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Analysis of Policies to Reduce Oil Consumption and Greenhouse-Gas Emissions from the U.S. Transportation Sector

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The views expressed within this paper are the authors' and do not necessarily reflect those of Harvard University. This paper is available at www.belfercenter.org/energy.

Energy Technology Innovation Policy

The overarching objective of the Energy Technology Innovation Policy (ETIP) research group is to determine and then seek to promote adoption of effective strategies for developing and deploying cleaner and more efficient energy technologies, primarily in three of the biggest energy-consuming nations in the world: the United States, China, and India. These three countries have enormous influence on local, regional, and global environmental conditions through their energy production and consumption.

ETIP researchers seek to identify and promote strategies that these countries can pursue, separately and collaboratively, for accelerating the development and deployment of advanced energy options that can reduce conventional air pollution, minimize future greenhouse-gas emissions, reduce dependence on oil, facilitate poverty alleviation, and promote economic development. ETIP's focus on three crucial countries rather than only one not only multiplies directly our leverage on the world scale and facilitates the pursuit of cooperative efforts, but also allows for the development of new insights from comparisons and contrasts among conditions and strategies in the three cases.

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Abstract

For the first time in decades, Corporate Average Fuel Economy (CAFE) standards for passenger cars were strengthened in the United States in the Energy Independence and Security Act of 2007 (EISA). As the nation considers how else to address remaining oil security and climate change concerns, the transportation sector deserves considerable attention as the primary consumer of imported oil and the producer of a third of total U.S. greenhouse-gas (GHG) emissions. This study examines different policy scenarios for reducing GHG emissions and oil consumption in the U.S. transportation sector. Using a variant of the National Energy Modeling System (NEMS), NEMS-ETIP, a number of policy scenarios were modeled using both the U.S. Energy Information Administration's "reference" case and "high-oil price" reference case. Quantitative estimates are provided of the impact of increases in fuel-economy standards similar to those contained in the EISA in combination with the likely impacts of two different economy-wide climate policies and several different kinds of taxes on transportation fuels.   Even the most stringent policy scenario modeled here failed to prevent an increase in oil consumption and greenhouse-gas emissions in the transportation sector mainly due to the persistent trend of rising vehicle-miles traveled, but some policy scenarios reduced oil consumption and greenhouse-gas emissions significantly below the business-as-usual projection. In general, individual policies prove less effective than combinations or packages of policies. The macro-economic impact of policies is dependent on how carbon permit or tax revenues are used.

Research Goals and Questions

The current debate on climate change in policymaking spheres has mainly focused on economy-wide carbon mitigation policies. Recent Congressional activity focused on transportation-specific policies that were expected by many to reduce oil imports and transport-sector greenhouse-gas (GHG) emissions. What the further impact of economy-wide policies would be on the transportation sector has not been carefully examined, especially if economy-wide policies are implemented together with transportation-specific policies, including those contained in EISA.

We first test three hypotheses: that currently proposed economy-wide carbon policies will (1) have little effect on the GHG emissions from transportation, (2) have a marginal effect on oil imports, and, (3) be unlikely to significantly stimulate advanced vehicle and fuel technological innovation. Then, we test the hypothesis that individual policy measures implemented on their own would produce insufficient results in terms of reducing oil consumption and GHG emissions below current levels. Finally, we investigate whether certain combinations of individual policies result in oil import and transportation-based GHG-emission reductions.

Our overarching research goal is to identify sets of effective and economically-efficient policies that are likely to succeed in achieving significant reductions in oil imports and GHG emissions below current levels in the transportation sector. We also seek to glean insights from the modeling process itself. Like every modeling exercise, these results ought to be interpreted with a good understanding of the model's limitations and assumptions.

Background

Oil security and global climate change are two of the biggest transportation policy challenges. While remarkable advances have been made in the United States in reducing emissions of tailpipe pollutants known to cause adverse public health effects, much less progress has been made on reducing overall oil consumption and emissions of greenhouse gases (GHGs). U.S. highway fuel consumption, almost all petroleum, increased 62 percent between 1973 and 2005, from 110.5 to 179 billion gallons (Davis and Diegel, 2007, 2-3). Overall, the U.S. transportation sector accounts for 33 percent of the nation's CO_2 emissions, half of which comes from passenger vehicles. U.S. oil imports increased from 6.3 million barrels a day in 1973 to 13.7 million barrels a day in 2006 (EIA, 2008). Net imports as a share of total U.S. consumption increased from 36% in 1975 to 60% in 2006 (Davis and Diegel 2007).

Methodology

To estimate the energy, environmental, and economic impacts of different policies on the transportation sector in the United States, we used the National Energy Modeling System (NEMS) to model different policy scenarios. A number of important assumptions are embedded in NEMS, and these are described next and summarized in Table 1.

NEMS-ETIP modeling framework

The National Energy Modeling System (NEMS) was developed by the Energy Information Administration (EIA) for use in making energy projections and analyzing the potential impacts of energy policies. The model provides the foundation of the Annual Energy Outlook published each year by EIA. EIA regularly uses the model to develop service reports responding to Congressional requests, many of which have focused on climate change or policies aimed at reducing U.S. oil imports.[1] NEMS has also been used by other offices within the Department of Energy (DOE) as well as numerous organizations outside of government. This model has established a high degree of credibility with Congress when it comes to assessing energy policy. For this reason, we chose to use it for this analysis.

NEMS is an integrated energy model with representation of U.S. energy supply, demand, and conversion all within an economic framework. We refer to our application of the NEMS model as NEMS-ETIP, and in doing so, take responsibility for all inputs and any changes made to the model assumptions required to assess the policies addressed in this report.[2]

Projections for light duty vehicles are performed within the Transportation Demand module of the model. This module projects the adoption of energy-efficiency technologies for vehicles, consumer choice among various vehicle types (such as conventional gasoline, diesel, E85 flex-fuel vehicles, and hybrids), vehicle-miles traveled, and resulting fuel consumption. Vehicle-stock accounting tracks retirements of existing vehicles by age to project the future stock of vehicles and their average fuel economy based on the projected sales. The adoption of technologies is based on relatively short payback requirements, and the selection among vehicles types takes into account vehicle attributes such as initial vehicle price, fuel economy, and refueling infrastructure availability.

The domestic conversion of crude oil and other products into refined petroleum-based products, such as the various types of gasoline and diesel, is performed in

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[1] EIA, *Energy Market and Economic Impacts of S. 280, the Climate Stewardship and Innovation Act of 2007*, July 2007 (SR/OIAF/2007-4); EIA, *Energy Market and Economic Impacts of S. 1766, the Low Carbon Economy Act of 2007*, January 2008 (SR/OIAF/2007-6); EIA, *Energy and Economic Impacts of Implementing Both a 25-Percent Renewable Portfolio Standard and a 25-Percent Renewable Fuel Standard by 2025*, August 2007 (SR/OIAF/2007-5).
[2] EIA requests that all users of NEMS clearly indicate that any use of NEMS and its inputs are the responsibility of the user and not EIA.

the Petroleum Market module. Other domestically produced liquid fuels such as fuels from natural gas or coal and ethanol, are also considered in this module. Ethanol is used as a gasoline additive and for blending, depending on its relative cost and demand. The model considers imported ethanol from Brazil, for which NEMS assumes a lower cost than domestic ethanol for relatively small production volumes but a relatively rapidly increasing marginal cost.

Table 1. Key Modeling Assumptions

Assumptions used in modeling can strongly influence the outputs. The assumptions we use are explained in detail in the methodology section.   Here is an abbreviated outline of the key assumptions for quick reference.

