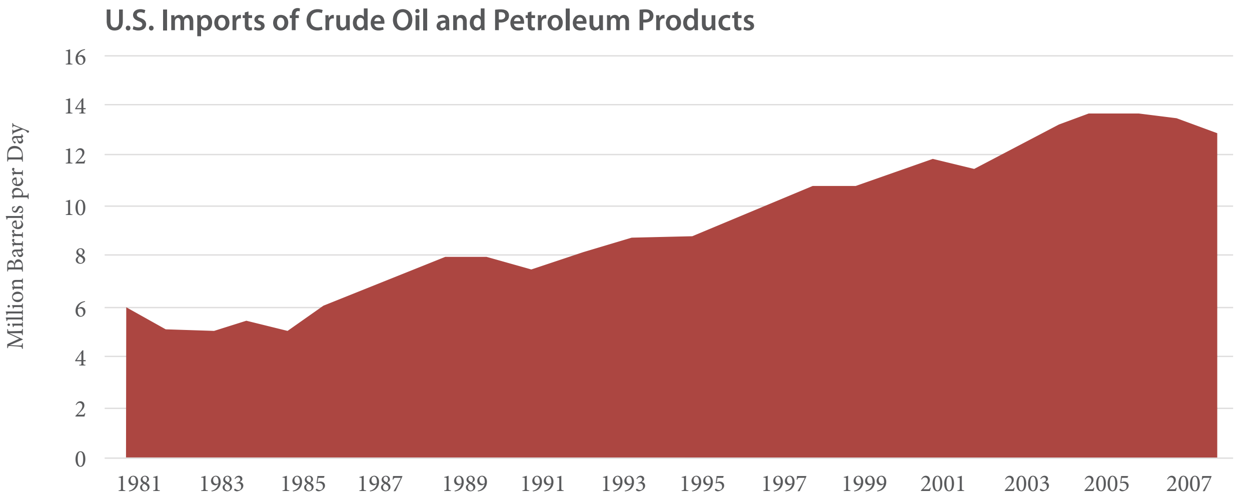

FIGURE 1: Historical imports of crude oil and petroleum products (EIA, 2009a).

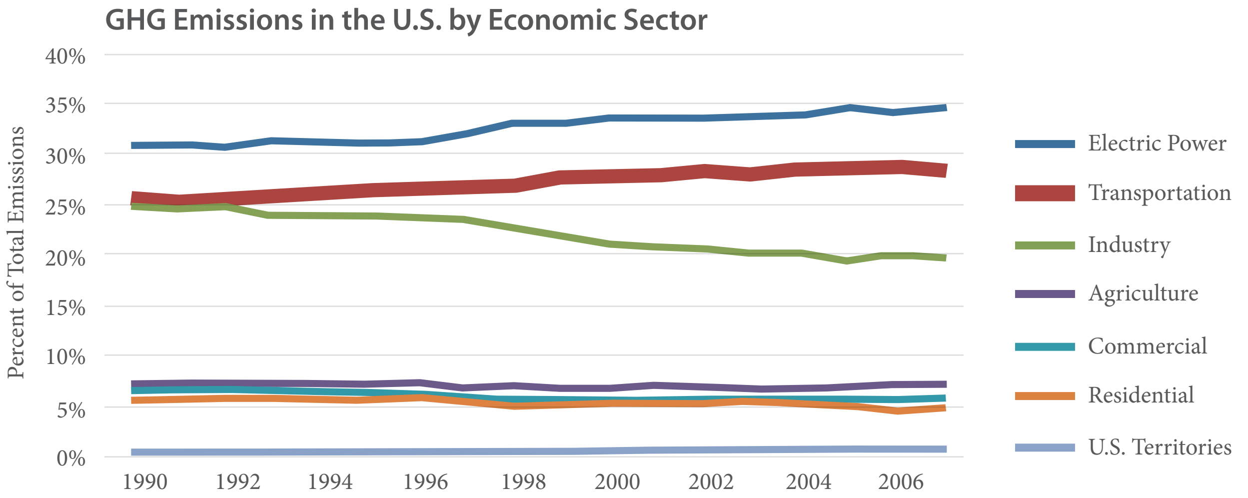

FIGURE 2: Historical GHG emissions from major sectors of the U.S. economy (EPA, 2009b).

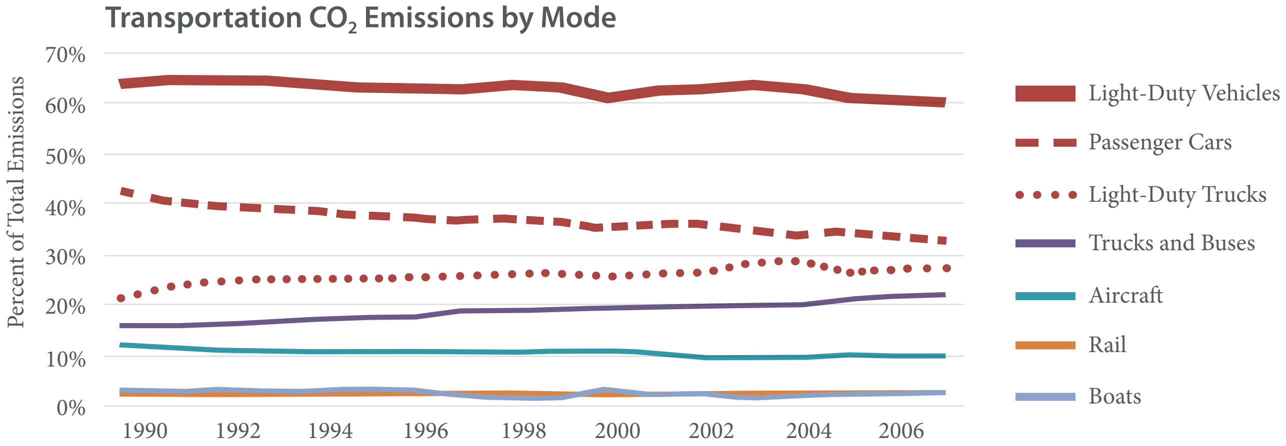

FIGURE 3: Historical CO_2 emissions from the Transportation Sector (EPA, 2009b).

percentage is likely to grow over time as emissions from other sectors are reduced (EPA, 2009b); see Fig. 2. Since measurements began in the early 1990's, 60% of transportation-related U.S. GHG emissions have come from the use of light-duty vehicles (Fig. 3). The share of emissions from medium- and heavy-duty trucks is on the rise, though partially offset by a decrease in the share of emissions from aircraft (EPA, 2009b). Addressing the growing emissions from light-duty vehicles must play a central role in the strategy to reduce the U.S.'s contribution to global climate change.

A strictly-enforced cap on CO_2 emissions will lead to reductions in emissions over all sectors in the economy in the most economically efficient manner. CO_2 prices will adjust to reflect the marginal cost of CO_2 abatement activities. Due to concerns about higher energy prices and their possible impact on economic growth, the United States is unlikely to adopt a strict cap. Instead, pragmatic policy options, such as "safety valves" and provisions for "offsets", will be adopted to reduce the uncertain economic impacts of a strict cap. Offsets are credits awarded to projects that generate the reduction, avoidance, or sequestration of GHG emissions (CT, 2009). Such projects serve as a compensating equivalent for reductions made at a specific source of emissions because they avoid or "offset" GHG emissions that would have occurred in the absence of the project. In the U.S. context, offsets often refer to purchasing emissions reductions made in developing countries, and in theory, they provide cheaper emission reduction options than will be available in the United States. Offsets are likely to be permitted under a total cap on U.S. emissions because they are intended to reduce the cost of meeting the cap and thus dampen the negative consequences of higher energy costs.

ACES allows for offsets, with some specific restrictions.[3] Accounting for these offset provisions, the EPA has recently estimated prices between $14-32 per Metric Ton (t) CO_2 equivalent (eq.) (EPA, 2009a). [4,5] Such low prices would cause very small increases in the cost of conventional petroleum fuels and thus by themselves will not stimulate the deployment of more fuel-efficient vehicle technologies, research and development of advanced vehicle or fuel technologies, nor significantly reduce the use of vehicles. This conclusion has also been reached by the Energy Information Administration (EIA) in their analysis of ACES, despite estimating significantly higher CO_2 prices of $18-65/t CO_2 eq. (EIA, 2009b).

Both Congress and the Obama administration recognize that a soft cap will not be sufficient to meet its GHG reduction goals and are seriously considering supplemental policies, such as tighter motor-vehicle CO_2 emission standards, low-carbon fuel standards, and tax credits for a range

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[3] The total number of offsets is capped at 2 billion tons per year, half must come from domestic sources "so long as they are available", and no more than 1.5 billion tons can come from international sources (CEC, 2009).

[4] All prices in this article are in 2007 dollars unless otherwise noted. All conversions are made using the Consumer Price Index (BLS, 2009).

[5] Reported as 13-30 2005$/t CO_2 (EPA, 2009a).

of new transportation technologies. The Energy Independence and Security Act of 2007 (EISA) strengthened the Corporate Average Fuel Economy (CAFE) standards after a decade of stagnation (Sissine, 2007).[6] The recent American Recovery and Reinvestment Act (ARRA) of 2009 (ARRA, 2009) contains tax credits for Plug-in Hybrid Vehicles (PHEV) like the Chevrolet Volt that are expected to be marketed within 2-3 years. To further reduce CO_2 emissions from passenger vehicles, the Obama administration announced a goal of achieving 35.5 mpg by 2016 (OPS, 2009). This strengthens CAFE ahead of the 35 mpg by 2020 goal mandated under EISA. The Cash-for-Clunkers program implemented in the summer of 2009 (NHTSA, 2009a) provided subsidies for the purchase of fuel-efficient vehicles contingent on the trade-in and disposal of older and less fuel-efficient vehicles. Indeed ACES itself contains myriad efficiency and investment provisions on top of the cap-and-trade program.

In this paper we explore the impacts of various transportation-specific policies in a world with economy-wide CO_2 prices. We focus on the ability to achieve significant reductions in oil imports and GHG emissions below both business-as-usual projections and 2005 levels. Our analysis applies the National Energy Modeling System (NEMS), a general equilibrium model of energy markets in the United States, maintained by the Department of Energy's Energy Information Administration (EIA) (EIA, 2009c-d). Like every modeling exercise, our results should be interpreted with a good understanding of the model's limitations and assumptions.

Our analysis examines three claims.

> **Claim (1):** *Currently proposed economy-wide CO_2 pricing policies will (i) have little effect on the GHG emissions from the transportation sector, (ii) have a marginal effect on oil imports, and (iii) be unlikely to significantly stimulate innovation in advanced vehicle and fuel technologies.*

Our results emphasize that while an economy-wide price of \$30-60/t CO_2 can have a significant impact on overall GHG emissions relative to a business-as-usual scenario, it will have a marginal impact on the factors that drive transportation-related oil imports and GHG emissions. Most of the emission reductions would occur in the electric utility sector and specifically in the coal-fired electricity-generating sector. Further, prices in the range of \$30-\$60/t CO_2 are much higher than the levels considered in Congress in the summer of 2009.

> **Claim (2):** *Individual policy measures implemented on their own would produce insufficient reductions in oil imports and GHG emissions below 2005 levels.*

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[6] In 2004, NHTSA released revised CAFÉ standards for light-duty trucks (NHTSA, 2004).

Economy-wide GHG emissions fall short of meeting the 2020 emissions goals set by the Obama administration or in ACES in all of our analysis cases, even though we select prices that are likely higher than those anticipated to result from ACES. By 2020, total annual GHG emissions are reduced to only 7% below 2005 levels and total annual CO_2 emissions are reduced 10% below 2005 levels. With higher fuel prices, CO_2 emissions are reduced to 12% below 2005 levels by 2020, dropping to 14% of 2005 levels by 2030. These projected shortfalls in national CO_2 emissions targets imply that, without additional policy action, the only way to meet the ACES targets will be to purchase large quantities of offsets. Practical legislation like ACES further addresses emissions with sector-specific policy options in all sectors of the U.S. economy. To focus on the transportation sector, we exclude action in these other segments that would help meet ACES-like caps on GHG emissions.

> **Claim (3):** *Combining individual policies results in greater reductions in U.S. oil import and transportation-based GHG emissions.*

This intuitive claim can be both true and false. Our analysis suggests that combining performance standards and fuel taxes results in greater reductions in oil imports and GHG emissions than would be possible with either approach in isolation. This is possible because performance standards alone are subject to rebound effects, and fuel taxes alone are subject to market failures that impede fuel economy improvement (Turrentine & Kurani, 2007; Greene et al. 2008). When combined, performance standards can compensate for these market failures while fuel taxes compensate for rebound effects. However our analysis also shows that there are cases in which combining policies can *reduce* their effectiveness. Subsidizing the purchase of fuel-efficient alternative motor vehicles allows automakers to satisfy the CAFE standards with lower conventional vehicle fuel economy, ultimately leading to slower improvement in conventional vehicle fuel economy over 2010-2030. If our subsidies were less expensive than the tax or cap options, this might not be a problem, but these subsidies require large government expenditures.

Generally our results show that increasing the cost of driving is essential to obtaining significant reductions in GHG emissions from transportation. Such cost increases will stimulate consumers to change their new vehicle purchases, their driving habits, and their choice of where to live. Performance standards alone cannot mitigate the growth in vehicle use that is projected to accompany population and income growth during 2010-2030.

