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Toward a New National Energy Policy: Assessing the Options

FULL REPORT

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RFF

Resources for the Future (RFF) is an independent, nonpartisan think tank that, through its social science research, enables policymakers and stakeholders to make better, more informed decisions about energy, environmental, and natural resource issues. Founded in 1952 and headquartered in Washington, DC, its research scope comprises initiatives in nations around the world.

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NEPI

The National Energy Policy Institute (NEPI) is a nonpartisan independent energy research organization, based at the University of Tulsa and funded by the George Kaiser Family Foundation. NEPI conceived of this project to undertake a comprehensive study of energy strategies, based on a rigorous application of common metrics to determine comparative cost.

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Foreword

Since the 1950s, the United States has almost tripled its annual energy consumption, following a trend of substantial U.S. economic growth in the latter 20th century. Yet with this growth in energy use have come new challenges—in particular, our increasing reliance on imported oil, which can have significant foreign policy implications; and a documented rise in the level of greenhouse gases accumulating in the atmosphere, which many scientists believe may lead to a rise in global temperature, changes in water supply, an increased threat of extreme weather events, and other negative consequences on food supply and human health.

From these twin challenges emerges a clear message: reducing our reliance on traditional fossil fuels must be central to any strategy to meet the goals of improving energy security and combating global warming. Despite numerous congressional proposals to control GHG emissions and promote alternative sources of energy, we have yet to pass and implement a comprehensive energy policy. With the recent volatility in the price of oil, continued warnings about climate change, and persistent dependence on oil from governments often hostile to our interests, the time is ripe for a rigorous, wide-ranging analysis of U.S. energy policy options.

Complicating matters is a bewildering array of policy alternatives. Some are substitutes for one another and others could reinforce each other; some directly target oil and others focus on emissions. How should policymakers choose among them? The analysis presented here helps meet this challenge. Carried out by Resources for the Future and the National Energy Policy Institute with support from the George Kaiser Family Foundation, it assesses 35 different policies and policy combinations based on their societal costs and their ability to reduce oil consumption and CO_2 emissions. Each is evaluated and ranked using a consistent and rigorous methodology. The results provide policymakers with a wealth of valuable information for developing a coordinated national energy policy.

This report provides a comprehensive examination of the study findings, built around three key chapters: one exploring the effects of oil policy options, focusing on transportation; another detailing impacts of policies to reduce CO_2, focusing on the electricity sector and energy efficiency; and a third that examines the results of combining policies to reduce both oil use and CO_2 emissions. We also provide considerable detail on our modeling and methodology, and highlight areas where future researched may be warranted.

The foundation of the effort is a series of technical papers commissioned by the study leaders and conducted by a cadre of notable researchers with expertise in each of the policies examined. These technical papers are listed in more detail at the end of this report, and are available online at the Resources for the Future website (www.rff.org) and the National Energy Policy Institute website (www.nepinstitute.org). Both this report and the technical papers rely on runs of the Energy Information Administration's National Energy Modeling System, and all were subject to thorough peer review.

We now challenge interested observers to participate in rationalizing and creating their own appropriate energy policy, using the information and interactions presented here to think strategically through the most effective and cost-effective options.

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Acronyms

Acronym	Meaning
AEO	Annual Energy Outlook
ARRA	American Recovery and Reinvestment Act
Btu	British thermal unit
C&T	cap-and-trade
CAFE	Corporate Average Fuel Economy
CBA	cost–benefit analysis
CBTL	coal-and-biomass-to-liquids
CCS	carbon capture and storage
CEA	cost-effectiveness analysis
CEC	California Energy Commission
CEPS	Clean Energy Portfolio Standard
CEPS-NG	Clean Energy Portfolio Standard with Natural Gas
CO_2	carbon dioxide
CO_2e	warming equivalents to CO_2
CRS	Congressional Research Service
CTL	coal-to-liquids
DOE	U.S. Department of Energy
DSM	demand-side management
EE	energy efficiency
EIA	Energy Information Administration
EISA	Energy Independence and Security Act of 2007
EMM	electricity market module
EPA	U.S. Environmental Protection Agency
EPAct	Energy Policy Act
FERC	Federal Energy Regulatory Commission
FIT	feed-in tariff
G8	Group of Eight
GDP	gross domestic product
GHG	greenhouse gas
GHP	geothermal heat pump
GW	gigawatt
HEV	hybrid electric vehicle
IGCC	integrated gasification combined cycle
IPCC	Intergovernmental Panel on Climate Change
kWh	kilowatt-hour

Acronym	Meaning
Li-ion	lithium ion
LNG	liquefied natural gas
MGCL	Morrow, Gallagher, Collantes, and Lee
mmbd	million barrels per day
mmtons	million metric tons
mpg	miles per gallon
MSW	municipal solid waste
MW	megawatt
NAS	National Academy of Sciences
NEMS	National Energy Modeling System
NEMS–RFF	Resources for the Future version of the National Energy Modeling System
NEPI	National Energy Policy Institute
NiMH	nickel metal hydride
NMS	net metering service
NPC	National Petroleum Council
NRC	National Research Council
OPEC	Organization of the Petroleum Exporting Countries
ORNL	Oak Ridge National Laboratory
PC	pulverized coal
PDV	present discounted value
PGC	Potential Gas Committee
PHEV	plug-in hybrid electric vehicle
ppm	parts per million
PTC	Production Tax Credit
PV	photovoltaic
R&D	research and development
REC	renewable energy credit
RFF	Resources for the Future
RINGPS	Renewable and Incremental Natural Gas Portfolio Standard
ROE	return on equity
RPS	Renewable Portfolio Standard
Tcf	trillion cubic feet
UCS	Union of Concerned Scientists
VMT	vehicle miles traveled
WM	Waxman-Markey

Despite numerous recent congressional proposals, the United States has yet to pass and implement a comprehensive energy policy. We analyze the effects and costs of a broad range of 35 domestic policy options for reducing oil consumption and CO_2 emissions, including many options currently under discussion in formal and informal policy circles.