- The **time period is 2010-2030.**
- AEO2007 version of National Energy Modeling System (**NEMS**) used as updated for Congressional service requests.
- **Covered gases** include energy-related CO_2, nitrous oxide (excluding agriculture and mobile combustion emissions), and hydrofluorocarbons (HFC), perfluorocarbons (PFC), and sulfur hexafluoride (SF_6).
- All policies are in terms of **carbon dioxide**, not carbon.
- **Some of the policies recycle revenue to consumers.**   The economy-wide carbon tax revenue is fully recycled to consumers.   For the gasoline and diesel taxes, the 5% escalating carbon tax on transportation fuels is recycled to consumers, but the 10% escalating tax on gasoline and diesel transportation fuels is not.
- **Motor fuel tax revenue** is not recycled to consumers.
- **Imported oil prices** are predicted to fall from $59/barrel in 2007 to $41/barrel in 2014, to then rise to $51/barrel by 2030 in the reference case.
- No "**offsets**" are allowed.
- NEMS was modified to allow **greater penetration of high-efficiency vehicle technologies** (including hybrids and diesels) than the EIA reference case for passenger vehicles (but not freight trucks).
- **Taxes** on transportation fuels are assessed at the exit gates of refineries.
- The **carbon content of transportation fuels**, for the purposes of the carbon fuel tax, 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 $13/tonCO$_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 is 5 percent in the short run and 20 percent in the long-run.
- **Biofuels blending** is determined by the relative cost to petroleum and oxygenate requirements.
- The current **ethanol subsidy** of 51 cents per gallon and the 54 cent per gallon **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.
- In terms of **vehicle choice**, multiple vehicle attributes are considered, including price, cost of driving, vehicle range, and performance.
- There are 13 **vehicle technology options**, and the availability of model choices for hybrids and diesels increases over time.
- Vehicle fuel saving technologies are adopted when they have a 3-year payback using a 15 percent **discount rate.**

The Macroeconomic Activity module within NEMS comprises five submodules. It solves iteratively with the energy supply, demand and conversion modules of NEMS to produce an energy- economy equilibrium. Changes in energy consumption and prices are passed from the energy modules to the macroeconomic module which projects macroeconomic impacts such as GDP, personal income, industrial output and vehicle sales which are then fed back to the energy modules.

The base case

The base case for this study was adapted from the EIA's 2007 Annual Energy Outlook (AEO 2007) and takes into account updates to NEMS that were made by EIA for their renewable fuels study.[3] The latter included updated biomass feedstock curves and a revised representation of ethanol supplies. The base case assumes continuation of existing energy and environmental laws and regulations, however, it does not specifically include the recent Energy Independence and Security Act (EISA) passed in December 2007, although we estimate policy changes similar to those contained in the Act. For an explanation of EISA, see Table 2.

Oil prices and other fuel price projections in our base case are essentially the same as in the AEO2007 Reference Case. The world oil price -- defined by EIA as the average cost to U.S. refiners of low-sulfur imported oil -- is projected to fall to a low of $44 per barrel in 2013[4] before rising again over the longer term to $52 by 2030.   Prices of average motor gasoline were projected at $2.63 per gallon in 2007, decreasing to $1.97 per gallon in 2014, and then increasing to $2.23 per gallon in 2030. EIA has subsequently revised upward its forecast of global oil prices and gasoline prices. In this revision, published in March, 2008, the price of gasoline is forecasted at $2.77 per gallon in 2007, decreasing to $2.19 per gallon in 2019, to then increase to $2.45 per gallon in 2030. These increases in gasoline prices would slightly decrease the baseline estimate of transportation fuel consumption and emissions.

Table 2. Energy Independence and Security Act of 2007 (EISA)

The Energy Independence and Security Act (EISA) of 2007 was signed into Law (Pub. Law 110-140) by President Bush on December 19, 2007.   This law requires that in 2008, fuel producers must supply at least 9 billion gallons of renewable fuels, and follow a specific schedule increasing to 36 billion gallons by 2022. By 2022, 21 billion gallons must be "advanced biofuels" out of which 16 billion should be cellulosic biofuel. The law also created new corporate average fuel economy standards for new passenger vehicles (combined fleet of automobiles and light-duty trucks, combined) of 35 miles per gallon by 2020.   Beginning in 2011, the National Highway Traffic Safety Administration (NHTSA) is directed to annually strengthen CAFE standards to a total of 40 percent by 2020.   Also, the CAFE standards will be assessed on an "attribute" basis and expressed in the form of a mathematical function. Manufacturers can earn credits for exceeding the standards for one vehicle class, and these credits can be applied to a limited extent to boost the CAFE of another vehicle class. Additionally, CAFE credits may be traded among manufacturers.   The extra fuel-economy credit for flex-fuel vehicles is gradually phased out starting in model year 2014 and eliminated in 2020.   The new law also directs NHTSA to set standards for medium and heavy-duty trucks as well as work trucks, but does not provide the specific levels. Source: Sissine 2007.

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[3] EIA, *Energy and Economic Impacts of Implementing Both a 25-Percent Renewable Portfolio Standard and a 25-Percent Renewable Fuel Standard by 2025*, August 2007 (SR/OIAF/2007-5).
[4] All prices are in 2005 dollars unless otherwise specified.

In addition to their reference case forecast of oil prices, EIA also makes projections for high and low oil prices, each of which makes different assumption regarding the behavior of the Organization of Petroleum Exporting Countries (OPEC). The reference case assumes that OPEC continues to be the primary source of oil, increasing their production through 2030 at a rate similar to that of the last 15 years. EIA's high oil price scenario accounts for a hypothetical scenario where aggressive OPEC behavior influence oil markets. The high oil price scenario in AEO 2007 projects a world oil price of $59 per barrel in 2007, continuously increasing through 2030 to $93 per barrel in real terms. The average price of gasoline in this scenario starts at $2.66 in 2007 and ramps up to $3.10 in 2030.   Of course, 2008 crude oil prices are much higher than either EIA's reference or "high" oil-price cases.   The NEMS-ETIP assumptions about the oil prices may be too sanguine, in which case the higher underlying oil prices would likely result in all of the other policy scenarios modeled more effective.   Oil prices are unaffected by the introduction of policies in the NEMS-ETIP model.

In addition to incorporating the updated biomass and ethanol assumptions mentioned above, the NEMS-ETIP base case diverges from the EIA assumptions regarding consumer preferences for hybrid and diesel vehicles. In the AEO 2007, EIA assumes that these vehicles are viewed by consumers as less desirable than conventional gasoline vehicles even if all attributes were otherwise equal. While this may represent the current state for the newly introduced hybrids and the existing diesels, we felt that over time any uncertainty over the new hybrid technology and the development of improved diesels would eliminate a bias against these vehicles. Therefore we gradually reduced the bias during the first five years of the projection period until it was eliminated.[5]   The net result is a projection of greater sales of these vehicle types compared to EIA's AEO 2007 Reference Case.

The EIA AEO 2007 reference case, which is the foundation for our cases, assumes that advanced vehicle and biofuel technologies remain through 2030 too expensive to become competitive and gain market acceptance through the entire time-period. In particular, we feel that the assumptions used to project the market penetration of cellulosic ethanol and plug-in hybrid electric vehicles (PHEV) may be too pessimistic.