The rest of this paper proceeds as follows. Section 2 details policy approaches for reducing GHG emissions from transportation. Section 3 describes the policy scenarios chosen for analysis. Section 4 discusses the National Energy Modeling System employed to carry out our analysis. Section 5 presents the results of these analyses. Section 6 closes with insights for policy makers.

2. SECTOR-SPECIFIC POLICIES FOR TRANSPORTATION

Putting a price on GHG emissions, increasing taxes on transportation fuels, or taxing oil imports are the most direct policy options for reducing gasoline consumption, increasing fleet efficiencies, and reducing driving. Many elected officials perceive these instruments as politically risky and too regressive, and thus they have embraced alternative policies. The four that have received the most attention are more stringent passenger vehicle efficiency standards, subsidies for alternative motor vehicles[7], requirements on fuels with lower carbon footprints, and incentive programs to scrap older, less efficient vehicles.

Passenger Vehicle Efficiency Standards

There are two basic options to strengthen motor vehicle fuel efficiency standards—the traditional Corporate Average Fuel Economy Standards (CAFE) or mandating reductions in CO_2 emissions intensity (g CO_2/mi). The former option has been in place in the United States since 1979, while the latter option has been embraced in the European Union (EU), California (with eleven other states), and recently by the EPA (EPA, 2009c).

The CAFE standards were originally enacted in the Energy Policy Conservation Act (EPCA) of 1975, largely in response to the 1973-74 oil embargo. The Energy Independence and Security Act (EISA) of 2007 (Sissine, 2007) contained the most recent revision to CAFE standards, mandating that the National Highway Traffic Safety Administration (NHTSA) set standards that achieve 35 mpg by 2020. The most novel feature of the EISA CAFE standards is the implementation of "attribute-based" minimum fuel economy levels. Each manufacturer receives a distinct average fuel economy they must meet or exceed to avoid fines. This manufacturer-specific fuel economy level is defined as a function of the footprints—the track width multiplied by the wheelbase—of the vehicles offered by the manufacturer. (See Appendix A for details.) EISA also has several other important modifications to CAFE.

California first proposed to regulate GHG emissions directly through standards for vehicle GHG emissions intensity (CARB, 2004).[8] A standard on GHG emissions intensity operates very much like standards on fuel economy. Indeed the EPA has proposed an attribute-based GHG emissions intensity standard that applies to cars and trucks separately, much like the fuel economy standards under EISA. On September 15th, 2009, the National Highway Traffic Safety Administration (NHTSA) and the EPA released a joint proposal for a harmonized approach for improving the efficiency of motor vehicles sold during 2012-2016 (FR, 2009a-b).[9]

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[7] Such as direct-injection diesels, gasoline-electric hybrids, plug-in hybrids, ethanol or flex-fuel vehicles, fuel cell vehicles, among others.

[8] California's regulation faced a long legal battle, and has only recently been granted a waiver by the EPA (EPA, 2009d). The EPA itself intends to exercise its authority to regulate GHGs, inspired by California's proposed approach (EPA, 2009c).

[9] These two approaches are GHG emissions intensity and fuel economy standards. Regulating GHG emissions from

Purchase Tax Credits

Tax credits for diesel vehicles, gasoline-electric hybrids, and other alternative motor vehicles have been in place since the Energy Policy Act of 2005 (EPACT) (IRS, 2008). By purchasing a qualified vehicle, consumers can receive income tax credits on the order of $1,000-$3,000 for hybrid vehicles and $1,000-$2,000 for diesels, in nominal dollars.[10] These credits phase out over six calendar quarters after 60,000 qualified vehicles are sold by a given manufacturer.[11]

The stimulus bill—ARRA, H.R. 1, Jan. 2009—modified tax credits for the purchase of Plug-In Hybrid Vehicles (PHEV's) originally introduced in October of 2008 as part of H.R. 1424. Purchasers of a new PHEV, none of which are currently available, receive an income tax credit in proportion to the battery capacity of the purchased vehicle. Specifically a $2,500 base credit is given for any PHEV with at least 4 kWh battery capacity. For PHEVs with over 5 kWh battery capacity, additional credit value is added at the rate of $417 per kWh beyond 5 kWh the vehicle obtains. A maximum credit of $7,500 is given for any vehicle at or above 17 kWh battery capacity.[12] Again, these values are in nominal dollars.

Cash-For-Clunkers

The fact that vehicles tend to have a very long lifetime in the national fleet is one of the basic impediments to reducing GHG emissions from transportation. "Cash-for-Clunkers" or "Fleet Modernization" programs intend to support national automotive firms as well as reduce fuel consumption by supporting trade-ins of relatively poor fuel-economy vehicles for new, relatively good fuel-economy vehicles. Germany has a Cash-for-Clunkers program, the "Umweltprämie" (Dougherty, 2009), in which consumers can receive 2,500€ (roughly $3,500) for trading in a car at least nine years old.

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vehicles is largely regulation of their tailpipe CO_2 emissions, closely related to regulating fuel economy, with one important exception: Air Conditioning (AC) units emit GHGs. The EPA, following California, is likely to count reduction of AC emissions towards satisfying a GHG emissions standard (FR, 2009a-b). On the other hand, "EPCA does not permit NHTSA to consider air conditioning credits in developing a proposed CAFE standard for passenger cars." (FR, 2009a, pg. 24009) This aspect of the combined regulation alone will decouple fuel economy and GHG emissions intensity standards, in so far as automakers can reduce the GHG emissions intensity of their vehicles through improvements to AC units without improving fuel economy.

[10] Because these values are in nominal dollars, the value of such credits decrease over time.

[11] For example, no more credits are allowed for Toyota and Honda hybrids (IRS, 2008). There are interesting issues regarding the salience of different income and sales tax credits that are not accounted for by models such as NEMS (Gallagher & Muehlegger, 2008).

[12] After a manufacturer sells 200,000 applicable PHEVs this credit phases out, and no further credits are given for purchases of PHEVs from that manufacturer. This is a small change from the original, H.R. 1424 PHEV credits, which started the sliding scale at 4 instead of 5 kWh and phased out after 250,000 PHEVs were awarded credits.

Recently a Cash-for-Clunkers program—the Consumer Assistance to Recycle and Save Act—was enacted in the United States (NHTSA, 2009a; NYT, 2009). This program subsidized fuel economy improvement by awarding vouchers towards the purchase of new vehicles upon the trade-in of existing vehicles[13] with a combined EPA fuel economy rating less than 18 mpg. For passenger cars, a voucher worth $3,500 was awarded if the new car fuel economy was at least 4 mpg higher than the trade-in vehicle, and a voucher of $4,000 was awarded if the new car fuel economy was at least 10 mpg higher than the trade-in vehicle.

This subsidy program has impacts that closely mirror those of energy tax credits. Its political popularity was fueled, in part, by the perception that it created jobs in the automobile sector, which was especially hard hit by economic recession. As of October 9th, 2009, the CARS program has paid or approved vouchers for 671,088 new vehicles at a cost of roughly $3 billion (DOT, 2009).[14]

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[13] Registered for at least one year prior to the trade-in date.

[14] As of October 9th, 2009, these CARS-related sales were roughly 9% of 2009 year-to-date sales (WSJ, 2009). The reported cost of the CARS vouchers was 2.85 billion in 2009 dollars; this is equivalent to $3 billion in 2007$ according to monthly CPI data (BLS, 2009).

3. POLICY SCENARIOS

To obtain a better understanding of the challenge of making meaningful reductions in GHG emissions in the transportation sector, we explore several policy scenarios. To provide a point of comparison, we start with a Business-as-Usual (BAU) scenario: the Department of Energy's 2009 Reference Case as described in the agency Annual Energy Outlook (AEO) (EIA, 2009e). This scenario predicts much higher oil prices than previous versions of the AEO, which triggers significantly greater demand responses than the 2008 version of our study (Gallagher & Collantes, 2008). Oil prices for 2010 are forecast to average \$77/bbl increasing in real terms to \$124/bbl in 2030. The EIA forecasts these prices to imply that gasoline prices will average roughly \$1/gal higher in 2030 than in 2010 (EIA, 2009e).

On top of the AEO 2009 Base Case we explore the impact of an economy-wide CO_2 tax, which is also a surrogate for a CO_2 price under a cap-and-trade program. We select prices that are significantly higher than those projected under the Waxman-Markey bill—\$30/t of CO_2 in 2010 escalating to \$60/t in 2030. In addition, we look at three other policy scenarios. First, we investigate what happens if, in addition to the economy-wide CO_2 tax, Congress also imposed a strong gasoline and diesel tax. Second, we examine the impact of continuing to improve the passenger car fuel efficiency standards between 2020 and 2030, reaching a new standard of 43.7 mpg in 2030. A third case examines how very aggressive performance-based tax credits for alternative motor vehicles would affect GHG reductions in the transport sector. In our final scenario, we assume that the United States adopted each of these policies.   See Table 1.

There are several other promising scenarios that we not not explore, such as dramatically increasing the stringency of CAFE standards, and aggressive use of feebates (a tax on less efficient vehicles). These scenarios deserve additional analysis.

Scenario A: "Business-as-Usual"

Our base case is the AEO 2009 reference case, except for the modification of the tax credits for plug-in hybrids enacted in the ARRA stimulus package. This scenario represents business-as-usual from today, assuming no new policies are put in place. The assumptions that characterize

	CO_2 Prices		Transportation Taxes		CAFE Standards			Tax Credit
	2010 (\$/t)	2030 (\$/t)	2010 (\$/gal)	2030 (\$/gal)	2010 (-)	2020 (-)	2030 (-)	2010-2020 (-)
Scenario A					EISA	EISA		
Scenario B	30	60			EISA	EISA		
Scenario C	30	60	0.5	3.36	EISA	EISA		
Scenario D	30	60			EISA	EISA	EISA	
Scenario E	30	60			EISA	EISA		Active
Scenario F	30	60	0.5	3.36	EISA	EISA	EISA	Active

TABLE 1: Policy scenarios considered in this work.

this base-case scenario thus influence the effect of new policies. Most of the AEO reference case is driven by oil price projections, which, as aforementioned, are much higher than in past studies. To account for the uncertainties in oil price projections and their potential impact on policy impacts (Collantes & Gallagher, 2008), we also looked at each of our policy scenarios using the AEO's high price projections of $88/bbl in 2010 increasing to $198/bbl. in 2030, bringing 2030 gasoline prices to $5.47/gal before we have incorporated any of our policy scenarios. These higher prices, by themselves, will significantly influence consumer behavior, though not enough to meet the Obama Administration's goals.

Scenario B: CO_2 Tax

This scenario places a price of $30/t CO_2 on CO_2 emissions in 2010 that escalates to $60/t CO_2 by 2030. These CO_2 prices influence the price of fuels in proportion to their CO_2 emissions intensity from combustion (not full lifecycle CO_2 emissions). Electricity prices rise as the increased cost of fuels increases the cost of operating existing power plants and affects decisions about the construction of new plants. Consumers react to higher prices by reducing their demand for energy, by increasing their demand for energy efficiency, and/or by switching fuels. Higher fuel costs also motivate the diffusion of fuel-economy improving technologies into conventional vehicles.

The $30-60/t CO_2 prices assumed for Scenario B are probably more aggressive than the prices discussed in Congress during the summer of 2009. Prior to passage of ACES by the U.S. House of Representatives, the Congressional Budget Office estimated that the allowance price would be $15-28/t CO_2 eq., not accounting for offsets (CBO, 2009) and the U.S. EPA forecast allowance prices within $13-24/t CO_2 eq in 2015 and $16-30/t CO_2 eq. in 2020, including some restrictions on the use of international offsets (EPA, 2009a). In August of 2009 the EIA obtained higher estimates for allowance prices, $18/t CO_2 eq. in 2010 rising to $65/t CO_2 eq. in 2030, using the National Energy Modeling System (NEMS) (EIA, 2009b). The EIA's analysis features a complete treatment of the offset restrictions in ACES.

Our economy-wide prices on CO_2 could result either from a CO_2 tax or a cap-and-trade program.[15] As we report in Section 5, GHG emissions in Scenario B will fall short of the reductions required by ACES, and our CO_2 prices do not adjust (increase) to make up this shortfall. If the CO_2 prices in Scenario B were derived from a cap-and-trade program without a price ceiling, i.e. "safety valve," or offset provisions, CO_2 prices should adjust to ensure the cap is satisfied. By fixing our CO_2 prices at levels that do not meet these caps, we are implicitly assuming that Congress sets a safety valve and either ignores satisfaction of the cap, or allows the shortfall to be filled with offsets.

In our analysis, all of the revenue that comes to the government through the economy-wide CO_2 price instrument is returned to consumers through (uniformly) reduced income taxes. In theory, CO_2

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[15] In equilibrium the impact of either approach is identical (Stavins, 2009). Permits have the same impact on energy prices as a tax, with the exception that the level of the tax is endogenous under a permitting scheme. While additional complexities associated with construction of permit markets should arise, NEMS does not model any of these additional complexities.

tax revenue could be recycled to taxpayers through reduced federal income taxes, through reduced social security or Medicare payroll deductions, or through improved social programs. When taxes are set at their optimal level, revenues ought to be used to pay for or prevent the further development of external costs. We believe, however, that in practice much of any revenue will be directed to ease the impacts of carbon policies on the economy. While it is practically difficult, theoretically one can design a carbon tax and refund program that is revenue neutral (Metcalf, 2007).