1. Introduction

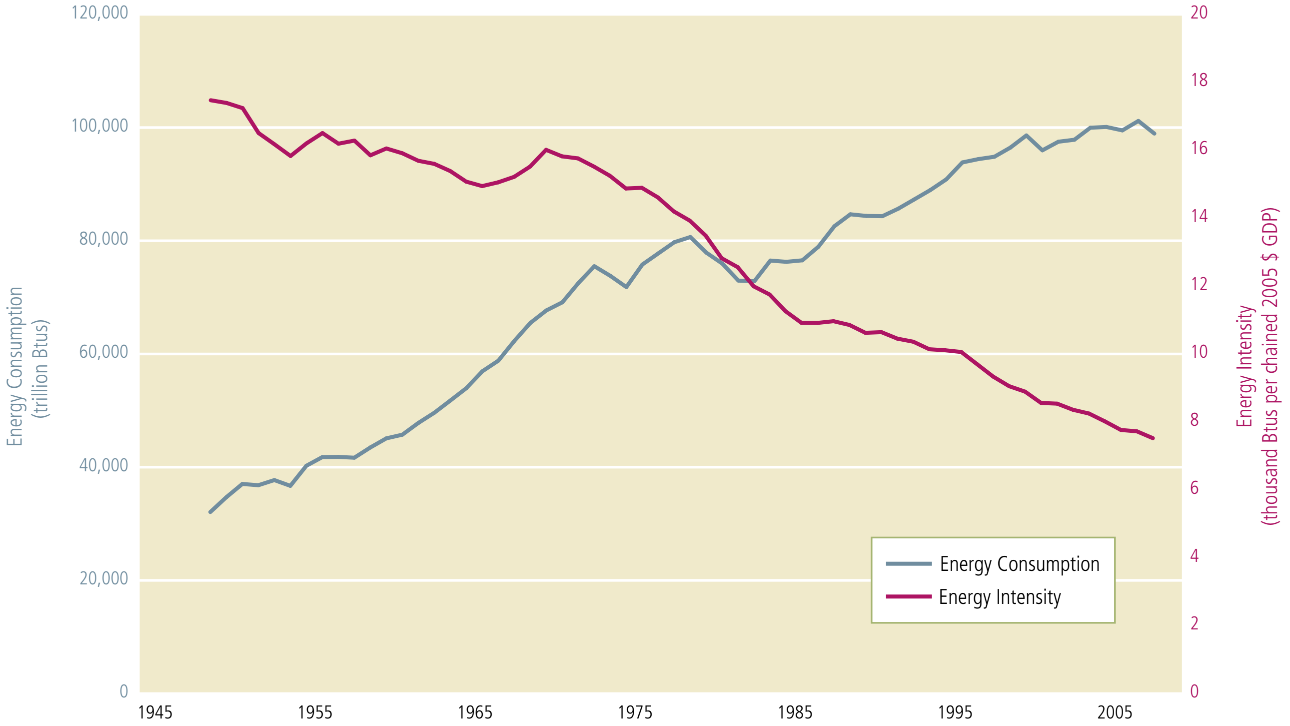
1.1 Energy and the American Economy

The role of energy in the American economy and in our lifestyle is profound and unquestionable. American consumers spend more than half a trillion dollars each year on energy for heating and cooling homes and schools, traveling for work and other activities, operating businesses, and fueling global trade. Energy truly is the lifeblood of the country.

We depend on fossil fuels for much of our energy use and, without major policy initiatives, no reversal of this reliance is in sight. Although a growing proportion of our energy comes from alternative energy sources, like wind power, these remain dwarfed by petroleum-based liquid fuels and coal.

Overall annual energy consumption in the United States has increased steadily by more than 200 percent since 1950, driven by population and gross domestic product (GDP) growth—and this is despite declining energy intensity (the amount of energy used per dollar of GDP) over the past six decades (Figure 1.1). A key tipping point came in the late 1950s, when expanding energy consumption began to outstrip the country's ability to produce energy. Today, America imports more than half the oil it consumes and relies on countries that are often politically unstable and hostile to U.S. interests. This reliance on imported oil has destabilized our economy in the past and,

Figure 1.1: Total U.S. Energy Consumption, 1949–2008



Source: EIA (2009a).

according to many serious studies, including one by the Council on Foreign Relations, constrains our foreign policy choices. For 35 years, U.S. political leaders have called for freedom from this dependence on foreign—and particularly Middle Eastern—oil. Most experts now agree this freedom can only be obtained by reducing our overall reliance on oil as an energy source.

Meanwhile, the international scientific community now issues nearly unanimous warnings about the danger of unchecked accumulations of greenhouse gases (GHGs), particularly carbon dioxide (CO_2), in the atmosphere, largely a result of burning fossil fuels. The United States, with 5 percent of the world's population, is the second-largest global emitter of GHGs, only recently surpassed by China. According to the U.S. Environmental Protection Agency (EPA), energy-related activities account for more than three-quarters of U.S. human-generated GHG emissions, most of which come in the form of CO_2 emissions from burning fossil fuels. The burning of fossil fuels also emits conventional and toxic pollutants and puts demands on water and land resources.

One thing is clear: a key to improving energy security and addressing climate change (as well as tackling pollution problems) lies—at least in part—in reducing our reliance on fossil fuels.

1.2 The Current State of U.S. Energy Policy

To date, the United States has lagged behind many of its developed country counterparts in implementing policies to reduce oil consumption and GHG emissions. U.S. fuel taxes are very low by international standards; state and federal taxes on gasoline and diesel fuel amount to about 40¢ per gallon, whereas in some European countries these taxes exceed the equivalent of $3 per gallon. The European Union has also moved ahead with a major program to control CO_2, whereas the United States—despite pledges of domestic action dating back to 1992—has not yet been able to implement a comprehensive federal climate policy. Nonetheless, several U.S. administrations, the U.S. Congress, and some state and local governments have taken initial steps, many in the last five years. In particular, under the Energy Independence and Security Act (EISA) of 2007, automobile fuel economy standards will be aggressively tightened, incandescent light bulbs will be phased out, and the mandated use of ethanol-based fuels will increase. Many states have been moving ahead with minimum requirements on the amount of electricity generated by renewable fuels, and many initiatives at the local level encourage "green" buildings, improve zoning, and more. Several northeastern states are participating in a regional GHG emissions cap-and-trade (C&T) program, with California poised to follow suit in 2012 and western states in 2015.

Still, these efforts lack coordination and, more importantly, an overarching vision for our energy future. Policies can contradict or work at cross purposes with one another. Some policies can have the effect of "picking winners" in technologies, rather than setting up mechanisms to let the market decide on the least costly ways of meeting policy goals. Finally, an understanding or even mention of true policy costs often is absent.

Given the emergence of energy security and climate change as issues facing the nation, a compelling opportunity now exists to move beyond public rhetoric and shape an energy future that is visionary, sustainable, and secure.

1.3 About This Study

This study, carried out by researchers at Resources for the Future (RFF) in conjunction with the National Energy Policy Institute (NEPI) and with a grant from the George Kaiser Family Foundation, analyzes the effects and costs of a broad range of domestic policy options for reducing oil consumption and CO_2 emissions, including many options currently under discussion in formal and informal policy circles. The study provides insight about how those policy options complement or duplicate each other and the extent to which more feasible policies (or combinations of policies) might be able to replicate the effects of more cost-effective, but perhaps less politically feasible, approaches.

Several important features of the study distinguish it from other assessments of U.S. climate and energy options (see section 1.4 for more detail).

- First, this research focuses explicitly on *policy design and evaluation.* Many previous studies have examined the technical feasibility of alternative fuels, new technologies, and future pathways to reduce oil use and CO_2 emissions. However, it is essential to look beyond engineering estimates and the availability of particular fuels and technologies, and consider the mechanisms that will bring about those reductions—that is, the specific government policy instruments that will drive changes in private markets. Those instruments are the key focus of our study. Without an understanding of how these policies work, decisionmakers have no clear guidance on how to move forward.

- Second, this report uses a *consistent economic modeling approach* as the backbone of the study. This model, which we call NEMS–RFF, is an RFF version of the National Energy Modeling System (NEMS) of the U.S. Department of Energy's (DOE) Energy Information Administration (EIA). We developed this version with the assistance of OnLocation, Inc. By using the same model with the same underlying assumptions, we can score different policies based on "apples-to-apples" comparisons. In this study, we based our analysis on two effectiveness metrics —the reduction in barrels of oil consumed[1] and the reduction in tons of CO_2 emitted—as well as the welfare (or opportunity) cost of each policy (see below).