Cellulosic ethanol gains very limited market share in our simulations. One reason for this result is that the base case does not incorporate the volumetric requirements adopted with EISA. Market-driven adoption of cellulosic ethanol—and other advanced biofuels—will certainly depend on technological progress over time as current costs are very high. Future costs of cellulosic ethanol are difficult to forecast at this point. However, some of the assumptions used by NEMS-ETIP may be questionable. The yield per ton of cellulosic biomass is assumed to increase to 85 gallons and then remain at the same level through 2030—an unrealistic assumption. Cellulosic ethanol costs are assumed to decline

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[5] If the constant coefficient was forced to be zero in the initial estimation of the choice model, that would affect the rest of the coefficients.

primarily through learning-by-doing as capacity is added. In the absence of a mandate, costs decline only by 16 percent by 2030, which is insufficient to lead to market adoption.

Regarding plug-in vehicles, in our reference case, the price differential of new PHEV relative to conventional gasoline cars remains about the same—just over $5,400 for compact cars—throughout the entire forecast period. In addition:

- PHEV's use electricity for only 10 percent of their VMT, and that this percentage remains invariable over time;
- PHEV's are introduced only in three passenger vehicle categories, namely compact, midsize, and large cars—no plug-in hybrid light-duty trucks are introduced;
- The fuel economy of PHEV's remains about constant throughout the estimation period, at circa 65 miles per gallon; and,
- PHEV's have a maximum of 50 percent market penetration potential, based on the fraction of homes that have garages for battery recharging.

These assumptions, in conjunction with the other NEMS-ETIP assumptions regarding low oil and gasoline prices, cause the NEMS-ETIP forecast of PHEV market penetration to be only marginal through 2030. Only using the high oil price scenario does NEMS-ETIP start to forecast the initial introduction of PHEV's into the market (about 1,000 in 2020 with sales remaining at that level each year thereafter through 2030). In future analyses, we might consider varying these assumptions to reflect greater PHEV technology improvement and availability.

Policy Modeling

As discussed above, this study aims to investigate the effects of individual policies as well as the effects of packages of different individual policies, with the ultimate goal of identifying cost-effective policy approaches to reduce transport-sector GHG emissions and U.S. oil imports overall. As explained in more detail below, different individual policies are considered: economy-wide carbon prices, fuel-economy performance standards, and several kinds of transportation-fuels taxes.

Modeling economy-wide carbon prices

The first policy considered in this study is the establishment of an economy-wide carbon price in order to estimate the impact of such a price on the transportation sector. Because it is simpler in NEMS-ETIP to impose a carbon tax, this specific instrument was used, but cap-and-trade mechanisms that resulted in the same prices modeled here for carbon dioxide emission permits would essentially have the same impact so long as the permits were fully auctioned. These taxes are represented in NEMS-ETIP as fuel price increases based on the carbon content of each fuel (i.e., coal by type, petroleum product,

and natural gas). Electricity prices are impacted as the increased cost of fuels increases the cost of operating existing power plants and affects decisions about the construction of new plants. Energy consumers react to higher prices by reducing their demand for energy services, by increasing their demand for energy efficiency, and/or by switching fuels.

In all the scenarios in this study, carbon taxes are assumed to be collected by the government and then fully recycled back to consumers as reduced income taxes[6]. In reality, there is no guarantee that such taxes would be fully recycled to consumers since the tax revenue would go into the U.S. Treasury unless otherwise specified by the Congress. Returning the tax revenue to consumers reduces the macroeconomic impact of the carbon policies because personal income increases.

Modeling of fuel economy performance-standard policies

We also considered two Corporate Average Fuel Economy (CAFE) standards for light duty vehicles. The base case represents CAFE requirements for cars and light duty trucks, including the March 2006 rule for light trucks, but excluding the amendments to the CAFE program in EISA. In our scenarios starting in 2010 we annually increased light-duty vehicle (cars and light trucks) fuel economy by 2 and 4 percent per year, as described in Table 3 in this report. We believe the CAFE standards that are stipulated in EISA are approximately equivalent to our 4 percent scenario, but the reality will depend on sales mix of personal cars and light-duty trucks each year. The more stringent CAFE requirement leads to the adoption of technologies to stimulate greater efficiency for all vehicle types as well as broadening the shares of hybrid and diesel vehicles. Overall, average vehicle prices rise which somewhat depresses vehicle sales. The shift among size classes tends to be relatively modest as prices increase for all vehicle size classes. Higher vehicle efficiency reduces the cost of driving and stimulates an increase in miles traveled. There has been some debate in the literature over the responsiveness of driving to changes in costs with some evidence that this effect is smaller than it was a few decades ago. The baseline here uses a value on the high side of the range.[7]

Modeling of transportation-fuel taxes

Because economy-wide carbon taxes do not cause a substantial increase in gasoline and diesel fuel prices, specific transportation-fuel taxes are also considered.[8] Two basic forms of fuel taxes are modeled. One is a volumetric tax on petroleum fuels which increases the price that consumers pay for these fuels at the pump. In some scenarios this tax is applied only to gasoline, and in others it is applied to all highway fuels. In this latter

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[6] No effort was made in this modeling exercise to re-distribute the tax revenue in a distribution-neutral fashion among consumers, but of course, it would be important to design such a scheme so as to prevent the carbon taxation from being regressive for low-income consumers.

[7] In our base case, the elasticity of miles traveled to driving cost is roughly -0.2 which means that a 10 percent decrease in driving costs would result in a 2 percent increase in miles traveled.

[8] For example, a carbon tax of $30 per metric ton CO_2 is equivalent to a tax of roughly 26 cents on the carbon content of one gallon of gasoline.

case, E85 is taxed based only on its petroleum content per gallon. When the tax is assumed to escalate over time, the tax differential between E85 and gasoline can become significant and lead to much more E85 use than in the base case. The revenue collected from the highway taxes is assumed to go to the government without being returned to consumers.

The other form of transportation fuel tax considered is a tax based on the carbon content of the fuel.[9] Here the tax is imposed on wholesalers and blenders, which provides an incentive to reduce the carbon content of highway fuels in addition to consumers having an incentive to use less due to higher prices. We constructed this tax as based on the carbon content of a gallon of final fuel, not on its lifecycle carbon emissions. There are three reasons for this choice: (1) It is difficult using NEMS-ETIP to model the carbon content of transportation fuels on a full lifecycle basis ("well-to-wheel" or "soil-to-wheel") including all GHG emissions; (2) The transportation fuels taxes were modeled in addition to an economy-wide carbon tax, so accounting for emissions during the extraction, transport, and conversion of fuels (well-to-tank) would result in double taxing of those emissions in the model[10]; (3) Assigning fuels a representative lifecycle carbon content would mask the inherent variability in this content across fuel production pathways. The exception was coal-to-liquids, which was taxed based on the carbon content of the coal used in producing the liquid fuel in the industrial sector (consistent with the economy-wide carbon fees). The carbon content of ethanol is, under this approach, somewhat less than that of gasoline although quite similar on a per energy unit basis. This makes ethanol more attractive for blending. The revenue collected from this transportation fuels carbon tax is assumed to be recycled back to consumers in a similar manner as the economy-wide carbon tax.

Policy scenarios

As discussed above three kinds of policies were modeled individually: (1) economy-wide carbon prices starting in 2010 at $10.50/ton (in 2010 dollars) and increasing at 5 percent per year in real terms through 2030 and $30/ton CO2 in 2010 (in 2010 dollars) and rising to $60/ton CO_2 in 2030, (2) corporate average fuel economy standards that increase at either 2 percent per year or 4 percent per year between 2010 and 2020, then holding constant from 2020-2030, and (3) three kinds of transportation fuels taxes: gasoline and diesel taxes, carbon taxes on transportation fuels, and a gasoline-only tax. Revenue from all of the carbon policies (economy-wide carbon taxes and the carbon tax on transportation fuels) is returned to consumers, but the revenue from fuel taxes (on gasoline and diesel) is not returned. In theory, carbon 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 (for a good example of a carbon tax swap that is revenue and distributionally neutral, see Metcalf 2007).