Given the politics surrounding the debate in Washington D.C., revenue neutrality is likely to be an elusive goal and thus our analysis may understate the economic impacts, since only a small number of the permits are likely to be auctioned. The Obama administration initially supported a 100% auction to fund a 10-year, $150 billion dollar energy investment program with these auction revenues, the remainder returned to the public "to help the transition to a clean energy economy" (pg. 21, OMB 2009). However ACES currently proposes to auction only 15% of the CO_2 permits in the initial years, and then gradually increase the percentage auctioned over time (CEC, 2009). It is important to recognize that the government does not receive any revenue from the permits that are not auctioned. The reality of small permit auctions may change over time, however, and will not significantly affect the overall impact of the program on reducing GHGs and oil consumption (Stavins, 2009).

Scenario C: Transportation Tax

This scenario builds on Scenario (B) by adding a strong gasoline and diesel tax beginning at $0.5/gal in 2010 and increasing 10% per year, relative to the previous year and in real terms, resulting in a $3.36/gal tax in 2030. This gasoline and diesel tax is *not* recycled back to consumers.

Scenario D: Increased CAFE

This scenario builds on Scenario (B) by continuing the increases in CAFE specified under EISA through 2030. The CAFE standards continue to take the form of the firm-specific attribute-based standard. The coefficients used in the formula defining these standards are provided in Appendix A, Tables A.1-A.3.

Scenario E: Performance-Based Tax Credit

Scenario (E) builds on Scenario (B) by replacing the ARRA PHEV tax credit with a "performance-based" tax credit for several alternative motor vehicles: diesels, gas- and diesel-electric hybrids, and PHEVs. The value of this credit increases on a linear scale with the reduction in fuel consumption over a comparable conventional vehicle. Using fuel consumption instead of fuel economy captures the large gains to be made in supporting the substitution of slightly higher fuel economy vehicles for low fuel economy vehicles, rather than the substitution of very high fuel economy vehicles for vehicles that already have relatively high fuel economies. This is related to the "MPG Illusion" demonstrated by Larrick & Soll (2008).

The monetary value of the credit, in real terms, is between $3-5 per gallon saved over the vehicle lifetime by driving the alternative motor vehicle instead of the conventional vehicle.[16] (See Appendix B for details.) This value is consistent with the implied value of the ARRA credit given to PHEVs in Scenario (A), and assumes that between 90,000 and 150,000 miles are driven over a vehicle lifetime, with no "rebound" effect. We understand that this assumption overstates reality and is a shortcoming of the model since a rebound effect does exist (Greene et al., 1999; Small & van Dender, 2007; Small & van Dender, 2008) that will function to decrease the fuel consumption avoided per dollar of government expenditure.

Table 2 provides representative values of this tax credit for selected 2009 model year vehicles. Most credits would be significantly higher than those put in place under EPACT 2005, but few existing vehicles would qualify for credits higher than those recently put in place for PHEVs.[17] While Congress almost always caps large credits, we exclude caps to design a scenario in which Congress attempts to get a higher percentage of emission reductions through purchases of alternative motor vehicles. We also index the value of our tax credits to inflation.

Perhaps a more appropriate alternative would be to attach a value to CO_2 emissions intensity instead of fuel economy. This is relatively easy for diesel vehicles and hybrids, but rather challenging for PHEVs. Because the electrical grid in the United States has many different CO_2 emissions factors, emissions intensity of PHEVs—assuming their charging capacity is employed—is quite uncertain at a national level. In practice, this might be mitigated by localizing the value of tax credits through the registration and certification process. However our analysis does not resolve such regional detail.

Scenario F: Combined Aggressive Case

Our final case applies all the policies considered in Scenarios (B)-(E) together.

		Fuel Economy (mpg) (EPA, 2009e)			
		Standard	Hybrid	Diesel	Credit Value
Cadillac	Escalade	15.0	20.0		$7,500
Chevy	Malibu	23.0	29.0		$4,048
Chevy	Silverado	16.0	21.0		$6,696
Ford	Escape (2WD)	20.5	28.0		$5,880
Honda	Civic	26.5	42.0		$6,267
Lexus	GS 460 / GS 450h	20.0	23.0		$2,935
Mercedes-Benz	E350 / E320 BLUETEC	19.0		26.0	$6,377
Toyota	Camry	24.0	34.0		$5,515
Volkswagon	Jetta	24.0		33.0	$5,114

TABLE 2: Performance-based tax credit values for some 2009 vehicles offered in both standard and hybrid/diesel models. Credit value taken relative to the standard offering, rather than average vehicle of the same size class. All credit values are in 2007 dollars.

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[16] These values are on par with the AEO projections regarding gasoline prices during 2010-2030.

[17] Furthermore, large tax credits for the purchase of diesel vehicles are unlikely to pass the U.S. Congress without significant changes in attitudes and regulatory policies towards diesel.

4. METHODOLOGY

In our analysis the National Energy Modeling System (NEMS) is used to estimate the energy, economic, and CO_2 impacts of different policies placed on the transportation sector in the United States from 2010-2030. NEMS is an energy-economic equilibrium model that projects annual average energy supply and demand in the U.S. economy (Gabriel et al, 2001; EIA, 2009c). Maintained by the Energy Information Administration (EIA), NEMS is primarily applied to produce the Annual Energy Outlook (AEO) published each year by the EIA (EIA, 2009e). EIA also regularly uses NEMS to respond to Congressional service requests regarding the potential impacts of proposed energy policy, such as ACES (EIA, 2009b). Reports on such analyses are available online (EIA, 2009d). NEMS has also been used by other offices within the DOE as well as numerous organizations outside of government. This model has established a high degree of credibility among members of Congress when it comes to assessing energy policy options. For this reason, we have chosen to apply NEMS in this analysis.

NEMS iteratively produces an energy-economic equilibrium using computational modules for energy supply, energy demand, energy conversion, and the macroeconomy (EIA, 2009c). Changes in energy consumption and prices are passed from the energy modules to the macroeconomic module, which projects macroeconomic indicators such as GDP, personal income, industrial output, and light-duty vehicle sales. These indicators are then fed back to the energy modules, which in part determine energy consumption and prices. This process is iterated until convergence.

See Table 3 for a quick reference to the key modeling assumptions applied in our analysis.

Transportation Energy Consumption

Projections for energy consumption from light-duty vehicles are determined by the Transportation Sector module (TRANS); see EIA (2009f) for detailed documentation. For the Light-Duty Vehicle (LDV) fleet, TRANS determines the fuel economy of new vehicles, sales shares of conventional and alternative fuel vehicles, stock turnover, and vehicle-miles traveled. Projections for freight, rail, shipping and air transport are also made. Unfortunately modal shifts between traffic using LDVs, freight, rail, and air transport as a consequence of fuel prices are not explicitly modeled by NEMS.

Oil Prices and Fuel Production

We adopt oil prices from the reference and high price cases in the 2009 AEO; see Table 4. As mentioned earlier, the 2009 reference case projections for world oil prices are considerably higher than in previous years with a world oil price of $77 per barrel (bbl) in 2010 continuously increasing through 2030 to reach $124/bbl. in real terms. EIA's high oil prices account for "differences in the assumptions about access to energy resources, production costs, and changes in OPEC behavior"

Key modeling assumptions (EIA, 2009c,e)

- The *time period* is 2010-2030.
- Without additional regulatory policy, the U.S. experiences economic growth at annual rates between 2.1% and 3.7% during 2010-2030.
- The 2009 version of NEMS was used for all analyses (EIA, 2009c,e).
- *Covered gases* include energy-related CO_2, nitrous oxide (excluding agriculture and mobile combustion emissions), hydrofluorocarbons (HFC), perfluorocarbons (PFC), and sulfur hexafluoride (SF6).
- All policies are in terms of *carbon dioxide* (CO_2), not carbon.
- *Some of the policies recycle revenue to consumers*. The economy-wide CO_2 tax revenue is fully recycled to consumers. Neither transportation tax is recycled to consumers.
- *Imported oil prices* follow the EIA's reference and high price projections (see Table 4).
- EIA's assumptions regarding *penetration of high-efficiency vehicle technologies* (including hybrids and diesels) were used.
- *Taxes on transportation fuels* are assessed at the exit gates of refineries.
- The carbon content of transportation fuels is not assessed on a lifecycle basis but rather in terms of the carbon content of the liquid fuel.
- *Coal-to-liquids* become uneconomical at a price of \$13/t CO_2 given all the other underlying assumptions about oil prices, etc.
- Use of *E85* in flex-fuel vehicles is determined by the relative price of E85 versus gasoline, and the number of E85 fueling stations available.
- The *price elasticity* for vehicle-miles traveled(with respect to the cost of driving a mile) in NEMS is -0.0351 in the short run and -0.1859 in the long-run. That is, a 10% increase in the cost of driving results in a 0.3% decrease in vehicle-miles traveled in the short-run and a 1.8% decrease in vehicle-miles traveled in the long-run.
- *Biofuels blending* is determined by the relative cost to petroleum and oxygenate requirements.
- The current *ethanol subsidy* of \$0.51/gal. and the \$0.54/gal. ethanol import tariff are assumed to be eliminated in 2010.
- *Cellulosic ethanol availability* in the modeling timeframe is limited due to its projected high costs.
- Multiple vehicle attributes influence *vehicle choice*. These include vehicle price, cost of driving, performance, and vehicle range.
- There are 16 *vehicle technology options* (EIA, 2009f), and the availability of model choices for hybrids and diesels increases over time. There are two PHEV's, one with a 10-mile all-electric range and one with a 40-mile all-electric range.
- *Fuel saving technologies are adopted* when they are cost-effective with respect to a 3-year payback period using a 15% discount rate.

TABLE 3: Key modeling assumptions (EIA, 2009c,e)

	Imported Oil Price (2007$/bbl)				
	2010	2015	2020	2025	2030
Reference Case	$77	$108	$112	$115	$124
High Case	$88	$155	$181	$189	$198

TABLE 4: Selected oil prices in the reference and high oil price cases (EIA, 2009e).

including “increased restrictions on economic access to non-OPEC resources and OPEC decisions to further limit its production” (EIA, 2009g). The high oil price scenario in the AEO 2009 projects a world oil price of $88/bbl. in 2010, continuously increasing through 2030 to $198/bbl. in real terms. World oil prices are unaffected by the introduction of transportation-specific policy options in NEMS.

Increased oil prices correspond to very high prices on combustion-related CO_2 emissions. Both CO_2 prices and increased oil prices increase gasoline prices. However, CO_2 prices must be more than twice as high (250%) as oil price increases to result in the same increase in the price of gasoline.[18] For example, a $50/bbl increase in the price of oil is comparable to a CO_2 price of $130/t CO_2 eq.

The Petroleum Market Module performs the domestic conversion of crude oil and other products into refined petroleum-based products such as various types of gasoline and diesel (EIA, 2009i). This module also considers other liquid fuels, such as fuels from natural gas, coal, and ethanol. Ethanol is used as a gasoline additive and for blending, depending on its relative cost and demand.[19]

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[18] Ignoring higher-order price effects from transportation costs, imperfectly competitive price-setting behavior, accounting for combustion emissions alone (EPA, 2005), and using petroleum product yield figures from the EIA (EIA, 2009h).

[19] The EIA uses the following CO_2 emissions factors for fuel combustion: E85 ~ 1.328 kg CO_2/gallon, E10 ~ 7.977 kg CO_2/gallon, gasoline ~ 8.861 kg CO_2/gallon (EIA, 2009j). Lifecycle emissions are not included.

5. RESULTS

In this section we discuss the results of our analysis. We first provide a summary of the results for our five policy scenarios. This summary is followed by a more detailed assessment of several key factors affecting future oil consumption in the passenger vehicle sector. Our results indicate that the present efforts to keep fuel prices low while simultaneously trying to significantly reduce oil imports and GHG emissions are inconsistent. To significantly reduce GHG emissions from the transport sector, it appears that a transportation fuels tax is the single most effective method to reduce emissions, with some form of performance standards an important complementary backstop policy.

Summary of Results from Scenarios (B-F)

Scenario B: CO_2 Tax

The economy-wide \$30-60/t CO_2 prices will significantly reduce GHG emissions in the power sector but will have a marginal impact on emissions from transportation, a conclusion also reached by the EIA (EIA, 2009b). The economy-wide ACES target of 15-17% below 2005 levels by 2020 is not met, even with our \$45/t price. Hence large quantities of offsets will have to be purchased in order to meet the projected cap on emissions (see Fig. 6). Fuel economy in new vehicles and net oil imports are not significantly changed by the economy-wide CO_2 prices in this scenario.

Scenario C: Transportation Tax

The incremental taxes on transportation fuels result in the largest reductions in both CO_2 emissions and oil imports, largely because the increased cost of driving reduces Vehicle-Miles Traveled (VMT). Between 2010 and 2020, these taxes also stimulate slightly larger improvements in the fuel economy of new conventional vehicles than are achieved with the existing EISA CAFE standards, included in all policy scenarios.[20] These findings suggest that higher fuel prices will have a greater impact on emissions from passenger vehicles than tighter CAFE standards in the 2010-2030 period. This scenario also has the reductions in GDP and light-duty vehicle sales relative to business-as-usual, though these impacts are small in absolute terms.