- Third, the study is *wide-ranging,* taking into account a broad menu of policies. Unlike some other studies, we also examine an array of crosscutting policies that combine multiple individual policies. We examine 35 policy scenarios, including 4 crosscutting policy options, against a baseline scenario (referred to throughout this report as the *Reference* case). Although no study can be completely comprehensive, we believe that this report covers many of the relevant energy policy options currently facing policymakers. We analyze the following types of policies:
  - broad transportation policies, such as fuel taxes, taxes on all petroleum products, Corporate Average Fuel Economy (CAFE) standards, and feebates, which feature fees and rebates for fuel-inefficient and -efficient vehicles, respectively;
  - policies to encourage the deployment of hybrid and plug-in hybrid light-duty vehicles as well as heavy trucks fueled by liquefied natural gas (LNG);
  - policies to encourage energy efficiency (EE), such as building codes and incentives for space-heating and -cooling technologies;
  - policies that encourage clean fuels to generate electricity, such as renewable and clean energy portfolio standards;
  - policies to expand nuclear power; and
  - broad policies targeting CO_2 emissions, such as carbon taxes and C&T programs with alternative coverage of emissions sources.

More detail on the policies examined can be found in Appendix A and a table summarizing key metrics for each policy can be found in Appendix B.

- Fourth, a hallmark of this report is its *examination of economic or welfare costs,* based on fundamental microeconomic principles in which the cost is the value of the resources that society gives up to achieve a given reduction in oil use and/or CO_2 emissions. These costs could include, for example, the costs of producing electricity with cleaner but more

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[1] Many studies focus on reducing oil imports. We look at total oil consumption because we agree with the position taken by the Council on Foreign Relations that the policy objective should be to reduce our reliance on oil generally, rather than simply to reduce imports.

expensive fuels, the costs of driving less, or the cost of adopting more energy-efficient technologies. Many studies calculate direct expenditure changes from scenarios in which one fuel substitutes for another or one energy-efficient technology replaces another, less-efficient one. Some studies, particularly those looking at broad-based policies such as carbon taxes or C&T programs, assess changes in GDP. Although such metrics provide important information, they may not reflect the true economic burden of the policy. Welfare cost, on the other hand, fully represents this overall economic burden.[2] More detail on welfare cost calculators can be found in Appendices C and D.

With both cost and effectiveness measures in hand, we then compare the *cost-effectiveness* of various policies, meaning the average cost per barrel of oil reduced and the average cost per ton of CO_2 emissions reduced. This helps us to identify those policies that can produce the biggest "bang for the buck" or, perhaps more accurately, the lowest buck for the bang.

- Fifth, for relevant policies, we consider three cases as possible explanations for the *energy paradox,* the observation that consumers appear reluctant to make investments in energy efficiency unless they see a payoff well before the lifetime of the investment. We distinguish these cases by degree of market failure: complete, partial, and none. Many advocates of EE standards believe that market failures can entirely explain the energy paradox—our *Complete Market Failure* case—and argue for using a very low discount rate in valuing the energy savings. On the other hand, some economists are skeptical of this argument and believe that markets work fine—our *No Market Failure* case; they advocate using a much higher discount rate that is consistent with observed behavior (or alternatively, allowing for various hidden costs in the evaluation of EE investments). In this report, we present results for both of these bounding cases, as well as a compromise *Partial Market Failure* case.

The main body of this report builds on and significantly extends a series of technical reports commissioned by the study leaders and conducted by a range of experts, each of whom specializes in a particular policy area. These reports are available from the RFF and NEPI websites. Each expert determined a reasonable set of policies to model in NEMS–RFF within his or her area of expertise. Other experts contributed background papers—for example, on oil and natural gas security and on the growth of shale gas resources—that give shape and substance to the overall study. These background papers are also available on the RFF and NEPI websites.

Each of these technical and background papers is listed in Appendix F.

1.4 Comparisons to Other Recent Assessments of U.S. Energy and Climate Options

Surprisingly, perhaps, only a few other studies have an explicit focus on policy evaluation. Instead, many focus on strategies or general recommendations, with fewer details on the policy specifics needed for their implementation. For example, the National Commission on Energy Policy (2004) has recommendations to pursue cost-effective efficiency improvements in the industrial sector, encourage the siting and construction of LNG infrastructure, or provide $3 billion in public incentives to demonstrate carbon capture and storage (CCS), but does not discuss the policies needed to achieve these measures. Other studies take an engineering perspective, providing quantitative assessments of the costs and effectiveness of a wide suite of energy technologies, but also without a focus on the specific policy levers required to bring about the widespread market penetration of such technolo-

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[2] This cost is reported as the present discounted value (PDV) of welfare cost due to the change in policy over the 2010–2030 study period. Fuel cost savings and associated implications for effectiveness are considered beyond 2030, however (up to the lifetime of the investment or 2050, whichever occurs sooner).

gies (e.g., Creyts et al. 2007; NRC 2009c; Lutsey and Sperling 2009).

This study evaluates 35 policies and policy combinations covering many of the major energy and climate policy options affecting the transportation and power sectors as well as the broader economy. In contrast, many other studies focus solely on GHGs and C&T legislation (EIA 2009b; U.S. EPA 2009; Paltsev et al. 2009) or on reductions in oil use (NPC 2007; Lovins et al. 2005; Drake et al. 2009). Some look only at transportation (Cambridge Systematics, Inc. 2009; Gallagher and Collantes 2008) or energy efficiency (Alliance to Save Energy 2009). Yet other studies drill down on a particular technology, such as solar, coal, or nuclear power (Deutch and Moniz 2007), energy efficiency in buildings (World Business Council for Sustainable Development 2009), or plug-in hybrid electric vehicles (PHEVs; NRC 2009e). Few, however, feature the wide-ranging policy discussion that is included here.

In addition, few studies use a consistent modeling methodology to score and compare policies based on identified metrics. For example, Lovins et al. (2005) use a wide variety of models (including NEMS), offline calculations, and literature reviews to evaluate policies. Similarly, Cambridge Systematics (2009) analyzes transportation strategies based on a wide variety of government and private models, rather than a single model that allows for apples-to-apples comparisons. And an NPC (2007) report was developed with public and proprietary data and input from more than 350 participants.

The studies that do use a single modeling framework usually have a very narrow focus. For example, an Electric Power Research Institute (2007) study uses NEMS to analyze the GHG implications of PHEVs. Appendix E provides a more in-depth comparison to two key studies.

1.5 Organization of This Report

The remainder of this report includes a brief overview (Chapter 2) of the drivers of the study's key metrics: energy security, climate change, and welfare costs. (Data for each of these metrics are presented in Appendix B.) Chapter 2 also includes a brief discussion of how targets for reducing oil consumption and CO_2 emissions were established and how these benchmarks helped shape the study's policy analysis. This is followed by a summary of the study's methodology (Chapter 3), with a particular focus on model choice, output, and limitations.

Chapter 4 describes trends in transportation, electricity generation, oil use, and CO_2 emissions from the study's Reference case. This provides the starting point for the primary analysis in Chapters 5 and 6, which examine how policies fare on reducing oil consumption and/or CO_2 emissions, and at what cost.