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[9] The transportation carbon tax feature was added to NEMS-ETIP.
[10] NEMS-ETIP reports these emissions as part of the industrial sector, rather than as transportation emissions.

Table 3. Policy Scenarios

Scenario	Abbreviation	Description
A	Base Case	Reference case for NEMS-ETIP model
B	E30	Economy-wide carbon price beginning at $30/ton CO_2 and rising to $60/ton CO2 by 2030
C	E30c2t5	Economy-wide carbon price beginning at $30/ton CO_2, plus 2% annual improvement in CAFE for cars and light trucks, plus an additional transportation carbon tax starting at 50 cents increasing at 5% per year in real terms (this tax is recycled back to consumers)
D	E30c4	Economy-wide carbon price beginning at $30/ton CO_2, plus 4% annual improvement in CAFE for cars and light trucks
E	E10c2	Economy-wide carbon price beginning at $10/ton CO_2 increasing at 5% per year, plus 2% annual improvement in CAFE for cars and light trucks
F	E10c2t10	Economy-wide carbon price beginning at $10/ton CO_2, plus 2% annual improvement in CAFE for cars and light trucks, plus a gasoline and diesel tax increasing at 10% per year in real terms (tax is <u>not</u> recycled back to consumers)
G	E10c2gf	Economy-wide carbon price beginning at $10/ton CO_2, plus 2% annual improvement in CAFE for cars and light trucks, plus flat gas tax that stays constant at 50 cents per gallon (tax is <u>not</u> recycled back to consumers)

<u>Note</u>: Revenue from the economy-wide carbon price instruments (tax or permit revenue) is fully recycled back to consumers as reduced income taxes.

After examining the individual impact of each of these policies, eight policy scenarios were modeled that combined individual policies into different policy packages The eight scenarios are summarized in Table 3, and they are described in more detail here.

Scenario A (Base) – This is the reference case, which represents the Energy Information Administration's Annual Energy Outlook 2007 reference case with minor modifications to the consumer preferences for hybrid and diesel vehicles. This scenario represents the business-as-usual case. The assumptions that characterize this base-case scenario thus influence the effect of new policies. In particular, we expect that the assumptions regarding future prices of oil could have significant implications for the outcome of the policies we model. For all of our scenarios, the base-case scenario assumes oil prices as stipulated in AEO 2007. A subset of scenarios were examined where the base-case assumes EIA's high oil prices projections.

Scenario B (E30) - This scenario places an economy-wide price of $30/ton CO_2 on carbon emissions that escalates to $60/ton CO_2 by 2030. For comparison, Senate bill S. 280, The Climate Stewardship and Innovation Act, is estimated to result in a price of $47/ton CO_2 in 2030 with no offsets,[11] although this bill encourages the use of offsets, which would likely reduce the price. [12] Senate bill S. 1766 is estimated to result in a price of $25/ton CO_2 in

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[11] An offset is generated by the reduction, avoidance, or sequestration of GHG emissions from a specific project. Offsets are so named because they offset greenhouse gases that would have been emitted into the atmosphere otherwise. Offsets are a compensating equivalent for reductions made at a specific source of emissions. In the U.S. context, offsets generally refer to emissions reductions made in developing countries that would be permitted to count under a total cap on U.S. emissions. Source: The Climate Trust, see www.climatetrust.org/about_offsets.php.

[12] Energy Information Administration, "Energy Market and Economic Impacts of S.280, The Climate Stewardship and Innovation Act of 2007," Report Number SR/OIAF/2007-04.

2030 with no offsets (the technology-accelerator payment price). The economy-wide price could result from a cap-and-trade program or a carbon tax. The choice of policy instrument here essentially makes no difference in the model because NEMS-ETIP considers the trading price of credits in a permit system to be approximately the same as a carbon tax. 100 percent of the revenue that comes to the government through the economy-wide carbon price instrument is assumed to be returned to consumers.   Of course, there is no guarantee that general revenue would be used to reduce income taxes.   Also, it is important to point out that in a cap-and-trade system, the government would not receive any revenue if the permits are not auctioned, so a 100 percent auction should be assumed.   The main point of this scenario was to see if transport-sector CO_2 emissions or transport-sector energy consumption was affected by a reasonably high economy-wide carbon price.

Scenario C (E30c2t5) – This scenario adds two more layers to Scenario B by combining the economy-wide carbon price beginning at \$30/ton CO_2 with a 2% annual improvement in CAFE for cars and light trucks, plus an additional carbon tax on transportation fuels that starts at 50 cents per gallon in 2010 and increases at 5% per year in real terms. This scenario is unique in that it is the only one that places a special carbon tax on transportation fuels.   The revenue from both the economy-wide carbon tax and the transportation-fuels carbon tax is fully recycled to consumers.

Scenario D (E30c4) – This scenario, like Scenarios B and C, places an economy-wide \$30/ton price on CO_2, but adds a 4% per year annual tightening in CAFE standards for light duty vehicles.   This is the most aggressive scenario for CAFE improvements that was modeled, and it is similar to the CAFE standard that was included in the Energy Independence and Security Act of 2007, which we estimate to be equivalent to slightly less than a 4% annual increase in stringency. This is the most aggressive scenario modeled that does not place any additonal tax on transportation fuels.

Scenario E (E10c2)- This scenario employs a 2% per year annual increase in stringency in CAFE standards light-duty vehicles along with an economy-wide beginning at \$10.50/ton CO_2 price and escalating by 5% per year in real terms. This is similar to the technology-accelerator payment price of Senate bill S. 1766.

Scenario F – (E10c2t10) – This scenario combines an economy-wide \$10/ton price on CO_2, a 2% per year annual tightening in CAFE standards for light duty vehicles, and a gasoline and diesel tax that starts at 50 cents/gallon and increases 10 percent per year in real terms. This gasoline and diesel tax is *not* recycled back to consumers.

Scenario G – (E10c2gf) – This scenario is the same as Scenario F except that there is a flat gasoline tax that stays constant at 50 cents per gallon in real terms. This tax is *not* recycled back to consumers.

Results

Numerous NEMS-ETIP modeling runs were completed. In this section, the integrated results from different modeling runs are presented, starting with the impact of individual policies, followed by the impacts of the different policy scenarios defined above.

Economy-wide carbon prices alone

Economy-wide carbon prices alone do very little to reduce CO_2 emissions from the transportation sector unless they are very high, which currently seems politically unrealistic in the United States. Even in the higher \$30/ton CO_2 case escalating to \$60/ton in 2030, transport-sector emissions rise 25% above 2010 levels, whereas they rise 30% in the reference base case.   In the "high-oil-price" case, the base case still rises 20%. A policy that resulted in a tax or tradable permit price of \$100 per ton carbon equivalent (\$27 per ton CO_2), for example, would translate into an increase in the cost of gasoline of only 26 cents per gallon of gasoline, not enough to provoke consumers to drive less or to go buy a more fuel-efficient car. At \$33 per ton of carbon equivalent (\$9 per ton CO_2), the carbon permit price or tax would translate into 8 cents per gallon of gasoline, which would be lost in the noise of day-to-day gasoline price volatility

The reason that economy-wide carbon prices do not have a significant impact on transportation-sector CO_2 emissions is that the carbon content of petroleum is less than that of coal and there are fewer cost-competitive low-carbon technology alternatives in the short-to-medium term in transportation than in other sectors, such as electricity generation. Even a relatively small economy-wide carbon price causes a noteworthy increase the cost of coal, and so reducing emissions from coal-burning facilities becomes the most economically-rational choice.