Scenario D: Increased CAFE

Extending the duration of the EISA CAFE standards in 2020-2030 achieves the highest long-term fuel economy gains, but this scenario fails to obtain significantly greater reductions in CO_2 emissions from transportation than would be achieved in Scenario B through CO_2 prices alone. VMT is reduced relative to the AEO 2009 base case but is slightly higher than in Scenario B (CO_2 prices only) due to the decrease in operating cost resulting from stronger CAFE standards.

Scenario E: Performance-Based Tax Credit

The purchase tax credits are the least effective at reducing GHG emissions and require excessive

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[20] We expect that NEMS underestimates the impact of fuel price on new conventional vehicle fuel economy.

government expenditures. Table 5 outlines the value of the credits and their total cost. Credits are higher than the existing tax credits for diesels or hybrids, ranging from $3,000-8,000 in real terms. Trucks receive the highest credits because they represent the largest reductions in fuel consumption and emissions.[21]

In total, subsidizing the purchase of alternative motor vehicles requires the government to invest $22-38 billion per year, on par with the 2008 U.S. auto bailout. In practice this cost would be constrained by an appropriations limit on the size and the timing of the credits, as in the case of the CARS Cash-for-Clunkers program. The longevity of a subsidy, however, may be an important determinant of its effectiveness when various dynamic effects are taken into account (Struben & Sterman, 2008).

The purchase tax credits also appear to impede conventional vehicle fuel economy improvement; see Fig. 10. Due to increased sales of higher fuel economy alternative motor vehicles stimulated by tax credits, automakers can satisfy the CAFE standards while offering conventional vehicles with lower fuel economy. Appendix A examines this phenomenon in greater detail.

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
	New Passenger Car Credit (2007$)										
Diesel	3,912	3,701	3,556	3,445	3,351	3,272	3,232	3,162	3,129	3,105	3,080
GHEV	4,432	4,273	4,118	4,005	3,863	3,778	3,733	3,647	3,594	3,598	3,546
DHEV	(NA)	6,188	6,058	5,883	5,692	5,585	5,251	5,110	5,011	4,693	4,619
PHEV-10	6,458	6,160	6,081	5,962	5,813	5,273	5,273	5,146	5,064	5,008	4,685
PHEV-40	6,888	6,590	6,492	6,323	6,165	5,852	5,748	5,619	5,533	5,490	5,892
	New Light Truck Credit (2007$)										
Diesel	4,314	4,205	4,203	4,155	4,078	3,957	3,880	3,698	3,604	3,523	3,455
GHEV	5,761	5,631	5,248	5,163	5,054	5,053	4,960	4,819	4,689	4,571	4,462
DHEV	(NA)	(NA)	(NA)	(NA)	(NA)	7,618	7,474	5,724	5,509	5,320	6,133
PHEV-10	8,334	8,114	8,007	7,902	7,768	7,608	7,496	7,284	7,122	6,977	6,864
	Total Value of Subsidies Dispensed by Government (Billion 2007$)										
Cars	7.3	9.1	11	12.2	13.2	15	17.1	17.4	18.3	19.1	19.1
Trucks	15.1	16.7	19.2	19.7	19.4	19.6	19.6	19.2	18.8	18.5	18.5
Total	**22.4**	**25.8**	**30.2**	**31.9**	**32.6**	**34.6**	**36.8**	**36.6**	**37.1**	**37.7**	**37.7**

TABLE 5: Representative value of the performance-based tax credits for applicable vehicles and total costs of the performance-based credit during 2010-2020. For cells marked "NA", no such vehicle was offered in the given calendar year.

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[21] For example, the 2009 Cadillac Escalade hybrid is rated at 20 mpg, 5 mpg higher than the standard Escalade, rated at only 15 mpg (city) (EPA, 2009e). The annual fuel consumption savings from trading the standard Escalade to the hybrid version is far greater than trading in some high-fuel efficiency sedans. For example, for 12,000 annual miles driven a consumer trading up to the Escalade hybrid saves 150% of the fuel saved by a consumer that trades a Honda Civic (29 mpg) for the Civic Hybrid (42 mpg) (EPA, 2009e). Trading up to the Escalade hybrid saves 300-400% of the fuel saved by trading a 2.4 liter Chevy Malibu (25-26 mpg) for the Malibu hybrid (29 mpg) (EPA, 2009e).

Scenario F: Combined Aggressive Case

Surprisingly, Scenario F, which combines the first four scenarios does not achieve the greatest reductions in GHG emissions and oil consumption in the transportation sector. We believe these reductions would be *greater* if the tax credits from Scenario E were eliminated. The combined policy approach also has the highest cost to the economy of all the policies. It typically has the largest reductions in GDP relative to the base case, though these reductions are small (generally less than 1%; Fig. 15) and in absolute terms GDP still grows at more than 2% per year. While this is comparable to Scenario C, the government must also find the $22-38 billion per year to fund the performance-based tax credit of Scenario E. This reality is not included in the NEMS model, hence the impact on GDP of the combined option may be slightly understated.

Economy-Wide GHG Emissions in the United States

Largely due to the impact of the CO_2 prices on the electrical power sector, the policies considered in scenarios (B-F) result in significant reductions in annual, economy-wide GHG emissions relative to the AEO 2009 "business-as-usual" base case; see Fig. 4. Loosely speaking, each policy scenario appears to reduce GHG emissions during 2010-2015 and stabilize GHG emissions between 2015 and 2020. All the policies fall short of the Obama administration's stated target of reducing GHG emissions to 14% below 2005 levels by 2020—a goal that many environmental advocates argue is too weak. Of course, these policies also fail to meet the slightly stronger ACES targets. The economy-wide CO_2 prices alone achieve annual economy-wide GHG emissions only 5% below 2005 levels in 2020. Transportation taxes, the most effective policy addition, reduce annual, economy-wide U.S. GHG emissions to only 7% below 2005 levels in 2020. None of the policy scenarios stop annual, economy-wide GHG emissions from continuing to increase beyond 2025, due to faster growth in population and income per capita than in GHG emissions reduction.

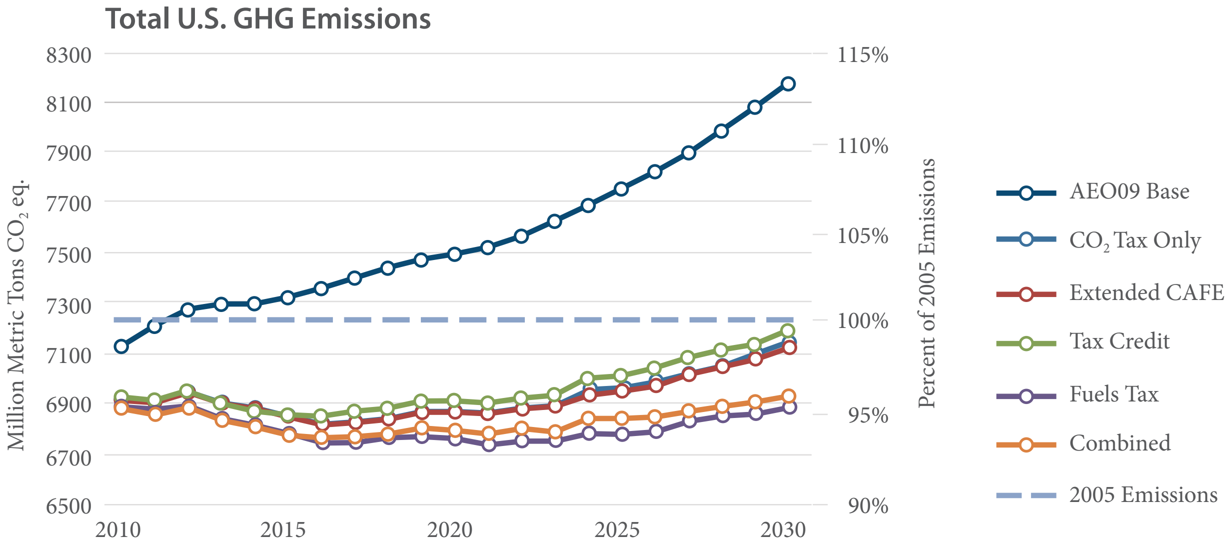

FIGURE 4: Total U.S. GHG Emissions.

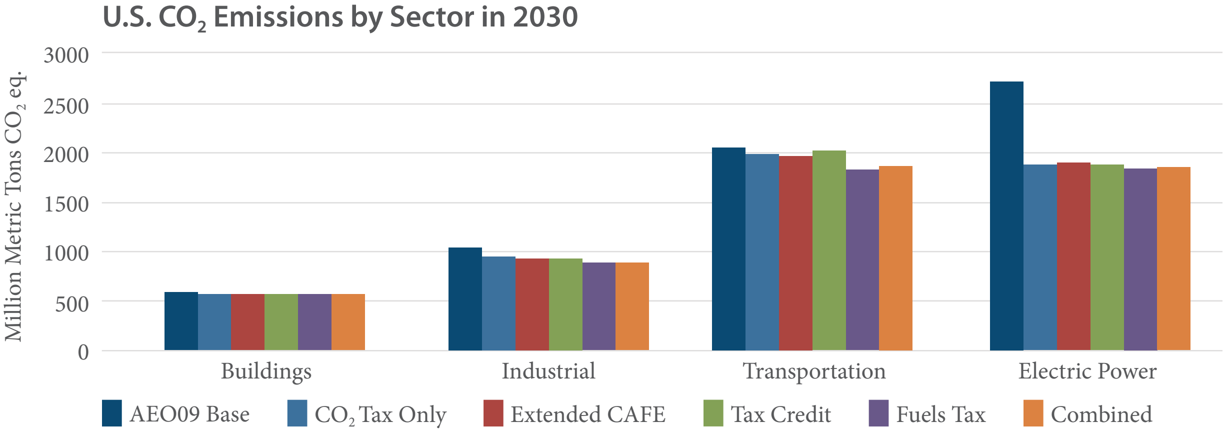

FIGURE 5: U.S. CO2 emissions by sector.

As also observed by the EIA in their detailed analysis of ACES (EIA, 2009b), the impact of the economy-wide CO_2 prices at \$30-60/t CO_2 is largely felt in the electric power sector alone. Fig. 5 illustrates that by 2030, CO_2 emissions from the generation of electricity have dropped 31%, relative to the AEO 2009 Base Case. CO_2 prices at this level have a relatively small impact on all other sectors of the economy, including on the transportation sector.

The Contribution of Offsets

Our analysis predicts that CO_2 prices on the order of \$30-60/t CO_2 are not high enough to achieve the caps like those set in ACES, at least considering sector-specific additions in only the transportation sector. If such caps are upheld, then emitters will have to purchase offsets at (or below) the corresponding CO_2 prices. The quantity of offsets required to meet ACES-like caps of

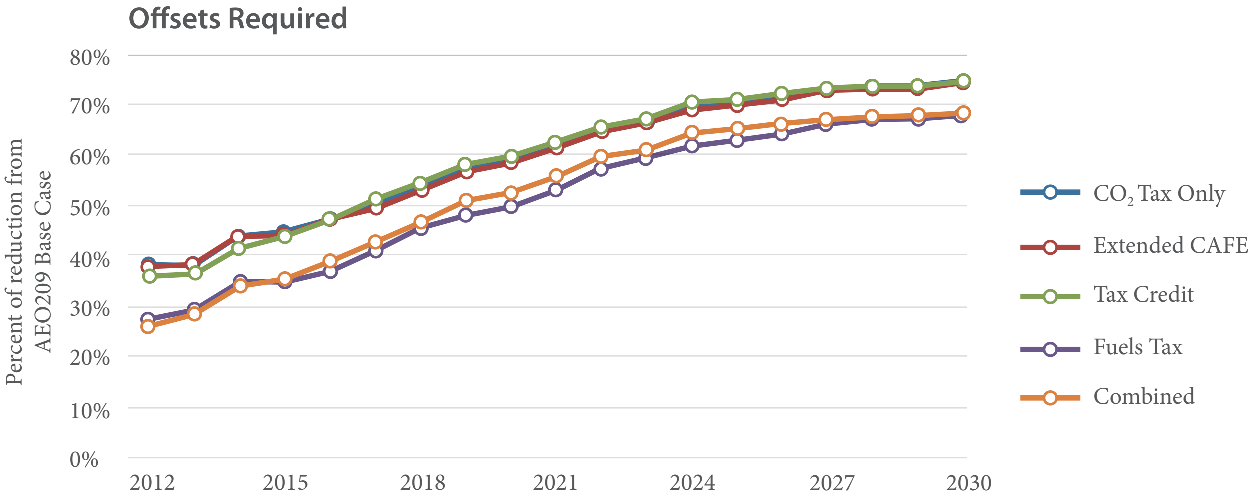

FIGURE 6: Offsets to maintain the ACES cap during years 2012-2030, as a percent of the required reduction in annual emissions under the various policy scenarios. The required reduction is the difference between the AEO 2009 Base Case and the ACES cap.