Chapter 7 then blends the individual policies examined in the previous two chapters into several crosscutting policy combinations, designed to simultaneously reduce oil consumption and CO_2 emissions. This chapter illustrates how policies can work in tandem to address multiple priorities for a national energy policy.

The final three chapters briefly discuss, respectively, areas for future research, broader considerations in policy evaluation, and conclusions of the study.

A broad consensus suggests that continued growth in U.S. dependence on foreign oil has reduced our national security, and evidence shows that rising concentrations of greenhouse gases in the atmosphere have contributed significantly to a rise in mean global temperature. This study focuses on policy options to address these two issues, using ambitious targets for reducing oil consumption and CO_2 emissions as benchmarks for comparing policies' effectiveness.

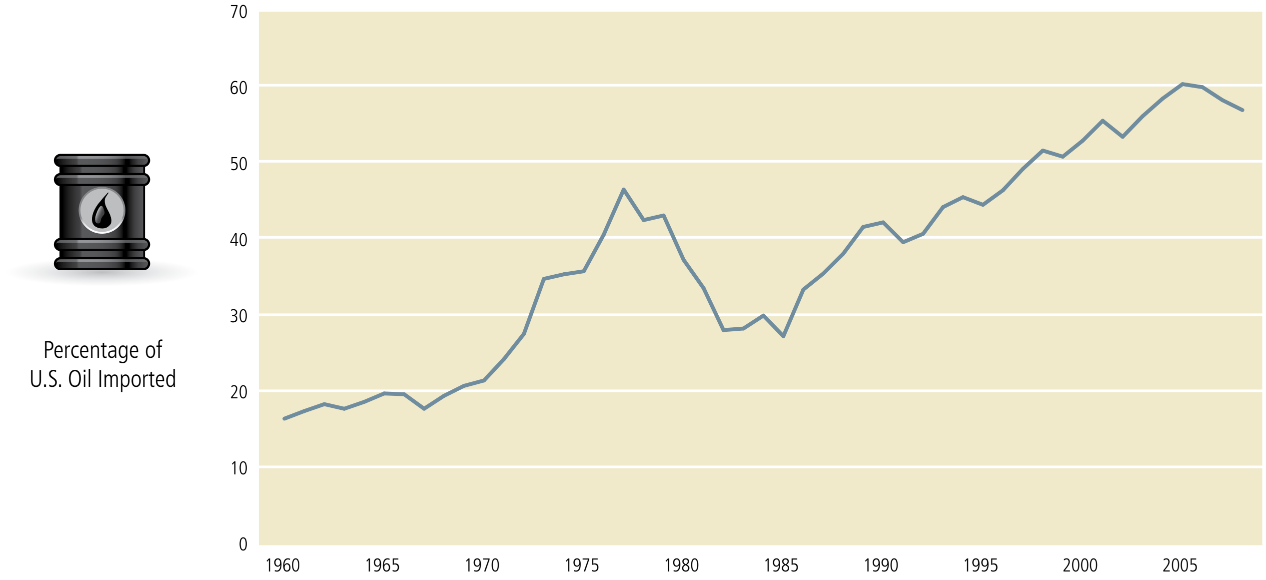
2. Understanding the Study's Key Metrics

2.1 Energy Security

Several factors have heightened concern about the dependence of the United States on foreign oil: volatility in world oil prices, current and projected pressure on oil markets from demand growth in industrializing nations, and the substantial current production and concentration of oil reserves in politically unstable, and often hostile, nations.

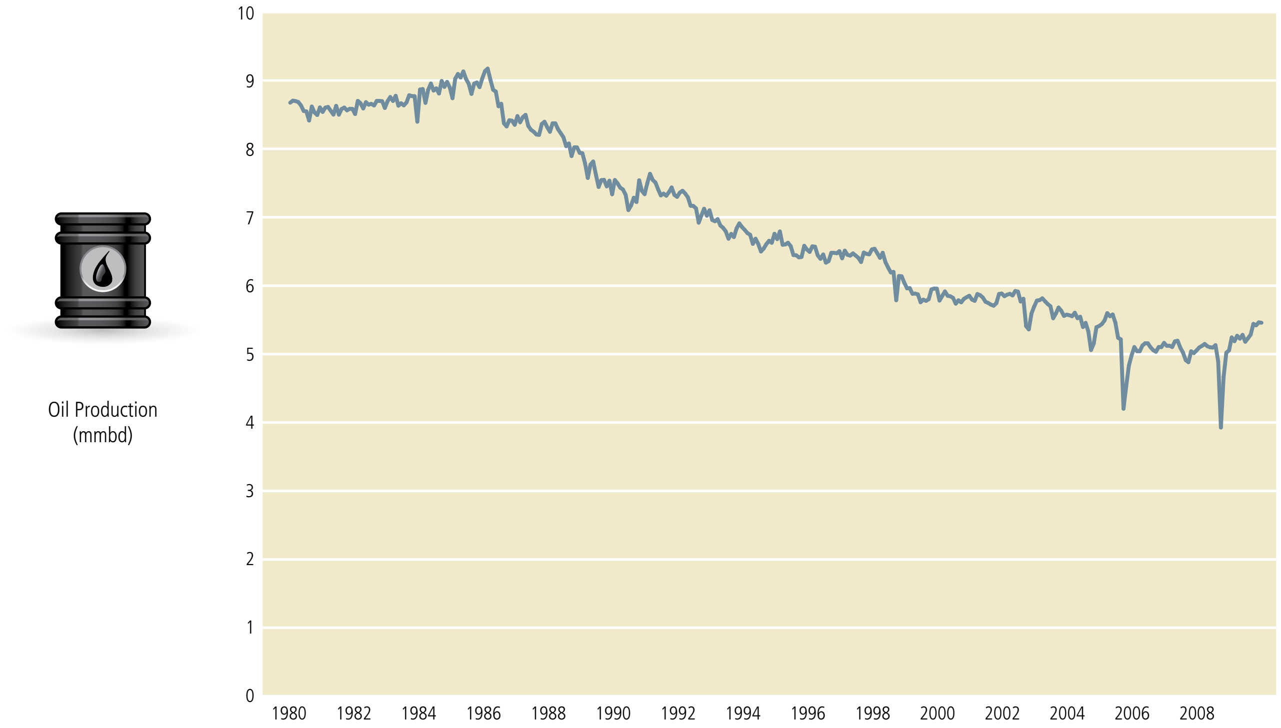
Every administration since the Nixon administration has recognized the potential danger this reliance on foreign oil poses to our national security and has called for a reduction in—or even an end to—oil imports. However, over the last 35 years, oil imports have grown from 3.4 million barrels per day (mmbd) to 11.2 mmbd and, as a percentage of oil used, imports have grown from 37 to 57 percent (Figure 2.1). U.S. domestic production of oil has been steadily dropping from 9 mmbd in 1985 to under 5 mmbd in 2008 (Figure 2.2).

Figure 2.1: Share of Imports in Oil Consumption, 1960–2008



Note: Total U.S. oil imports in 2008 were 4.7 billion barrels.
Source: EIA (n.d. a).