CAFE standards alone

In the lower oil price reference case scenario, both the 2% and 4% annual increases in CAFE requirements achieve reductions in carbon dioxide emissions and petroleum net imports below the business-as-usual base case, but there are nonetheless increases above 2010 levels in both cases, as shown in Charts 1 and 2. Transportation sector CO_2 emissions rise 27% from 2010 levels in the 2% case, and 20% above 2010 levels in the 4% case. U.S. net petroleum imports rise 33% above 2010 levels in the 2% case and 24% above 2010 levels in the 4% case.
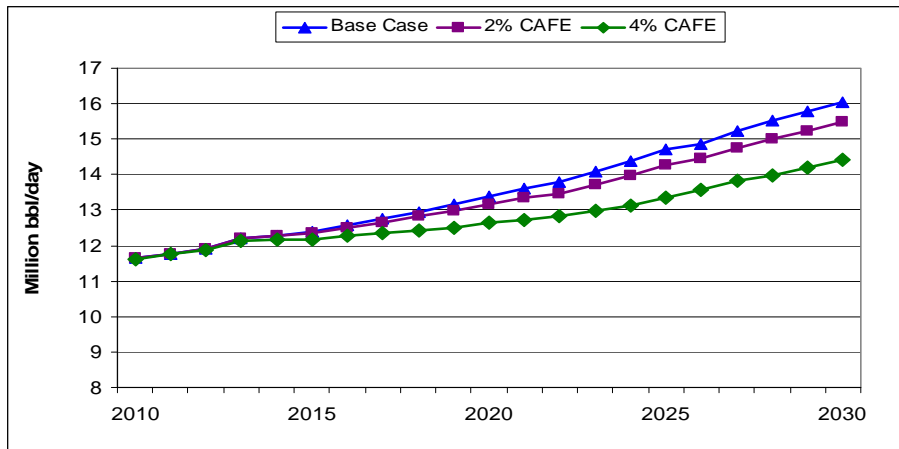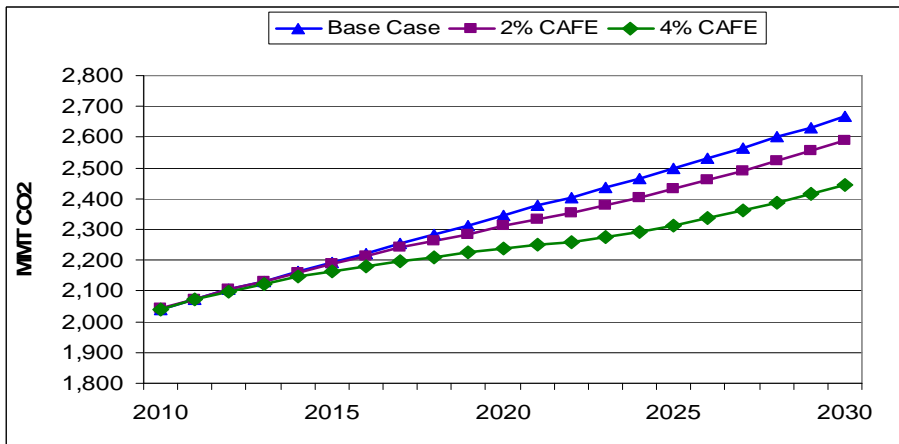
Chart 1. Net Petroleum Imports with CAFE Alone

Chart 2. Transport Sector CO$_2$ Emissions with CAFE Alone

Transportation fuels taxation alone

In the reference oil price scenario, all cases achieve reductions in carbon dioxide emissions and petroleum net imports below the business-as-usual base case, but there are increases above 2010 levels, just as in the CAFE cases alone, as shown for the CO$_2$ case in Chart 3. In the reference case, CO$_2$ emissions rise 28%. Both the flat gas tax and the case with a 5% escalating carbon tax starting from a 50 cent per gallon base results in CO$_2$ emissions that are 20% higher in 2030 than 2010 levels. The more stringent 10% escalating gas and diesel taxes result in 10% higher emissions in 2030 above 2010 levels.

Chart 3. Transportation Fuels Taxation: CO$_2$ Emissions
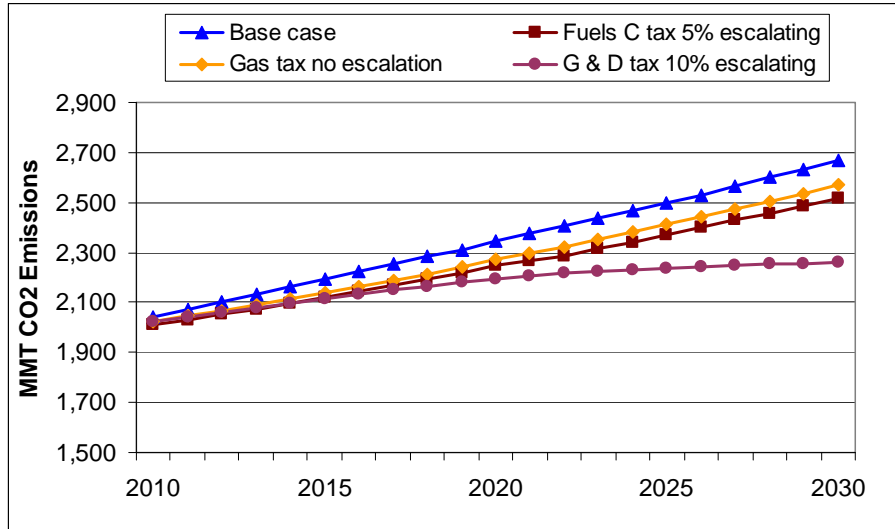
Total U.S. greenhouse gas emissions

As expected, in the reference lower oil price case the $30/ton economy-wide CO$_2$ price first produces a stabilization, and eventually a slight reduction, below 2010 levels in total U.S. greenhouse-gas emissions by 2030 – the "slow, stop, reverse" pattern – as can be seen in Chart 4. The $10/ton economy-wide CO$_2$ price alone fails to produce more than a stabilization of total U.S. emissions in 2030, and some of the $10/ton cases result in modest increases in total U.S. emissions by 2030. In the $30/ton CO$_2$ cases, emissions from the electric power sector are severely curtailed, as illustrated in Chart 5. The results are essentially the same even in the high oil-price scenario.