3%, 17%, and 58% below total 2005 GHG emissions[22] grows monotonically. In 2020, 730-860 Mt CO_2 eq. of offsets must be purchased to meet the cap. By 2027, the number of offsets required to satisfy the cap breaches the 2 billion metric ton limit on offsets stipulated in the current version of ACES. Fig. 6 plots offsets purchased as a percent of the total reduction in CO_2 emissions, relative to the AEO 2009 reference case, required by ACES-like caps of 3%, 17%, and 58% below 2005 levels. Beyond 2020, more than 60% of the GHG emissions reduction required to comply with the cap is coming from offsets, rather than direct GHG emissions reduction.

Transportation Sector Energy Consumption and CO_2 Emissions

The relative impacts of the different scenarios we have modeled on CO_2 emissions from the transportation sector alone are depicted in Fig. 7. Note that the economy-wide CO_2 prices of \$30-60/t only result in a 50 Mt CO_2 reduction in annual emissions relative to the AEO 2009 Base Case, and do not meaningfully change the trajectory of CO_2 emissions from the transportation sector. As expected, our CAFE standard case (Scenario D) differs from the economy-wide CO_2 price case (Scenario B) only beyond 2020 and only modestly decreases CO_2 emissions further than the economy-wide CO_2 prices alone do by 2030. The transportation taxes clearly have the most significant reductions in CO_2 emissions, ending up with lower emissions in 2030 than in 2010. The surprising results occur under the performance-based tax credits and the combined policy case.

Though the tax credits still present a reduction in emissions relative to the AEO 2009 base case, they actually cause CO_2 emissions to rise *higher* than they would be if there was only an economy-

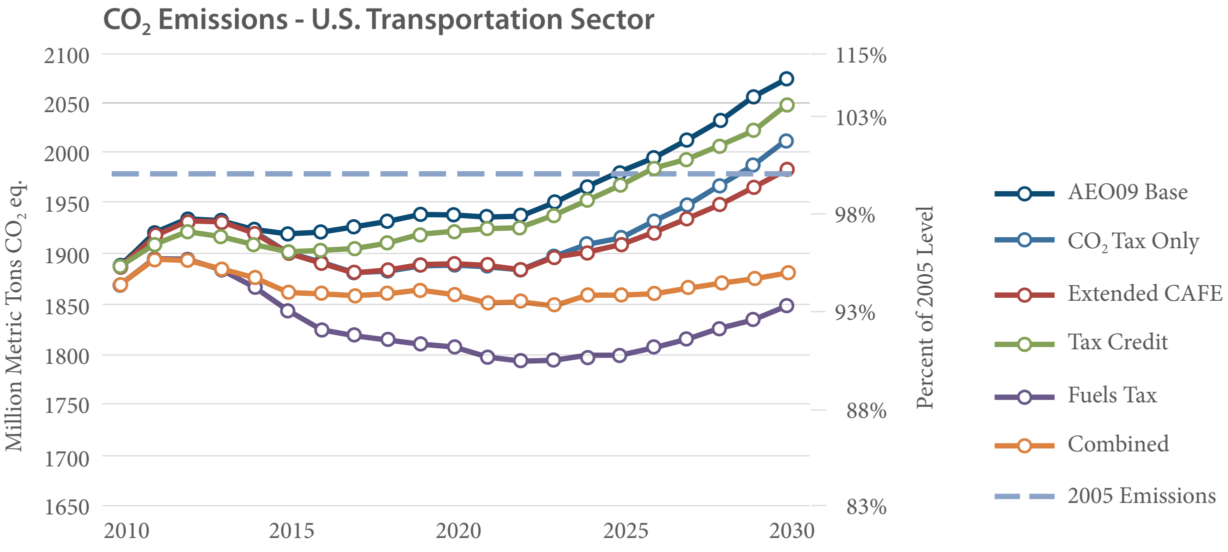

FIGURE 7: CO2 emissions from transportation.

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[22] For simplicity, we consider 3%, 17%, and 58% of total U.S. GHG emissions. ACES restricts its cap to specific sources, estimated to cover roughly 85% of U.S. emissions. The EIA's comprehensive analysis of ACES includes tracking of emissions from covered sources and demonstrates an even larger dependence on offsets (EIA, 2009b).

wide CO_2 tax. There are several reasons for this counter-intuitive result. First, as discussed earlier there is an unintended interaction between the tax credits and the CAFE standards that decreases the efficiency of conventional vehicles. Since conventional vehicles still occupy the majority of the market, this has significant consequences for GHG emissions. Second, the tax credits give a significant boost to diesel vehicles. Diesels gain significant market share under the credits and increase driving, because they are more efficient. We believe this analysis underestimates the impact of these credits because NEMS does not account for the black carbon from diesel soot that has a medium-to-large global warming potential.

Note also that the combined policy case has noticeably higher CO_2 emissions than the case with only transportation taxes. Again, the alternative motor vehicle income tax credits actually impede fuel economy improvements in conventional gasoline vehicles, diluting the power of the transportation taxes to reduce CO_2 emissions with lower VMT.

Fuel Prices

Fig. 8 plots gasoline prices. The AEO 2009 Base Case already projects gasoline prices to rise from \$2.84/gal in 2010 to \$3.60/gal by 2020 and \$3.88/gal by 2030. The CO_2 prices in Scenario B add an additional \$0.24-0.46/gal to retail gasoline prices during 2010-2030. As should be expected, these CO_2 prices put additional pressure on refiners and retailers, reducing margins on gasoline. Finally, the transportation taxes (Scenario C) increase gasoline prices from \$3.55/gal in 2010 to \$5.02/gal by 2020 and \$7.15/gal by 2030. The high price case results in even higher gasoline prices, ultimately reaching \$8.71/gallon in 2030 with the transportation taxes.

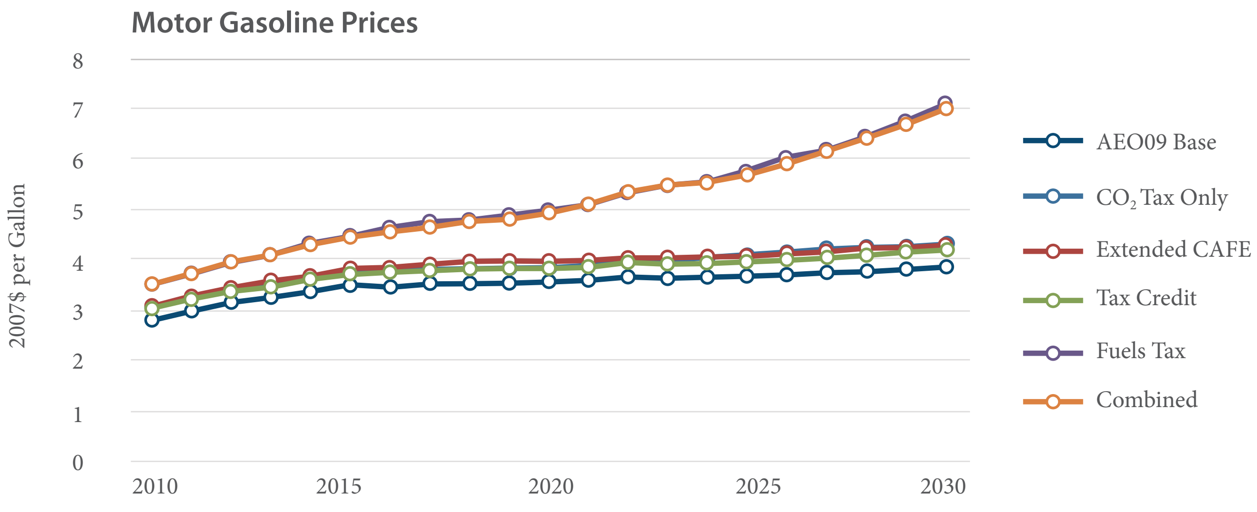

FIGURE 8: Gasoline Prices.

New Light-Duty Vehicle Fuel Economy

New vehicle fuel economy is already predicted to increase quite substantially in the AEO 2009 Base Case (EIA, 2009e); see Fig. 9. Unlike during the 1990s, fuel economy is expected to rise each year, exceed 35.5 mpg in 2020, and reaching 38.0 mpg in 2030.

Note that new vehicle fuel economy gains from the tax credits (Scenario E) are immediate: the average fuel economy of new vehicles starts at 30.1 mpg in 2010, rising to 37.8 mpg by 2020. The higher new vehicle fuel economy under the tax credits is based on increased sales of fuel-efficient alternative motor vehicles, rather than improvement in the fuel economy of conventional or alternative motor vehicles (see Fig. 10). When the subsidies are removed, normal purchasing behavior returns, lowering the average fuel economy of the new vehicle fleet to 34.8 mpg, below even the AEO 2009 Base Case at 35.8 mpg.[23] The combined policy case (Scenario F) has slightly stronger gains in new vehicle fuel economy during 2010-2020 (a consequence of the additional transportation taxes), to 36.1 mpg in 2021. Note also that the combined policy case (Scenario F) achieves an average new vehicle fuel economy of 35.0 mpg in 2016, just 0.5 mpg below the Obama administration's recently announced target of 35.5 mpg (OPS, 2009).

Sustainable gains in new vehicle fuel economy are driven by fuel taxes and increased CAFE. The transportation tax policy achieves 36.4 mpg in 2020, roughly equivalent to the tax credit case, and 36.8 mpg in 2021. Beyond 2020 the extended CAFE policy generates the largest increases in new vehicle fuel economy. The CAFE case (Scenario C) obtains 43.7 mpg in 2030, while the combined

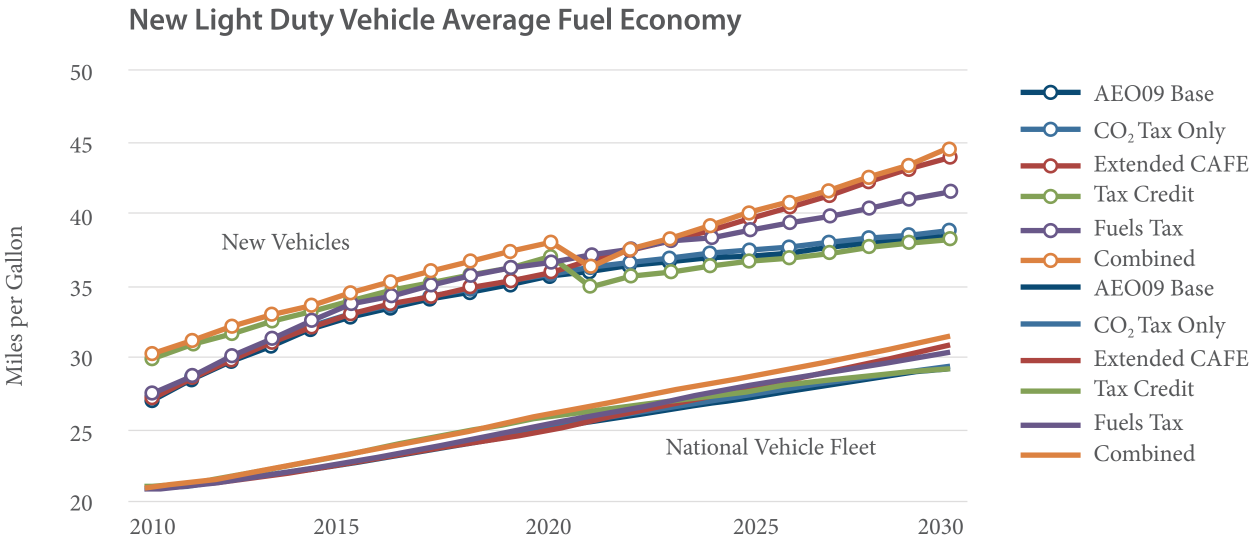

FIGURE 9: Light duty vehicle fuel economy, both new vehicles and the vehicle fleet.

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[23] We understand that such dramatic changes in fleet average fuel economy projections may not occur in the real world, but rather may be driven by assumptions in NEMS. On the other hand, the recent Cash-for-Clunkers program demonstrates that it is possible to dramatically influence sales patterns in the automotive industry using government subsidies.

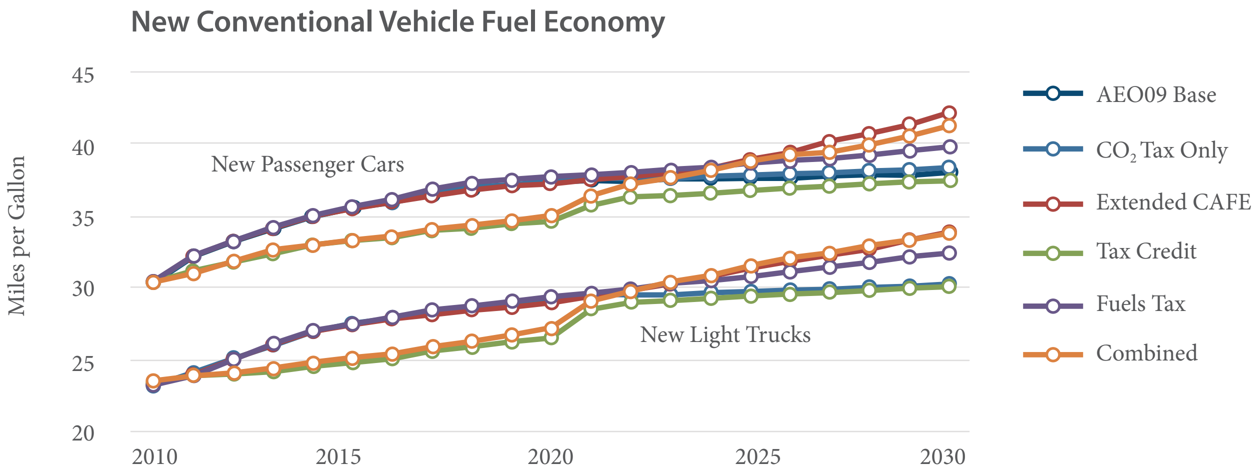

FIGURE 10: New conventional vehicle fuel economy.

case (Scenario F) receives some additional fuel economy from the increased purchases of fuel-efficient vehicles motivated by higher operating costs.