Figure 2.2: U.S. Production of Crude Oil, 1975–2008



Source: EIA (n.d. b).

During this same time period, consumption of oil increased 25 percent from 15.7 to 19.5 mmbd. In 2008, member countries of the Organization of the Petroleum Exporting Countries (OPEC) in the Middle East, Africa, and Venezuela represented 56 percent of U.S. imports (Figure 2.3).

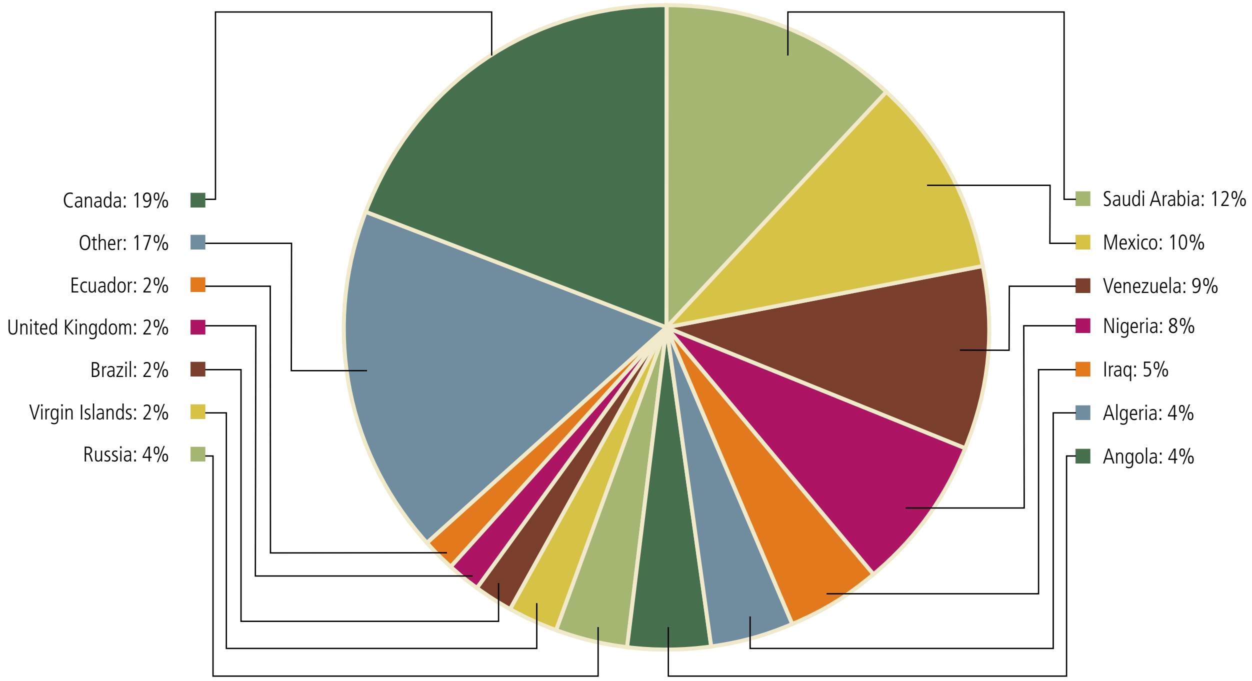
Today it is widely recognized that *energy independence*, when defined as self-sufficiency in meeting domestic energy needs, is an unattainable—and in fact unacceptably costly—goal. Yet at the same time, a broad consensus suggests that continued growth in our dependence on foreign oil has endangered our national security. Policymakers largely agree with the need to reverse this historical trend to bring America to a new level of energy security. The devastating oil spill in the Gulf of Mexico has only served to further push America’s reliance on oil to the top of the public agenda.

2.1.1 Oil Security: Economic and Foreign Policy Implications

What has been referred to as the United States’ “oil addiction” has had a significant effect on our economy. In 2007, oil imports totaled $293 billion and represented 41 percent of a record trade deficit (CRS 2008; EIA 2009d). Oil imports represent a massive transfer of domestic wealth to oil-exporting countries, put a downward pressure on the dollar, and have contributed to global capital imbalances (Greene and Ahmad 2005; Setser 2007).

Oil is responsible for 95 percent of the fuel for transportation, which accounts for 10 percent of GDP. Not surprisingly, considering this position of economic dominance, economists have noted that, in 10 of the last 11 recessions since World War II, oil prices have risen markedly just before a recession—including in the 18 months from January 2007 to July 2008, when oil advanced from $50 per barrel to $136 per barrel.

Figure 2.3: Oil Imports by Country of Origin, 2008



Source: EIA (n.d. c).

Other oil cost externalities have been identified by economists and energy experts. Brown and Huntington (2010) identify three specific areas of societal costs—GDP losses associated with increased oil consumption, a shift of spending power from U.S. consumers to foreign oil producers during oil price shocks, and an elevated risk of future oil price shocks—but suggest that the increase in oil price required to address these externalities is fairly modest.

Perhaps the most serious consequence of the vulnerability caused by foreign oil dependence is the realignment of key foreign policy goals. An "oil-centric" foreign policy concentrates on access to global oil markets for a stable oil supply. This realigns geopolitical alliances and potentially compromises policies addressing world hunger, disease, poverty, genocide, human rights, and strategic alliances to reduce regional conflicts. As suggested by the Council on Foreign Relations (2006, xi), the "lack of sustained attention to energy issues is undercutting U.S. foreign policy and national security."

Eliminating oil imports may prove infeasible, at least in the near future. Nonetheless, there is a strong drive to improve energy security by reducing U.S. dependence on oil imports to a level at which foreign exporting countries cannot use oil to constrain our foreign policy objectives. Much debate centers on the specific level of reduction that would lead to energy security defined in this manner, but the common perspective is that a meaningful reduction in oil use will be the key to a successful transition to a more secure energy supply.

2.1.2 Study Objective for Oil Reductions

This study uses ambitious targets for reducing oil consumption and CO_2 emissions as benchmarks for comparing policies' effectiveness and to provide a context for setting the stringency of policies. These targets should not be considered policy recommendations; rather, we use them as guideposts to examine how well each policy would perform.

The target reduction for oil was set at 4 mmbd from the baseline year, 2007, for the years 2020 and 2030. This represents an overall reduction of 20 percent of oil use, a 36 percent reduction of imports (assuming that all oil reductions are from reductions in imports), and a reduction in the oil import share from 57 to 36 percent (EIA 2010). If the United States accomplished a reduction of 4 mmbd by 2030, it would reduce the world's projected increase in oil use by 50 percent. If the rest of the world were to equal that reduction, projected global oil consumption over the next 20 years would remain roughly flat.

Notably, even in the absence of further policy changes, our baseline scenario results in total petroleum consumption that is 2 mmbd lower in 2030 than in 2007. This is the result of rising oil prices, tighter automobile fuel economy standards, and the substitution of ethanol for oil to meet the renewable fuel standards set by EPA. We therefore look for the policies—or, more likely, the crosscutting policy combinations—examined in this study to reduce oil consumption by an additional 2 mmbd beyond the baseline reduction in 2030.