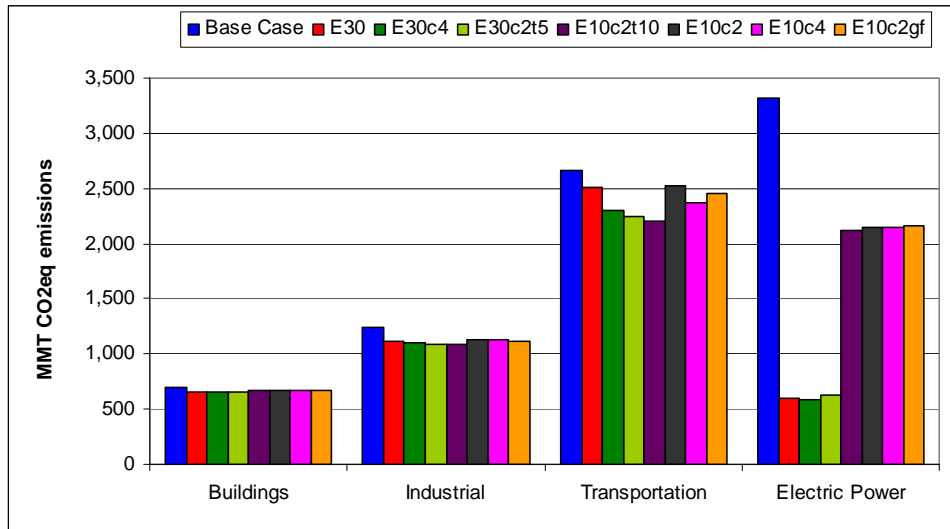**Chart 4. Total U.S. Greenhouse Gas Emissions**
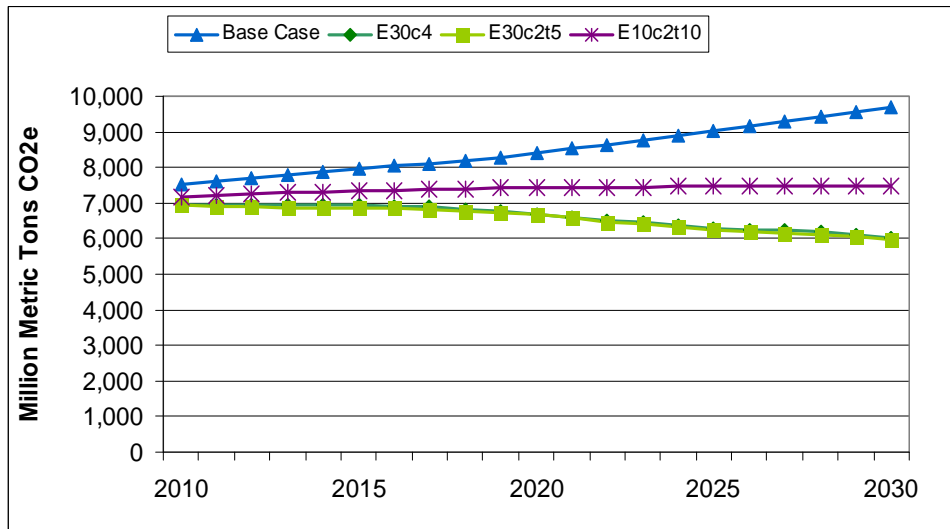
**Chart 5. U.S. CO$_2$ Emissions by Sector (2030)**

Energy consumption impacts

In all reference case scenarios modeled, light-duty vehicle energy consumption (including alternative fuels) increases. There is a 4.8 quadrillion BTU difference in 2030, however, between the "business-as-usual" base-case light-duty vehicle energy consumption and the E10c2t10 case, so avoidance of significant growth in light-duty energy consumption is possible in the E10c2t10 case. Note, however, that avoiding significant growth in light-duty vehicle energy consumption is only achieved when some form of tax is imposed on transportation fuels.

Vehicle-miles traveled by light-duty vehicles

In both the lower oil price reference case and "high" oil price reference cases, vehicle-miles traveled by light-duty vehicles are projected to increase continuously over the 2010-2030 period (by 51 percent and 44 percent, respectively). It's worth reiterating in this context that the price elasticity of fuel demand in NEMS-ETIP is 5 percent in the short-run and 20 percent in the long run. In the reference case, the E30c4 case actually increases vehicle-miles traveled (VMT) slightly above the base case, but the cases with taxes on transport fuels produce a noteworthy reduction in VMT below business-as-usual. The reference case projects a 52% increase in VMT during the time period in the base case, and the high-oil price case projects a 44% increase. The impact of the transportation fuels taxes in the high oil-price case is illustrated in Chart 6.

Chart 6. Vehicle-Miles Traveled by Vehicle Type and Policy Scenario
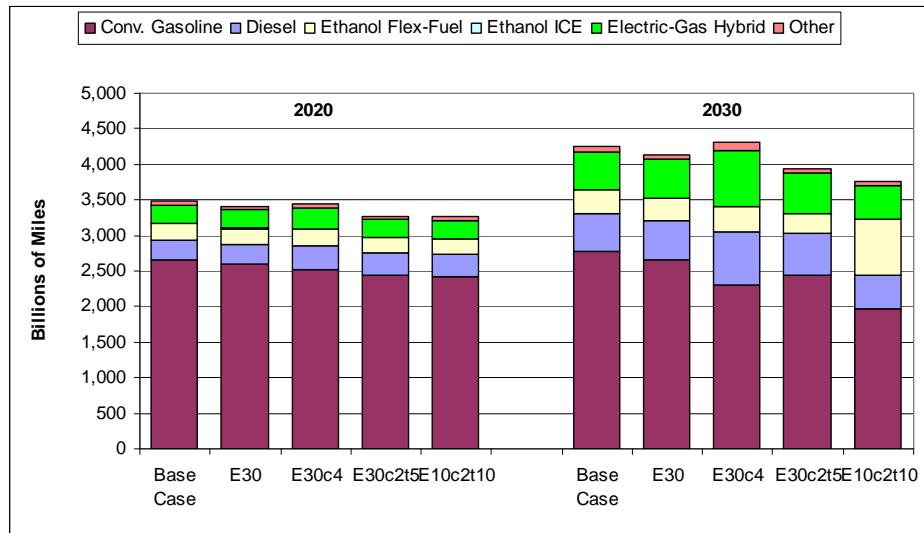

Net petroleum imports

For the reference case policy scenarios, U.S. net oil imports rise in all cases, although there is a very significant difference of almost 3 million barrels of oil per day between the base case and the E10c2t10 cases in 2030.   In the high-oil-price case, U.S. net oil imports only fall in the E10c2t10 case.   In that case where there is a 10% escalating gasoline and diesel tax, there is a 23% reduction from the base in 2030, and a 7% reduction below 2010 levels.

Transport sector greenhouse gas emissions

Transport-sector greenhouse gas emissions rise in all of the scenarios in the reference case, and some policy scenarios are significantly below business-as-usual (see Chart 7). In the E10c2t10 case, transport-sector emissions are 102 million metric tons below the E30c4 case, which in turn is 363 MMT below the base case.   In the high oil-price scenario, the E10c2t10 case comes close (within 30 MMT) to achieving a stabilization at 2010 levels.