It is important to note that the response in fuel economy of the national fleet is muted despite these strong gains in new vehicle fuel economy; see Fig. 9. It takes a number of years for new more efficient vehicles to penetrate into the fleet because so many relatively inefficient cars remain on the road. Scenarios (A-E) had a varied impact on new vehicle fuel economy in 2030, achieving between 38-43.7 mpg, while overall fleet fuel economy in 2030 varied only between 28.9 and 31.2 mpg.

Light-Duty Vehicle Sales

Fig. 11 illustrates the losses in Light-Duty Vehicle (LDV) sales as a consequence of the policies considered. Each policy increases the cost of driving relative to the AEO 2009 Base Case, which should be expected to decrease the relative size of the new vehicle market. Economy-wide CO_2 prices alone decrease the LDV sales by 2-3% relative to the AEO 2009 Base Case. However none of the policies result in a contraction in LDV sales that does not occur in the Base Case; see Fig. 12. LDV sales are projected to grow strongly through 2013 with year-on-year growth rates between 6-10% (depending on the policy), after which year-on-year growth rates between -1 and 3% are projected. Average growth in LDV sales for 2014-2020 under all policies (and the Base Case) is 1%. These increases are driven by annual increases in per-capita GDP between 1-1.5%.

Plug-in Hybrid Vehicle (PHEV) sales by 2020 are driven largely by the tax credits, while by 2030 high fuel prices under the transportation taxes leads to the same penetration of PHEVs. The tax credits drive large increases in diesel sales—from 2% in 2010 under the AEO 2009 Base Case to 27% in 2010 with the credit—that do not continue after the credits are removed in 2020.[24] Gasoline-

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[24] The model does not consider other constraints on diesel sales that might significantly reduce these estimates.

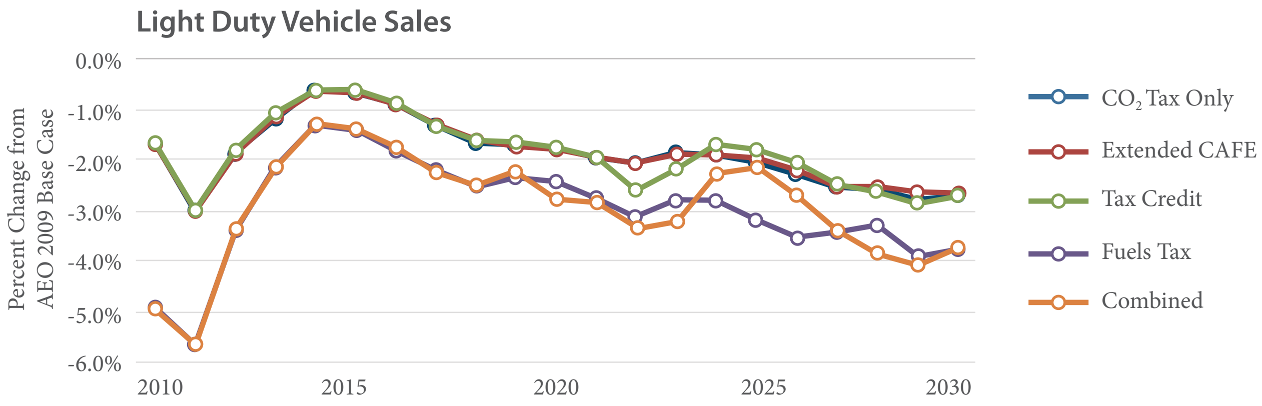

FIGURE 11: Light-Duty Vehicle (LDV) sales, as a percent of AEO 2009 Base Case.

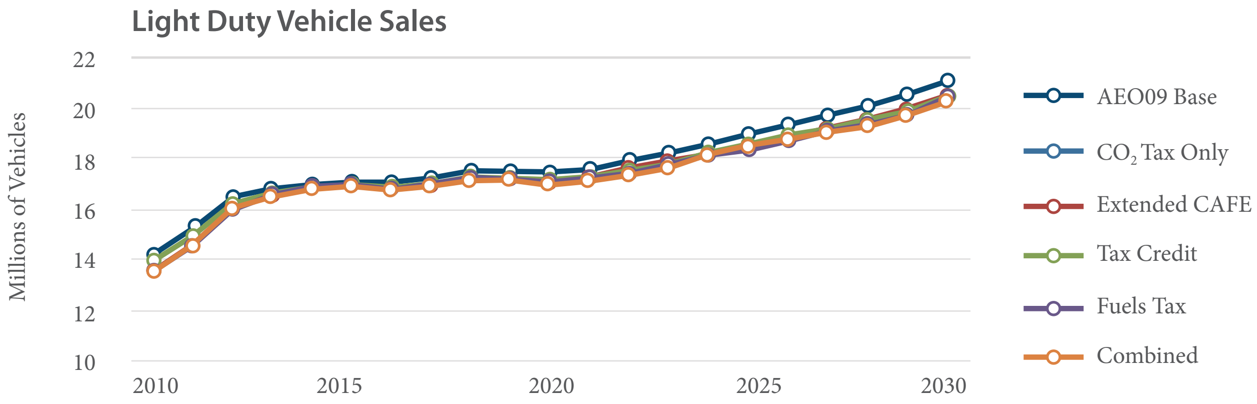

FIGURE 12: Light-Duty Vehicle (LDV) sales, in terms of vehicles sold.

electric hybrid vehicles (HEVs) see a similar jump from 3% in 2010 under the AEO 2009 Base Case to 10% in 2010 with the credit. The extended CAFE standards are met mostly with additional sales of HEVs, which obtain 33% of the new vehicle market.

Light-Duty Vehicle Miles Traveled

Much of the benefit of the transportation taxes lies in their ability to dampen growth in Vehicle Miles Traveled (VMT). As illustrated in Fig. 13, the transportation taxes (on their own or as part of the combined policy case) are the only policy option that reduces the large growth in VMT that is expected to result from the increase in household incomes and population. In the AEO 2009 Base Case, VMT is projected to grow 39% by 2030. Transportation taxes at the levels considered in this study reduce this growth rate to 25%. Economy-wide CO_2 prices and the subsidies reduce VMT in 2030 by only 1% (0.9% and 1.4%, respectively) relative to the AEO 2009 base case. Even this 1% reduction in VMT disappears with the extended EISA CAFE standards due to the decrease in operating costs resulting from having more fuel-efficient vehicles. VMT in 2030 in Scenario D is only 0.3% below VMT in 2030 in the Base Case. Transportation taxes, on the other hand, decrease VMT by 9.8% in 2030 relative to the base case.

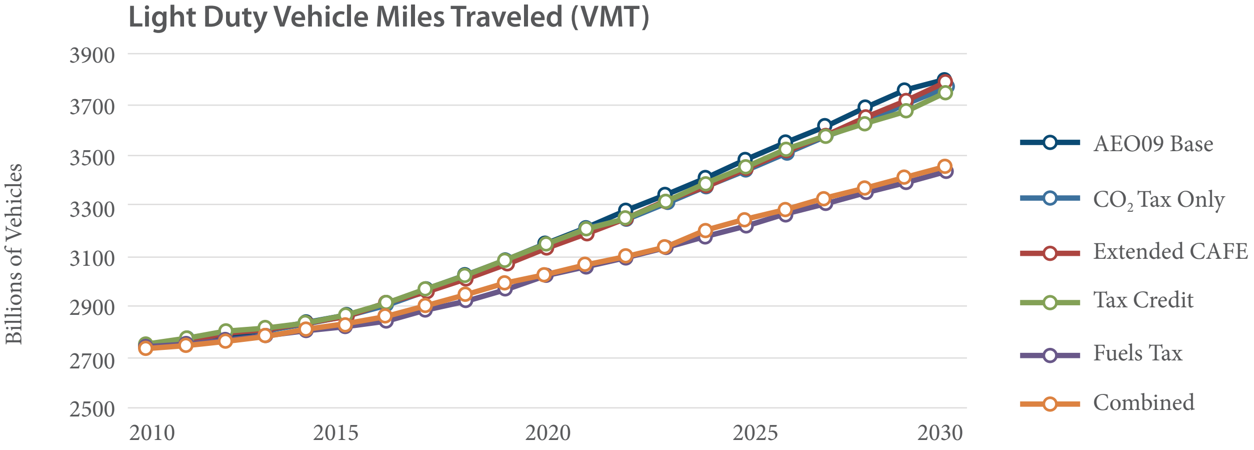

FIGURE 13: Vehicle Miles Traveled (VMT).

The high oil prices dampen VMT growth under all policies. VMT in the high price AEO 2009 base case grows only by 31% by 2030, down 203 billion miles per year in 2030 (5%) relative to the reference price AEO 2009 base case. The reductions in VMT from Scenarios (B-F) with high oil prices are slightly different relative to the reference price case. Economy-wide CO_2 prices and the tax credits reduce VMT in 2030 by 1.1% and 1.5%, respectively relative to the high price AEO 2009 base case.

Again this small percentage disappears with the extended EISA CAFE standards due to the decrease in operating costs, which decreases VMT by only 0.7%. Transportation taxes on top of high oil prices decrease VMT in 2030 by 8.4% relative to VMT in 2030 under the high price AEO 2009 Base Case and 13% relative to the reference case AEO 2009 Base Case.

Oil Imports

Oil imports decrease in all scenarios, including the AEO 2009 base case, relative to imports today; see Fig. 14. In the AEO 2009 the EIA has projected that by 2030 2.8 million fewer barrels per day of net crude oil and petroleum product imports will be needed than in 2008. CO_2 prices, extended CAFE standards, and the tax credits further reduce net crude oil and petroleum product imports, but by less than half a million barrels per day (0-5%). Imports decrease until 2025 under all scenarios, while increasing slightly during 2025-2030 in all scenarios without the higher fuel costs of the transportation taxes. Transportation taxes reduce net crude oil and petroleum product imports by another 1.5 million barrels per day (18%) to reach 6.8 million barrels a day in 2030, as compared to 11.1 million barrels per day in 2008.

These reductions are stronger with the high price case. In the base case, net crude oil and petroleum product imports are 5.7 million barrels a day lower in 2030 than in 2008. Again CO_2 prices, extended CAFE standards, and the tax credits further reduce net crude oil and petroleum product imports

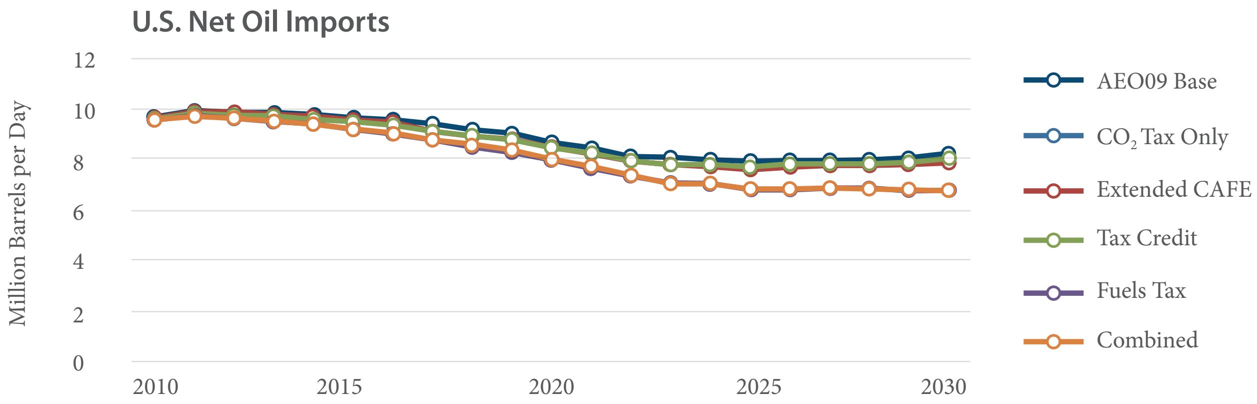

FIGURE 14: Net Oil and Petroleum Product Imports

by less than half a million barrels per day (3-6%) in 2030. Transportation taxes and the combined scenario are more effective at stabilizing oil imports, reducing net crude oil and petroleum product imports by a further 1 million barrels per day (20%) to 4.3 million barrels per day in 2030. Gasoline prices, however, are above $8/gal in these scenarios.