2.1.3 Reducing All Oil Consumption vs. Imports

Our primary oil metric in this study is the impact of policies on overall petroleum consumption, rather than on oil imports alone. (We therefore do not examine policies that would focus on oil imports, such as an oil import tariff.) This decision is based on the logic that oil is a fungible commodity traded on a world market, and therefore policies addressing U.S. oil consumption will have implications throughout the world oil market. Consonant with this idea, Brown and Huntington (2010) show that the consumption of either imported or domestically produced oil will create energy security externalities (although they find somewhat greater externalities with imports).

For those who remain concerned about the shares of imported and domestic oil, our work finds that both oil imports and domestic production are reduced by the policies that reduce oil consumption, with a bigger share coming from reduced imports. Moreover, the share of any consumption reduction coming from imports is relatively stable across various policy scenarios, which suggests that reduced oil consumption is a very good proxy for security gains—even though the consumption of oil imports has a somewhat higher security externality than the consumption of domestically produced oil.

2.1.4 Natural Gas Security

Natural gas generates far less concern about U.S. energy security. The United States currently meets 89 percent of its natural gas needs from domestic sources and, although conventional gas production is declining, this is more than offset by the rapid expansion of nonconventional sources (Gabriel 2010).[3] In particular, significant new shale gas plays have been tapped in Texas, Arkansas, Oklahoma, and Appalachia, and developments in horizontal drilling and hydraulic fracturing technology have increased production rates. According to the Potential Gas Committee (PGC 2009), which audits natural gas reserves every two years, economically recoverable natural gas reserves in the United States have increased by 515 trillion cubic feet (Tcf), or 39 percent, in the last two years alone.

Given this abundance—and the low carbon content of natural gas compared to coal—many envision a role for natural gas as a *bridge fuel* during the transition away from traditional coal-fired electricity generation and toward a low-carbon future with generation from nuclear, renewables, and "clean coal" technologies. Natural gas has also been proposed as a bridge fuel for transportation, playing a role in a transition away from traditional fuel vehicles toward PHEVs (recharged with gas-fired electricity generation) and vehicles (particularly heavy-duty ones) that run on natural gas (Deutch 2010). Brown et al. (2009) and

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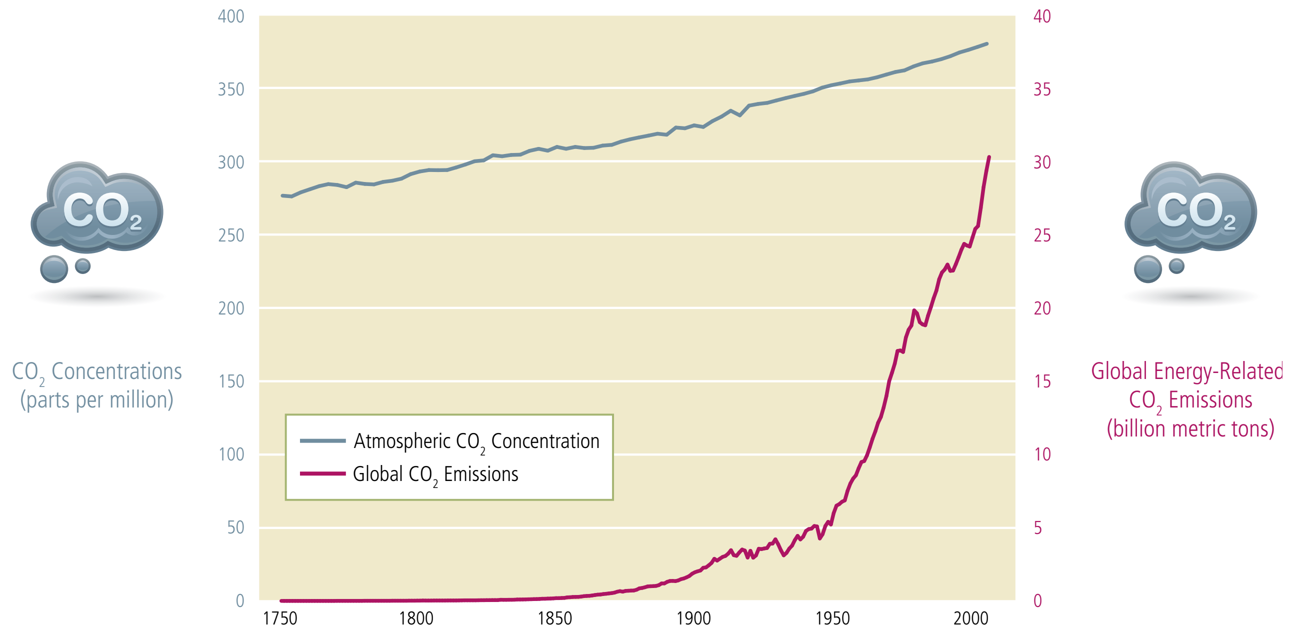
[3] Significant natural gas resources also remain untapped in Alaska; these resources could be transported to the Lower 48 states if the necessary pipeline infrastructure were developed. Currently, imports come in the form of pipeline gas from Canada and LNG from Trinidad, Tobago, Egypt, Nigeria, and elsewhere.

Figure 2.4: Global Annual CO_2 Emissions and Concentrations (Preindustrial to 2006)



Source: Etheridge et al. 1998; Tans n.d.; and Boden et al. 2010.

Brown et al. (2010) include more in-depth discussions of natural gas as a bridge fuel and the role that enhanced natural gas supplies may play in affecting other policies.

2.2 Climate Change

2.2.1 The Status of Global CO_2 and Other GHG Emissions

Concentrations of CO_2 in the global atmosphere have increased from preindustrial levels of about 280 parts per million (ppm) to current levels of about 385 ppm (Figure 2.4), largely as a result of the rising combustion of fossil fuels (IPCC 2007). Moreover, the total concentration of all GHGs—including methane and nitrous oxide from agricultural practices—in the atmosphere is about 435 ppm, with all gases expressed in lifetime warming equivalents to CO_2 (CO_2e). Without major efforts to mitigate global emissions, atmospheric concentrations of CO_2e are expected to double from preindustrial levels by midcentury, with developing country emissions rising above those for developed countries.

Why does this increase in concentrations of GHGs matter? According to IPCC (2007), these higher concentrations have contributed significantly to a rise in mean global temperature of about 0.75°C since 1900. Even with no additional increases in GHG concentrations, global temperatures are predicted to rise higher, as it takes several decades for the climate system to fully adjust to higher concentrations. Mean warming is projected to be 2.0, 2.9, or 3.6°C, for CO_2e concentrations stabilized at 450, 550, or 650 ppm, respectively—and a host of other climatic changes may accompany these warmer temperatures. Many areas are expected to experience more weather extremes. In many regions, stronger storms are anticipated;

prolonged droughts are forecast in other locations. Sea level rise is predicted in many areas of the world, altering land uses and ecosystems.

To address rising concerns over climate change, the Group of Eight (G8) large industrial countries (the United States, France, the United Kingdom, Germany, Japan, Italy, Canada, and Russia) has agreed to a target of limiting global warming to 2°C above preindustrial levels. The G8's stated goal of reducing global GHG emissions 50 percent by 2050, if applied relative to year 2000 emissions, would be more consistent with stabilizing atmospheric GHGs at about 550 ppm (Aldy et al. 2009), or a mean global temperature increase of 2.9°C above preindustrial levels. Given its responsibility for historical GHG accumulations, the G8 set a goal of reducing *developed* country emissions 80 percent by 2050 (although a baseline year was not specified), with progressively increasing reduction targets between 2010 and 2050.