Chart 7. Transportation Sector CO$_2$ Emissions
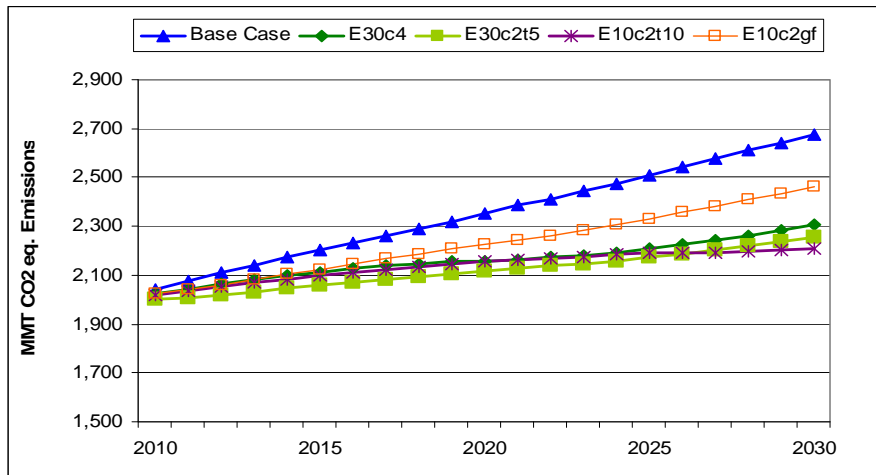
New light-duty vehicle fuel economy

Light-duty vehicle fuel economy for new vehicles reaches 38 mpg in 2020 in the 4% CAFE scenarios, and then stays constant thereafter because the policy is unchanged after 2020. There is more variation in the 2% scenarios. Note that these results are only for new vehicle fuel economy; the fleet as a whole lags considerably due to slow vehicle turnover. In the E10c2 scenario, new light-duty vehicle fuel economy reaches 31 mpg in 2020, rising only to 32 mpg by 2030. But, with the addition of any of the transportation fuels tax scenarios, fuel economy rises to 33 mpg by 2030 in the E10c2gf scenario to 35 mpg in 2030 in the E10c2t10 scenario. In other words, there is a clear consumer response to more expensive transportation fuels, as evidenced by significantly more purchases of new passenger vehicles with greater fuel efficiency than is required by the standard.

Alternative fuels

The only alternative fuels that see significant market penetration, either under the reference case or our scenarios, are coal-to-liquids (CTL) and ethanol (there is also some biodiesel). The production of Fischer-Tropsch fuels increases in the reference case to about 0.45 million barrels a day by 2025. Incentives to produce these fuels decrease rapidly as the price of carbon increases, and essentially no production is seen under the policy scenarios that tax carbon emissions on an economy-wide basis. Our modeling projects that a carbon tax above $13/ton CO$_2$ will effectively eliminate any market penetration of CTL. This result applies, however, assuming prices for petroleum-derived fuels as projected in AEO2007. Should underlying oil prices be higher, CTL may become more competitive, except that it appears that an economy-wide carbon tax of $30 per ton CO$_2$ would preclude CTL production even in EIA's high oil-price scenario, not taking into account the possibility for carbon capture and storage (CCS).

The results on ethanol consumption are more difficult to interpret, particularly in light of the revision of the renewable fuels standard (RFS) in EISA 2007. In virtually all of the scenarios, all ethanol is used in low-fraction blending, replacing MTBE as an oxygenate and octane enhancer. Only in the E10c2t10 case are significant volumes of ethanol used in E85 fuel. In this scenario, consumption of ethanol reaches 19 billion gallons by 2030, 15 billion of which are used in E85 fuel. The observed market penetration of E85 is due to its price, on an energy basis, becoming cheaper than gasoline for this scenario around 2017.

Even when the tariffs on imported ethanol are assumed to be eliminated after 2010, NEMS-ETIP projects that most of the ethanol consumed is produced domestically from corn, although the increase in the E10c2t10 case relative to the other cases is primarily from imports. This result can be explained by the assumptions about the marginal costs of production of corn and sugarcane ethanol, which may be inaccurate. Only one quarter of a billion gallons of ethanol is produced from cellulosic biomass in the scenario with more ethanol adoption, E10c2t10. As discussed above, NEMS-ETIP makes very conservative assumptions about the reductions in production costs of cellulosic ethanol, which explains its very limited market penetration.

In light of the new renewable fuels standard in EISA, assuming that the new requirement of 36 billion gallons by 2022 can be met, the directive would probably translate into an increase in fuel prices equivalent to a tax (without the tax revenue). One might also expect a reduction in oil consumption because of the substitution effect and because of consumer response to higher prices. Such a case was not modeled in this study, but since the RFS requires 16 billion gallons of ethanol to be produced from cellulosic biomass, it is easy to conclude that the impact on fuel prices could be sizeable, unless significant progress is made in reducing production costs.   The EPA is granted the ability to reduce these requirements.

GDP, personal income, investment, and trade

The overall impact on GDP for all the policies modeled in the reference case is less than 1 percent each year during the 2010-2030 time period, as can be seen in Chart 8.[13]   In year 2030, all of the scenarios except the E30c2t5 case ended up with GDP losses of 0.4%-0.6%.   In the E30c2t5 case, the worst case, GDP losses in 2030 are 8 tenths of 1 percent.   The GDP impacts in the high-oil price scenario are essentially the same.

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[13] Note that the waviness of the results from NEMS in the chart is due to the lag structure of the macroeconomic model as it captures adjustment costs in the economy on its way to equilibrating at a long-run solution.

Chart 8. GDP: Percent Change from Base
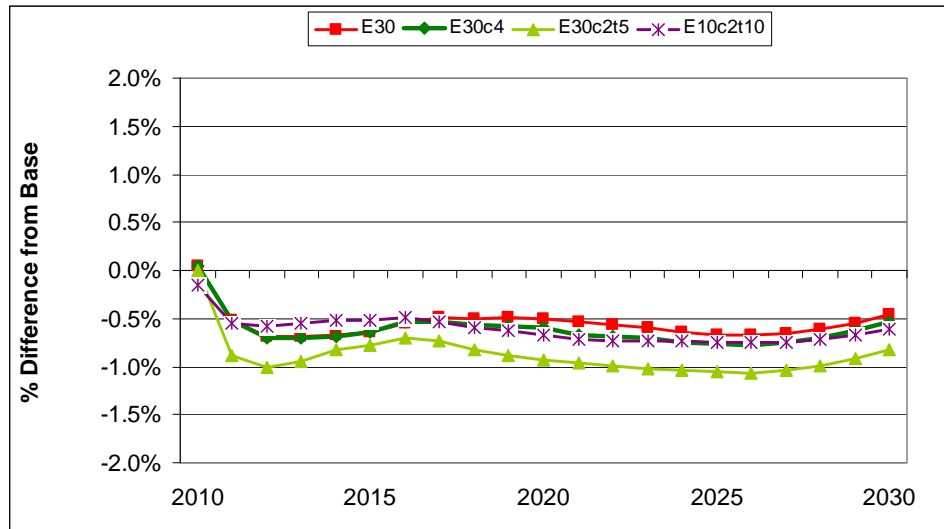
It is important to remember that all of the revenue from the carbon taxes was assumed to be recycled back into the economy through reduced income taxes, and if this were not true, then the macroeconomic impact would likely be worse.   If, for example, a cap-and-trade program were adopted where the permits were not auctioned, there would be no government revenue with which to offset the costs of the program.   If permits were not auctioned, they would be allocated for free to industries and hence reduce their costs.   In the case of regulated electricity markets, these costs should then flow to electricity consumers, but for deregulated markets, the benefits would probably flow to the electricity producers. In the scenarios where both an economy-wide and transportation fuels tax were employed, since they both recycled the revenue from the taxes to consumers personal income is unchanged or actually rises to up to 5 tenths of 1 percent in 2030. In the case where there was no recycling of the transportation fuels tax to consumers (E10c2t10), personal income falls slightly more than 2 tenths of 1 percent in 2030.

NEMS-ETIP predicts no impact in terms of aggregate investment for all scenarios except E10c2t10, which rises to 2 percent in 2030.   NEMS-ETIP assumes that exports fall and imports rise in all scenarios, but critically assumes that other countries have no comparable policies, which is not accurate today given that the European Union has a mandatory cap-and-trade program in operation.   If other countries (including all of our trading partners) had comparable policies, one would not expect exports to substantially decline since no other country would have comparative advantage.   If other countries did not have comparable policies, then our analysis shows there could be a 2.5%-4.5% decline in exports and a 0.5%-2.2% increase in imports in 2030. If other countries had policies and the United States did not, then the United States would have an advantage that would be eliminated if the U.S. government adopted a policy.