Macroeconomic Impacts

The overall impact on GDP is small for all policies considered. The largest decreases in the growth of GDP, relative to the AEO 2009 base case, are just over 1% (1.1%) and occur with the combined case (Scenario E) in 2022-2023; see Fig. 15. As with LDV sales, this does not mean GDP decreases: GDP grows steadily through 2030 at 2-4% under all scenarios. Real Disposable Personal Income (RDPI) increases relative to the AEO 2009 base case in all scenarios except the transportation tax and combined cases. These scenarios decrease RDPI by less than 1/2%, relative to the AEO base case through about 2023, after which all scenarios increase RDPI relative to the base case.

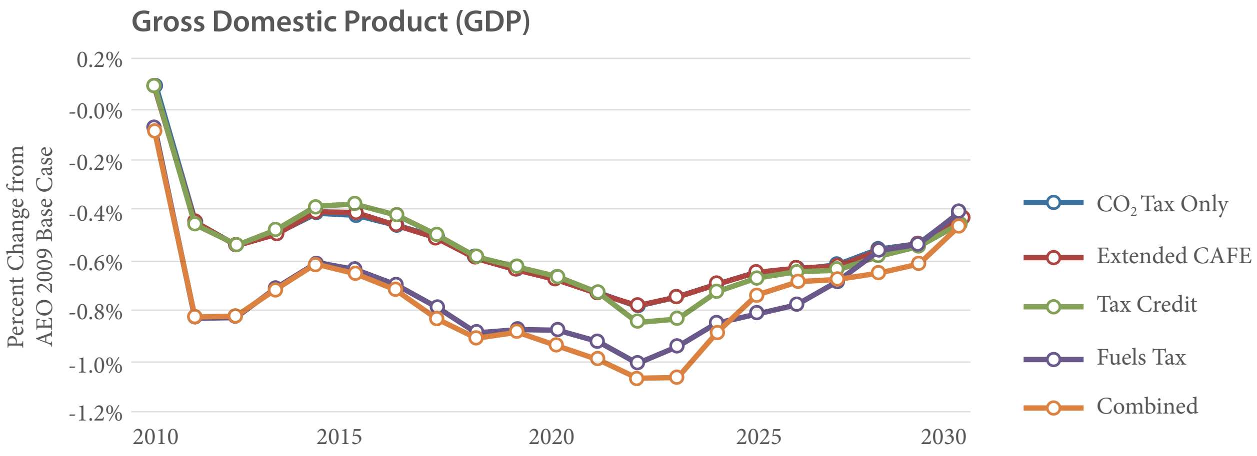

FIGURE 15: Gross Domestic Product (GDP), as a percentage of the AEO 2009 Base Case.

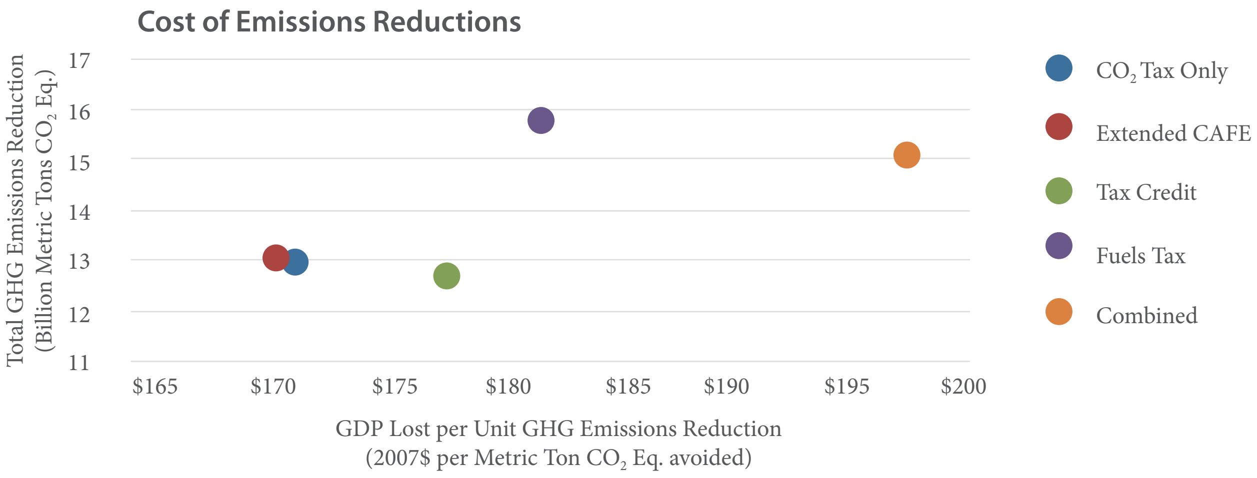

FIGURE 16: Cost of GHG emissions reductions, in terms of GDP lost per unit GHG emissions reduction, against the total GHG emissions reduction.

The recycling of CO_2 tax revenue and increases in vehicle fuel economy determine these relatively small macroeconomic impacts. Recall that only revenue raised through auctions of permits can be recycled. If less auction revenue exists, or if some or all of the auction revenue that does exist was not recycled to consumers as lower income taxes, the macroeconomic impacts of these policies will be worse. Permits allocated to industries for free reduce the costs to those industries and are intended to reduce costs to consumers, though industries would not necessarily pass on the savings.

A reasonable pair of objectives for climate change policy is to obtain as large a reduction in GHG emissions as possible, while paying as low a price *per unit* reduction as possible. In Fig. 16 we plot the cost to the nation per unit GHG emissions reduction against the total GHG emission reduction for each of the policy scenarios we consider. The total GHG emissions reduction is simply the cumulative GHG emissions reduction during 2010-2030, relative to the AEO 2009 Base Case. The cost to the nation is quantified by dividing cumulative GDP lost during 2010-2030, again relative to the AEO 2009 Base Case, by the total GHG emissions reduction.[25] Fig. 16 illustrates that the extended CAFE (Scenario D) and transportation taxes (Scenario C) are efficient strategies for these two objectives. That is, any of the other policy scenarios results in either lower GHG emissions reduction or higher costs per unit reduction, or both. This does not suggest that CAFE should be made strict enough to reduce GHG emissions to match the performance of our higher fuel taxes. Due to diminishing returns on investments in fuel economy performance (NRC, 2002) and rebound effects, the per-unit cost of GHG emissions reductions using performance standards like CAFE should increase.

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[25] Note that the GDP cost per unit emissions reduction need not be constant over policy parameters. In other words we should expect both economies and diseconomies of scale in emissions reduction. Thus, we should not expect to simply strengthen CAFE, extend tax credits, or increase fuel taxes to obtain a more GHG emissions reduction and expect to maintain the same GDP loss per unit emissions reduction.

6. INSIGHTS FOR POLICY

Reducing GHG Emissions and Oil Imports from Transportation

Meeting the policy goals of reducing GHG emissions and oil consumption from the transportation sector is a complex task. Even individual policies that seem radical in the present U.S political context do not meet targets set by the Obama administration or proposed by Congress in ACES. A fundamental insight from this study is that if one wishes to reduce U.S. CO_2 emissions or net petroleum imports from the transportation sector, the costs of driving must be significantly higher than they currently are today. Increasing the cost of driving with higher fuel costs (or other operating fees) will be required to motivate deployment of fuel economy improving technologies in conventional vehicles, accelerate penetration of high-fuel economy vehicles into the existing fleet, and reduce vehicle-miles traveled.

Our analysis suggests that economy-wide CO_2 prices at their currently projected levels will fail to produce the reductions in GHG emissions and oil imports from the U.S. transportation sector that might be needed to meet the Obama Administration's goal. The strengthened EISA 2007 CAFE standards, or continued increases in new vehicle fuel economy past 2020, are also unlikely to prevent growth in U.S. transportation-sector GHG emissions and oil imports, especially in the 2020-2030 period. These policies will, however, prevent even *larger* growth from occurring. Our analysis also suggests that tax credits for alternative vehicle purchase are more expensive than the CO_2 tax per unit of greenhouse gas reduced and largely ineffective at reducing GHG emissions and oil imports.

The Centrality of Oil Prices

Another key insight is that the efficacy of energy and climate policies depends on the underlying world oil prices from now to 2030. If oil prices are $198 per barrel by 2030, reductions in net crude oil and petroleum product imports on the order of 5.7 million barrels per day in 2030 are projected for "business-as-usual" (EIA, 2009e). Adding gasoline taxes starting at $0.50/gal in 2010 and escalating 10% per year (in real terms) through 2030 further reduce net oil imports by an additional 1.1 million barrels per day in 2030, relative to 2008. In that case, CO_2 emissions from the transportation sector may be stabilized near 2010 levels. If, however, the underlying world oil prices are much lower during the next two decades as EIA predicts, then none of the policy scenarios modeled achieve the desired targets for annual U.S. CO_2 emissions.

Putting the Brakes on Vehicle Miles Traveled

A critical underlying challenge for oil security and GHG emissions from the transportation sector is the persistent historical trend of growth in Vehicle-Miles Traveled (VMT) in the United States

(Collantes & Gallagher, 2008). The EIA currently projects that VMT will grow more than 30% between 2010 and 2030 (EIA, 2009e).[26] While most of our policy scenarios affect consumer choice regarding which passenger vehicle to purchase and which fuel to consume, only high transportation fuel prices reduce the growth in the amount of driving that is projected to occur. In the combined policy case, the fuel tax effect on VMT is, however, partially offset by the increases in driving induced by reductions in per-mile operating costs resulting from strengthened CAFE requirements and the tax credits (the "rebound" effect).

The modeling in this study probably does not accurately reflect consumer expectations about future oil or fuel prices. If consumers have the expectation that oil or fuel prices will be relatively high in the future, and especially if they believe that oil or fuel prices will continue to increase indefinitely, they are much more likely to purchase fuel-efficient vehicles and to drive less. In NEMS, consumer response to higher fuel prices is embedded in the alternative fuel vehicle choice and VMT models. The VMT model assumes price elasticities, with respect to operating cost ($/mi), of -0.0351 for the short- run and -0.1859 for the long-run. That is, a 10% increase in the cost of driving results in a 0.3% decrease in vehicle-miles traveled in the short-run and a 1.8% decrease in vehicle-miles traveled in the long-run. This is consistent with existing evidence (Small & van Dender, 2007; Small & van Dender, 2008; Hughes et al., 2008).

Realistically, U.S. consumers have never experienced an escalating tax on transportation fuels, so it is not clear that consumers would respond as weakly to fuel pricing policies in the way that NEMS suggests, especially in the long run. Higher gasoline prices in the United States extending through 2008 have already resulted in increased purchases of high-fuel-economy hybrid vehicles (Gallagher & Muehlegger, 2008; Beresteanu & Li, 2008) and unprecedented reductions in U.S. VMT (FHWA, 2009). U.S. consumers may indeed be more responsive than the NEMS model currently suggests in terms of both their car purchasing and driving behavior.

Macroeconomic Impacts

Recycling the revenue from auctioned CO_2 permits or CO_2 taxes to consumers lessened the macroeconomic impact of the policies scenarios modeled. In this study, the economy-wide CO_2 tax revenue was fully returned to U.S. consumers as reduced income taxes. For simplicity, the income taxes were reduced in a uniform manner. Transportation tax revenue was not recycled, but in reality it too could be returned to consumers. All of the policy scenarios modeled resulted in GDP growth of 2-5% per year, and in all cases, GDP losses relative to business-as-usual were less than 1% each year through 2030. Except for the cases in which we imposed a transportation tax that was not

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[26] As a comparison, VMT in the United States grew roughly 44% from 1988 to 2008, including the sharp decrease in VMT during 2008 (FHWA, 2009).

recycled, Real Disposable Personal Income (RDPI) increased over the base case. By 2025, RDPI increased over the base case even in the cases with transportation taxes.

Of course, tax revenue should be recycled to consumers using a more equitable distribution method than uniform recycling through income tax reductions. If recycled back to consumers as reduced income taxes, the distributional impacts of the policy should be taken into account in the design of the policy (Metcalf, 2007). The revenue could also be used to reduce payroll taxes, to shore up social programs like Medicare or Social Security, or to fund research, development, and demonstration of low-carbon technologies, or to reduce the costs of existing technologies. A comparison of the various alternative uses for the tax revenue was not conducted in this study; the key lesson is that it is both possible and important to use CO_2 tax revenue "to help the transition to a clean energy economy" (OMB, 2009, pg. 21).

Stabilizing CO_2 Emissions

CO_2 prices, combined with transportation sector specific policies can reduce GHG emissions below 2005 levels, a significant reduction from business-as-usual projections for 2030. However, these policy options alone cannot achieve existing targets of 14% or 15-17% below 2005 levels. The most effective policy for reducing CO_2 emissions and oil imports from transportation is to increase the costs of driving with strong fuel taxes. Our analysis of higher fuel taxes included the existing EISA CAFE standards, which mandate a 35 mpg vehicle fleet by 2020. Our results suggest that complementing performance standards like CAFE with some form of fuel taxation is important to mitigate the GHG emissions coming from VMT growth while improving the fuel economy of the vehicle fleet. Indeed, one can think of CAFE or GHG performance standards as providing an important backstop to fuels taxation in the event that the underlying oil price falls too low to render the tax effective, or in the presence of market failures that prohibit efficient delivery of fuel economy to consumers. Without addressing VMT growth, due both to population and income growth over time, CO_2 emissions from transportation cannot be stabilized.