There is considerable debate over whether these goals are feasible, especially as current total GHG concentrations are approaching 450 ppm. A recent Energy Modeling Forum study (Clarke et al. 2009) found that meeting a 450-ppm CO_2e stabilization target will require global GHG emissions to be reduced to close to zero or even to be negative after 2050 (see also Krey and Riahi 2009).

2.2.2 Study Objective for CO_2 Emissions Reductions

For the purposes of this study, we do not establish targets for all GHGs, but instead concentrate on reductions in domestic energy–related CO_2 emissions.[4] This is partly because many of the policies examined in this study affect only CO_2 (rather than all GHGs), but also because the costs and potential for valid reductions through non-CO_2 GHGs and emissions offsets (domestic and international) are highly uncertain.

Our benchmark goal for domestic energy–related CO_2 emissions is a cumulative reduction by 2030 of around 12,400 million metric tons (mmtons). These CO_2 reductions are approximately consistent with those in recently proposed federal legislation:[5] a 17 percent reduction in total GHG emissions by 2020 and a 42 percent reduction in GHG emissions by 2030, when compared against a 2005 baseline.

The bills' proposed targets are consistent with global CO_2e stabilization at 450 ppm only with the full and immediate participation of all major emitters, including major developing economies such as China and India. Realistically, most developing countries will probably delay participation in mitigation policy—and in that case, the C&T program described in the bills is instead consistent with a 550-ppm concentration where "overshooting" occurs (in which the ultimate GHG concentration goal is surpassed before the concentration is reduced, and the goal achieved, by the end of the century).

2.3 Defining Welfare Cost

Of the three metrics in our study—oil consumption, CO_2 emissions, and costs—costs are most prone to misinterpretation.

As detailed in later chapters, each expert involved in the production of this report calculated costs based on principles of welfare economics, which is the standard approach to measuring policy costs among economists (see, for example, Just et al. 2004). According to this definition, *cost* is the value of the resources society gives up to take a course of action intended to reduce dependence on foreign oil or reduce CO_2 emissions. Welfare costs summarize the costs to the economy of all different actions taken to reduce fossil fuel use. This would include, for example, such direct costs

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[4] The discussion in Chapter 6 on emissions pricing policies does consider other GHGs to some extent, as well as emissions reductions realized through carbon offsets.

[5] In particular, H.R. 2454, the American Clean Energy and Security Act, proposed by Representatives Waxman and Markey (referred to as Waxman–Markey or WM), was passed by the House of Representatives in June 2009; the draft Senate version, the Clean Energy Jobs and American Power Act, is sponsored by Senators Kerry and Boxer. Similar levels of reductions are reportedly proposed in upcoming Senate legislation sponsored by Senator Jeff Bingaman.

as producing electricity with cleaner but more expensive fuels. Welfare costs also include the less obvious costs to households from driving less or utilizing fewer energy-using products and services than they would otherwise prefer.

It is often easier to define welfare costs by what they are not. They are not measured in terms of *job losses* in industries most directly affected by new policies. Many of those jobs are usually made up by other sectors of the economy after a period of time.

Welfare costs also are not measured by changes in GDP. Welfare economics in general is associated with impacts on private consumption and production, but GDP includes investment and government spending. GDP also fails to capture non-market values, such as environmental damages, that can be important for welfare costs. GDP also can sometimes be misleading: a regulation or policy that leads to the use of a higher-priced alternative and raises product prices may actually increase GDP, but this provides little information about the actual costs of the policy. For broad-based policies, such as C&T, that make their impacts felt across many markets and sectors of the economy, GDP can be a somewhat useful metric, but it is problematic for other policies.

Welfare costs are not concerned with who pays. Thus, transfers between producers and consumers or between consumers and the government are not welfare costs. This means also that tax revenues raised through oil or gasoline taxes are not part of welfare costs, nor are subsidy payments for hybrid electric vehicles (HEVs) or geothermal heat pumps (GHPs). These are simply transfers from one segment of society to another.

The welfare cost concept has been endorsed by governments around the world for purposes of evaluating regulations, government investments, taxes, and other policies. In the United States, a series of executive orders, dating from the Carter administration to the present, has made it mandatory for government agencies to perform cost–benefit analyses (CBAs) using welfare economics to determine whether their planned "major" regulations are justified from society's point of view. Hundreds of regulatory impact analyses are performed every year, with welfare cost estimates as a key component.

Policies usually act over a number of years. Some policies, like those affecting travel demand, have immediate costs and effects on oil use or CO_2 emissions, whereas others have high up-front costs, followed by years of energy savings and reductions in oil use and CO_2 emissions. We want to express costs and the cost-effectiveness of policies with different time profiles of effects in a consistent and comparable manner.

Because incurring costs in the future is less costly from today's vantage point than incurring the same costs today,[6] we want to give credit to policies that delay their costs more than another policy (given the same costs for both). This is another way of saying that costs incurred in the future must be discounted back to the present, calculating what is termed the *present discounted value* (PDV). To make this calculation requires that one choose a discount rate as well as a reference year to which to discount (in this case, the chosen reference year is 2010). Typical options for the discount rate are the social rate of discount and the market rate of interest. We use a social rate of discount, set at 5 percent, because this rate is often used by the government in policy decisions. We apply this rate to all policies except those targeted to obtain fuel cost or efficiency savings associated with EE investments (see Box 2.1).

2.3.1 Measures of Cost-Effectiveness

Welfare costs by themselves are not enough to rank policies; it is important to compare their costs and effectiveness jointly. Both CBA and cost-effectiveness analysis (CEA) do this: the former monetizes all of the positive effects of a policy and compares them to the costs, and the latter divides costs by a particular physical measure of effectiveness—in this case, barrels of oil or tons of CO_2 emissions reduced.

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[6] The basic reason is that interest can be earned on money saved or invested—in other words, money has a time value.

Given the difficulty of monetizing the benefits of reducing oil dependence and CO_2 emissions, this study focuses on CEA and comparisons across policies. CEA helps identify the policy or policies that achieve the greatest bang for the buck in terms of reducing emissions or oil by a given amount at the lowest economic cost. Because we are using two cost-effectiveness metrics (reductions in oil consumption and in CO_2 emissions), it is possible that a given policy will score relatively well on one of these and poorly on the other.

At the same time, calculating cost-effectiveness requires that we address what economists call the *joint cost allocation* problem. When policies have multiple outcomes, it is difficult to know how to allocate the costs across those outcomes to assess cost-effectiveness. To give a simple example, consider a policy with welfare costs of $100 that leads to a reduction of two tons of CO_2 emissions and four barrels of oil use. Cost-effectiveness is then calculated as $50 per ton for carbon and $25 per barrel for oil, when actually costs are $100 to jointly obtain a two-ton carbon reduction *and* a four-barrel reduction in oil use.

The approach followed in this study is to categorize each policy based on its primary area of impact (reductions in oil consumption or CO_2 emissions), allowing us to rank the carbon policies and the oil reduction policies separately—and essentially consider the reductions achieved in the other metric as unimportant. This approach is more problematic the more policies obtain significant reductions in both metrics.