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Insights for Policy

It is a complex task to meet the policy goals of reducing GHG emissions and oil consumption from transportation sector. Our analysis shows that individual policies largely fail to produce the intended results on their own. Indeed, the new CAFE standards contained in EISA 2007 are not likely on their own to prevent significant growth in U.S. oil consumption and transport-sector greenhouse gas-emissions by 2030, although, critically, they will prevent even larger growth from occurring. The new renewable fuel standards could result in greatly expanded use of ethanol, but whether this outcome materializes will depend on highly uncertain factors, such as ethanol production costs, investments on distribution and refueling infrastructure, and the deployment of flex-fuel vehicles. Even individual policies that seem radical in the U.S. context, most notably taxation of transportation fuels, do not on their own produce the intended results. Thus, a fundamental insight from this study is that if one wishes to reduce U.S. net petroleum imports or to reduce CO_2 from the transportation sector, packages of policies will be needed. If meaningful progress towards meeting the goals is to be achieved, such packages are likely to require combinations of bold policies.

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 relatively high, we found that it is possible to achieve a reduction in net oil imports with a package that includes an initially modest 50 cent/gallon tax on gasoline and diesel that escalates 10 percent per year in real terms reaching $5.02/gallon in 2030. In that case, CO_2 emissions from the transportation sector were stabilized close to 2010 levels. If, however, the underlying world oil prices are much lower during the next two decades as EIA and others predict, then none of the policy scenarios modeled achieve the desired goals.

Much also depends on the success of current and future efforts to spur technological innovation in low-carbon biofuels and advanced vehicle technologies. In this study, the renewable fuel provisions of EISA 2007 were not taken into account. With the new renewable fuel standard, there is now a mandate for biofuels, starting with 9 billion gallons of renewable fuels initially and increasing to 36 billion gallons by 2022. By 2022, 21 billion gallons must be "advanced biofuels" out of which 16 billion should be cellulosic biofuels. The modeling here shows that in the absence of EISA, total ethanol supply by 2030 would be only 14 billion gallons per year, most of which would be corn-based.

An expected — though often overlooked — result is that demand for E85 becomes significant only when its price is lower than that of gasoline on an energy basis. Our results suggest that fairly stringent policies may be needed to generate this effect. Increased use of ethanol, as directed by the new Renewable Fuel Standard, if indeed met, would result in considerable reductions in oil consumption. The extent to which such volumetric mandates result in reductions in greenhouse gas emissions from the transportation sector will depend on how they are actually implemented. Both a low-carbon fuel standard or carbon tax on

transportation fuels, if assessed on a lifecycle basis, could help reduce CO_2 emissions, especially in combination with other measures. The debate over how to design and implement such policies is far from being resolved. Additional challenges associated with greatly expanded use of biofuels include the increased competition for agricultural land, the fragmentation of ecosystems, and the increased pressure on water supplies.

A critical underlying challenge for oil security and greenhouse-gas emissions from the transportation sector is the persistent historical trend of growth in vehicle-miles traveled in the United States (Collantes and Gallagher, 2008). While most of our policy scenarios affect consumer choice regarding which motor vehicle to purchase and which fuel to consume, they have only a small effect on vehicle-miles traveled. The NEMS-ETIP reference case projects that vehicle-miles traveled will grow more than 50 percent between 2010 and 2030. Aside from increasing the price of transportation fuels, policies were not modeled in this study that resulted in VMT reductions. From the E10c2t10 case, we see that transportation fuels pricing helps to moderate the growth in vehicle-miles traveled because in that case, VMT was 13 percent lower in 2030 than in the base case. The effect on VMT of fuel taxes is, however, partially offset by the rebound effect from increases in fleet fuel economy resulting from strengthening CAFE requirements. The modeling in this study probably does not accurately reflect consumer expectations about future oil prices. If consumers have the expectation that oil prices will be relatively high in the future, and especially if they believe that oil prices will continue to increase indefinitely, their behavior is likely to change. In NEMS-ETIP, consumer response is embedded in the assumptions of price elasticities of 5% for the short-run and 20% for the long-run. There is evidence that in the very short-run (i.e. immediately), the price elasticities may be even smaller than 5% (Small and Van Dender 2005, Hughes et al. 2008). There is limited evidence, moreover, that the 20% long-run elasticity does not accurately reflect consumer expectations about the future. In the most recent study available, Small and Van Dender (2005) estimate the long-run elasticity of fuel consumption with respect to fuel price, for the period of 1997 to 2001, at between -0.34 and -0.64, depending on the estimation method. U.S. consumers have never experienced an escalating tax on transportation fuels, so it is not clear that consumers would respond as weakly to policies as NEMS-ETIP suggests. Strong consumer response to higher gasoline prices in terms of increased purchases of high-fuel-economy hybrid vehicles (Gallagher and Muehlegger 2008) also suggests that in the longer-term, consumers may be more responsive than models currently suggest in terms of their car-purchasing behavior. Thus, a general insight is that policies must be devised to make driving consumers care more about which cars they purchase and how much they drive.

We find that recycling the revenue from auctioned permits or carbon taxes to consumers lessened the macroeconomic impact of the policies modeled. In this study, the economy-wide carbon tax revenue was fully recycled to consumers as reduced income taxes. For simplicity, the income taxes were reduced in a uniform manner. For the gasoline and diesel taxes, the 5% escalating carbon tax on transportation fuels was recycled to consumers, but the 10% escalating tax on gasoline and diesel transportation fuels was not. All of the policy scenarios modeled had a GDP impact of less than 1% each year through

2030, and all of the policy scenarios where revenue from the policy instruments was re-directed to consumers resulted in slightly increased personal income in 2030. The tax revenue should not be recycled in the way it was modeled here because it would be regressive — the revenue could be recycled to consumers using a more equitable distribution method. If recycled back to consumers as reduced income taxes, distributional impacts of the policy should be taken into account in the design of the policy (see, for example, Metcalf 2007). The revenue could also be used, for example, to reduce payroll taxes, to shore up Social Security, or to fund research, development, and demonstration of low-carbon technologies to invent new technologies or 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 the revenue in a way that mitigates the macroeconomic impacts of the policies.

There were some relatively moderate policies that, in combination with each other, almost stabilized oil consumption and GHG emissions from the transportation sector at current levels, resulting in a significant reduction from business-as-usual by 2030, even if they did not result in actual reductions below 2010 levels. The two policy scenarios that proved most effective at meeting the two policy goals in both the low and high-oil-price cases were the ones that combined an economy-wide carbon price with the 2% annual increase in CAFE standards for light-duty vehicles, and a moderate but escalating tax on transportation fuels. The 2% annual increase in CAFE standards lost some relevance when EISA was passed establishing significantly more stringent CAFE requirements. Our results do show, however, that complementing CAFE increases with some form of fuel taxation is important to mitigate the GHG emissions coming from VMT growth. Further, we show that lower CAFE increases combined with a transportation fuel tax can result in lower greenhouse-gas emissions at a lower cost than a higher CAFE standard alone.

Finally, we conclude by highlighting once again the many limitations of modeling. Areas where we especially feel that ETIP-NEMS could use more refinement include modeling more rapid technological change, modeling the impact of policies that explicitly required a lifecycle analysis of biofuels, and being able to juxtapose the potential costs of climate change and energy insecurity against the costs caused by the policies themselves.

Acknowledgements

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