Modeling

Finally, we are acutely aware that the NEMS model has limitations and that these affect our results. Areas where we feel that NEMS could use more refinement include the modeling of feedbacks between transportation demand and oil prices, modeling more rapid technological change, modeling the impact of policies that explicitly required a lifecycle analysis of biofuels or regional electricity grids, integrating the influence of market-based incentives with technology adoption in conventional vehicles, and modeling the impact of volatility in energy markets on energy producer and consumer behavior. We also feel that it is important to juxtapose the potential costs of climate change and energy insecurity against the costs caused by the policies themselves.

7. CONCLUSIONS

This study has examined a number of important transportation sector specific policy options to reduce GHG emissions and the United States' dependence on imported oil under economy-wide CO_2 prices. Our analysis has applied the National Energy Modeling System (NEMS), an energy-economic equilibrium model of energy markets in the United States maintained by the Energy Information Administration (EIA). Though economy-wide CO_2 prices will soon become a reality, they will likely be too low to significantly induce emissions reductions from the transportation sector. Transportation sector-specific policies such as fuel taxes, mileage charges, fuel economy or GHG emissions intensity standards, and/or purchasing incentives will need to be put in place if emissions reductions from this sector are desired.

Economy-wide CO_2 prices of \$30-60/t CO_2 are too weak on their own to motivate significant reductions in CO_2 emissions from transportation. The key to obtaining significant reductions in transportation-related GHG emissions is to increase the cost of driving. The economy-wide CO_2 prices applied increase the cost of driving only marginally with respect to the business-as-usual case. Direct transportation (fuel) taxes generate the greatest reductions in CO_2 emission from transportation, achieving CO_2 emissions at 86% of 2005 levels by about 2025. The gasoline prices that achieve these reductions are in the range of \$7-9/gal, however, which is considerably higher than the American public has been historically willing to tolerate. Strong income tax credits for the purchase of new diesel, hybrid, and plug-in hybrid vehicles are very expensive and essentially ineffective at reducing GHG emissions from transportation.

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APPENDIX A: CORPORATE AVERAGE FUEL ECONOMY STANDARDS

The Corporate Average Fuel Economy (CAFE) standards regulate the average fuel economy of two key fleets of new vehicles: passenger cars and light trucks. We refer the reader to other comprehensive reviews of CAFE (NHTSA, 2009b). In this Appendix we present aspects of CAFE relevant to understanding our analysis. First we define the attribute-based CAFE standards currently in place, the standards adopted by EIA for use in NEMS (also used in all of our scenarios), and the extended standards adopted for Scenario D. Following this, we provide a simple example to illustrate how tax credits can interact with binding CAFE standards to decrease conventional vehicle fuel economy.

Attribute-Based CAFE Standards

Historically, CAFE has been defined as follows. Suppose an auto firm offers J vehicles with fuel economies of $\{f_1, \dots, f_J\}$ and annual sales of $\{s_1, \dots, s_J\}$. To avoid penalties this firm's sales-weighted harmonic average of fuel economies,

$$E = \frac{\sum_{j=1}^{J} s_j}{\sum_{j=1}^{J} s_j / f_j},$$

must meet or exceed a standard fuel economy level E^S. That is, the firm pays no fine if $E \geq E^S$, but is fined if $E < E^S$. Regulatory penalties c^R can be written compactly as

$$c^R = r\left(\sum_{j=1}^{J} s_j\right)\max\{0, E^S - E\}$$

for some penalty rate r with units dollars per mile per gallon under the standard level, per vehicle. Historically, $r = \$55$. This calculation is done for both passenger car and light-duty truck fleets sold by each manufacturer.

In recent revisions of CAFE, this standard was argued as discriminatory to U.S. automakers that produced a higher share of larger, more fuel-intensive vehicles. To account for this, EISA (Sissine, 2007) has put in place an attribute-based standard stipulating that any vehicle with footprint should F achieve a fuel economy $f^S(F)$ satisfying

$$\frac{1}{f^S(F)} = \frac{1}{a} + \left(\frac{1}{b} - \frac{1}{a}\right)\left(\frac{e^{(F-c)/d}}{1+e^{(F-c)/d}}\right) \tag{A.1}$$

where a, b, c, d are parameters chosen to obtain increasingly stringent standards over 2011-2015 (NHTSA, 2009b). By using this function larger vehicles (having higher footprints) are not required to achieve the same fuel economy level as smaller vehicles.

Suppose an auto firm again offers J vehicles with footprints $\{F_1, \ldots, F_J\}$, achieved fuel economies of $\{f_1, \ldots, f_J\}$ and annual sales of $\{s_1, \ldots, s_J\}$. To avoid penalties this firm's sales-weighted harmonic average of fuel economies, E (as above), must meet or exceed the *sales-weighted harmonic average of standard fuel economies*

$$E^S = \frac{\sum_{j=1}^{J} s_j}{\sum_{j=1}^{J} s_j / f^S\left(F_j\right)}.$$

The definition of regulatory penalties c^R is the same.

The values of the parameters a, b, c, d chosen by NHTSA are given in Table A.1.

Passenger Cars

	2011	2012	2013	2014	2015
a	38.2	40	40.8	41.2	41.7
b	25.9	27.4	28.7	29.9	31.2
c	45.9	45.8	45.7	45.6	45.5
d	1.6	1.5	1.5	1.4	1.4

Light Trucks

	2011	2012	2013	2014	2015
a	30.9	32.7	34.1	34.1	34.3
b	21.5	22.8	23.8	24.3	24.8
c	51.9	52	52	52.1	52.1
d	3.8	3.8	3.8	3.9	3.9

TABLE A.1: Parameters for footprint-based fuel economy levels in Eqn. (A.1) proposed by NHTSA for footprint-based CAFE standards in 2011-2015 (NHTSA, 2006; NHTSA, 2008b).

Although NHTSA has only specified the parameters a, b, c, d through 2015, EIA has implemented the same parameters in NEMS through 2020. These parameters are given in Table A.2 below.

Passenger Cars

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
a	38.2	38.2	38.2	38.2	40.0	40.8	41.2	41.7	42.2	42.7	43.2	43.7	44.2
b	25.9	25.9	25.9	25.9	27.4	28.7	29.9	31.2	31.4	31.6	31.8	32.0	32.2
c	45.9	45.9	45.9	45.9	45.8	45.7	45.6	45.5	45.4	45.3	45.2	45.1	45.0
d	1.6	1.6	1.6	1.6	1.5	1.5	1.4	1.4	1.4	1.4	1.4	1.4	1.4

Light Trucks

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
a	28.6	30.0	30.0	30.9	32.7	34.1	34.1	34.3	34.8	35.3	35.8	36.3	36.8
b	20.0	20.9	21.2	21.5	22.8	23.8	24.3	24.8	25.3	25.8	26.3	26.8	27.3
c	49.3	48.0	48.5	51.9	52.0	52.0	52.1	52.1	52.1	52.1	52.1	52.1	52.1
d	5.6	5.8	5.5	3.8	3.8	3.8	3.9	3.9	4.0	4.0	4.1	4.1	4.2

TABLE A.2: Parameters for footprint-based fuel economy levels in Eqn. (A.1) used by EIA in NEMS for footprint-based CAFE standards during 2008-2020 (EIA, 2009e).

We adopt the values of a,b,c,d used in NEMS for the period 2008-2020. Our extended CAFE scenario, Scenario D, requires defining the parameters a,b,c,d beyond 2020, and through 2030. Our values of a,b,c,d for this period are listed in Table A.3.

Passenger Cars

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
a	45.3	46.4	47.5	48.6	49.7	50.8	51.9	53	54.1	55.2
b	33.3	34.4	35.5	36.6	37.7	38.8	39.9	41	42.1	43.2
c	45	45	45	45	45	45	45	45	45	45
d	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4

Light Trucks

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
a	37.7	38.5	39.4	40.2	41.1	41.9	42.8	43.6	44.5	45.3
b	28.2	29	29.9	30.7	31.6	32.4	33.3	34.1	35	35.8
c	52.1	52.1	52.1	52.1	52.1	52.1	52.1	52.1	52.1	52.1
d	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2

TABLE A.3: Parameters for footprint-based fuel economy levels in Eqn. (A.1) used in Scenario D for footprint-based CAFE standards during 2020-2030.

Interactions Between Tax Credits and CAFE

We now provide a simple example to illustrate how tax credits on alternative motor vehicles could decrease fuel economy of conventional vehicles. Suppose an automaker offers two vehicles: a conventional vehicle, with fuel economy f_c, and an alternative motor vehicle with fuel economy f_a. The sales in a particular year of these two vehicles are denoted s_c and s_a, respectively. For a binding CAFE standard with standard fuel economy level f^S, we have

$$f^S = \frac{s_c + s_a}{s_c / f_c + s_a / f_a} = \frac{1}{\tilde{s}_c / f_c + \tilde{s}_a / f_a}$$

where $\tilde{s}_c = s_c / (s_c + s_a)$ and $\tilde{s}_a = s_a / (s_c + s_a)$ are the sales *shares* of the two vehicles.

Suppose the government subsidizes the purchase of the alternative motor vehicle, with the effect of increasing the alternative's sales share to $\tilde{s}'_a > \tilde{s}_a$. We define $\delta s = \tilde{s}'_a - \tilde{s}_a > 0$, and note that because the sales shares must sum to one, we also have $\tilde{s}'_c = \tilde{s}_c - \delta s$. Assuming that the fuel economy of the alternative motor vehicle is not changed, and that the CAFE standard remains binding after the subsidy, the equation

$$\frac{1}{\tilde{s}_c / f_c + \tilde{s}_a / f_a} = f^S = \frac{1}{\tilde{s}'_c / f'_c + \tilde{s}'_a / f_a} \qquad \text{(A.2)}$$

holds for some f_c'. We claim that $f_c' < f_c$. To prove this, note that Eqn. (A.2) is equivalent to

$$\frac{f_c}{f_c'} = \frac{\tilde{s}_c - \delta s(f_c / f_a)}{\tilde{s}_c - \delta s}.$$

Since $f_c < f_a$, $\delta s(f_c / f_a) < \delta s$, $\tilde{s}_c - \delta s(f_c / f_a) > \tilde{s}_c - \delta s$ and thus $f_c' < f_c$. Note that this result implies that even if the firm chooses f_c' *optimally*, e.g. to maximize profit subject to satisfying the CAFE standards, $f_c' < f_c$ holds.

The analysis above may be too simple, for at least several reasons.

First, we have not used the attribute-based standard as will be in place under EISA. Extending this analysis for an attribute-based CAFÉ suggests that $f_c' < f_c$ will still hold in most cases. Certainly $f_c' < f_c$ holds under an attribute-based standard when $f_a^S = f_c^S$. While there may be some situations in which $f_c' < f_c$ under attribute-based standards, these situations seem unlikely.[27]

Second, we have assumed firms offer only two vehicles: a conventional and an alternative motor vehicle. Contemporary automotive firms offer many vehicles, and there is no reason they would not adjust the fuel economy of all vehicles—including the alternative—given the government's decision to subsidize vehicles. Extending this analysis to automotive firms that offer many vehicles will require a detailed numerical analysis.

Third, this analysis does not take into account organizational structures that preclude automakers from making choices simple theoretical economic analyses would suggest. For example, automakers typically plan vehicles three (or more) years in advance. Announcing a tax credit for a niche market alternative motor vehicle may not be significant enough to justify re-engineering conventional vehicles to have lower fuel economies. This may be reflective of quantitative decision-making (i.e. optimal for an appropriate economic model), or it may be a heuristic employed by management.

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[27] The authors can be contacted for their derivations in this case.

APPENDIX B: PERFORMANCE-BASED TAX CREDIT

We formally define the performance-based credit as follows: Let f^C be the average fuel economy in miles per gallon for the conventional vehicle in a particular vehicle size class. Let f_a be the fuel economy in miles per gallon for the alternative motor vehicle a in that size class. Then the value of the performance-based credit is

$$r\left(\frac{1}{f^C}-\frac{1}{f_a}\right)$$

where r, the "rebate" level, is in (2007) dollars per gallon per mile saved. Each of the alternative technologies considered decreases fuel consumption, and thus the credits are always positive.

In this study the value of r is set to be \$450,000 per gallon per mile improvement relative to the conventional vehicle. This is consistent with the ARRA credit given to PHEV-40s in Scenario (A), the AEO 2009 Base Case: PHEV-40s receive a credit roughly equal to \$500,000 per gallon per mile improvement relative to the conventional vehicle (EIA, 2009e). This number is so high because changes to fuel consumption are very small, on the order of thousandths, in the conventional gal/mi units.

This formula can be translated from "gallons per mile saved" units to "gallons per vehicle lifetime saved" by assuming a lifetime miles driven m, with no rebound effect. We can then write

$$r\left(\frac{1}{f^C}-\frac{1}{f_a}\right)=\tilde{r}\left(\frac{m}{f^C}-\frac{m}{f_a}\right) \quad \text{where} \quad \tilde{r}=\frac{r}{m}.$$

$\tilde{r}$ is in units of dollars per gallon per vehicle lifetime saved. The values reported in the text are

$\tilde{r}$ = \$450,000/150,000=\$3 per gallon saved over a vehicle lifetime

$\tilde{r}$ = \$450,000/90,000=\$5 per gallon saved over a vehicle lifetime

with annual miles driven (m) of 150,000 and 90,000 miles, respectively, and no rebound effect.

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