The issue of joint allocation is most prominent in Chapter 7, where we examine the crosscutting policies that target reductions in both oil and carbon. Standard CEA cannot be used for such policies, as neither effectiveness metric is more prominent than the other.

In this case (and even in the case of single policies), several other options are available to address joint allocation of costs for crosscutting policy combinations. One is to assign weights to each effectiveness metric, and then to use both weighted measures to calculate total cost-effectiveness. The most appropriate way to assign weights is to base them on the (monetary) benefit per ton of reduction in CO_2 and the benefit per barrel of reduction in oil use—but there is substantial disagreement on what these weights should be, making this approach problematic.

A second approach is to calculate monetary (welfare) benefits for one of the effectiveness metrics and subtract them from costs, still dividing by the other effectiveness metric; this approach is termed *net* cost-effectiveness. The virtue of this approach is that only one of the two effectiveness metrics needs to be monetized. But, again, with no agreement on benefits, this method is not very promising. A third approach, and the one we take in this report, is to simply present the PDV of welfare costs (rather than cost-effectiveness) and the effectiveness measures together for each of the crosscutting policy combinations.

One final issue of nomenclature: although an increase in cost-effectiveness may intuitively seem to indicate an improvement, in fact the opposite is true. A decrease in cost-effectiveness indicates a lower cost per ton or barrel, and therefore an improvement; this is an important detail to consider when comparing policies. In referring to cost-effectiveness, we also occasionally use the interchangeable term *average cost*.

2.3.2 Calculating Costs and Cost-Effectiveness over Time

On the cost side, when policy costs or savings occur over time, their PDV is calculated. In this report, we express the PDV in year 2010 for all policies. Investment costs are counted in the year in which they occur and are counted only when they occur within the study period (2010–2030). Cost savings, however, will occur over multiple years, depending on the economic life of the asset being purchased. Vehicles may last 15 years, houses far longer and, in calculating cost-effectiveness, we therefore count savings over the full economic life of the investment, up to 2050. As NEMS–RFF does not predict fuel prices and other necessary information beyond 2030, reasonable assumptions are made about savings beyond that date. These savings, as noted above, are then discounted back to the year in which the investment is made, creating a net cost estimate for that year. Then this estimate is discounted back to 2010 at a 5 percent rate.

On the effectiveness side, NEMS–RFF projects reductions in CO_2 emissions and oil use associated with the investments up to 2030. Once these physical effects have been expressed over time, a valid question is whether these effects should also be discounted back to 2010. Discounting physical units is controversial and in some cases misleading, however; we therefore simply sum emissions and oil reductions over the forecast period and do not discount.

Box 2.1: Calculating Policy Costs at Varying Discount Rates: Alternative Interpretations of the Energy Paradox

Many studies have shown that investing today in energy-efficient technologies will return fuel savings that significantly outweigh the initial investment cost over the lifetime of the purchase—but that businesses and consumers often reject such investments. This inconsistency is referred to as the energy paradox, and it appears to occur because of possible hidden costs or market failures. As a result, businesses and consumers may demand payback periods of perhaps 4 years or less on investments with lifetimes of 15 to 50 years, implying required rates of return that are well above market rates, perhaps as high as 40 percent.

The alternative explanations for this paradox can be modeled in different ways, where the easiest model to understand is the use of alternative discount rates. A discount rate represents how much consumers would be willing to pay today for a benefit they will receive in the future. Higher discount rates mean that consumers value the future benefit less than they would with a lower discount rate.

Our No Market Failure case is based on the observed behavior of consumers. We can summarize their reluctance to invest in energy efficiency by using discount rates, embodied in the NEMS–RFF model, that are much higher than market interest rates. Underlying the use of these high rates is the idea that consumers' behavior is rational because there are unpriced or hidden costs associated with the technology. For example, perhaps the new technology proves to be unreliable, or performs its task less well than the technology it replaces.

In contrast, the Complete Market Failure case can be represented by using the social discount rate (5 percent) to value energy savings over the lifetime of the investment. In this case, the energy paradox is explained entirely by market failures (e.g., consumers with short horizons or imperfect information about energy-saving benefits). In the absence of any policy, consumers would invest inadequately in EE because consumers as individuals value it less than society does. A lower interest rate increases the social value of fuel savings, implying a lower cost for any policy that promotes EE investments. Indeed, costs could even become negative.

The No Market Failure and Complete Market Failure cases provide upper-bound and lower-bound estimates of the net costs of efficiency investments. Our third case, the Partial Market Failure, represents a compromise between these two bounding cases. Here the discount rate is 10 percent or the study experts' best judgment about how much of the energy paradox can be explained by market failure versus hidden costs.

2.4 Additional Metrics

The key metrics highlighted in this study are central to policy evaluation. However, other metrics also will likely be of interest—for example, changes in energy expenditures and the distribution of those expenditures across sectors, income groups, regions, and other demographic groups. Measuring these outcomes is beyond the scope of the initial phase of this study, but we acknowledge their relevance and anticipate exploring these additional metrics in future work.

A number of other important impacts are qualitative in nature, or at least are difficult to quantify—for example, a policy's political feasibility; its administrative, transaction, and enforcement costs; or its revenues to the government. We do not attempt to estimate these costs or revenues, although we again acknowledge their relevance and include discussion where appropriate.

As noted, this study focuses on true welfare costs or, in some cases, welfare benefits that can be subtracted from costs. We have captured these quantifiable costs, but with the exception of tallying CO_2 and oil consumption reductions, we have neither converted them into benefits nor captured any of the ancillary quantifiable benefits.

For example, two significant additional benefits of policies to reduce oil consumption are the reduced probability of oil spills and the lessening of conventional air pollution, particularly energy-related pollutants regulated under the Clean Air Act (primarily nitrogen oxides, sulfur dioxide, direct particulates and their secondary air pollution products, ozone, and accompanying volatile organic compounds). Health benefits of reductions in these pollutants include lowered risks of premature death, reduced hospital admissions, and fewer respiratory symptoms. A substantial literature aims to quantify and monetize these effects—this includes a recent National Research Council report (NRC 2009d) that measures emissions by fuel type and links them to health endpoints. Although the NRC report and similar studies cannot be used directly to attribute monetary benefits to particular policies, they can help identify the benefits of reductions in fuel use in particular sectors.

Other largely external impacts include changes in roadway congestion and safety (from motor vehicle travel, nuclear plant operation, and so on). Although these were not a focus of the present study, in some cases the study's experts chose to quantify and discuss these ancillary impacts, which are examined further in Chapter 9 and Appendix D. For example, good estimates exist in the economics literature on the benefits of reducing congestion and accident externalities; the work by Small (2010) discusses these benefits.

Finally, we mention in several places that some policies spur the development of new markets, which can lead to *learning by doing* and can ultimately bring down the costs of new technologies. These benefits of a policy are difficult to quantify and the extent to which they exist, though beyond our scope, would be a useful subject for another study.

A defining feature of this study is its use of the same economywide model across all policy simulations (NEMS–RFF). Policy effects and costs are computed against a reference case developed in NEMS–RFF, based on data included in DOE's *Annual Energy Outlook 2009,* and including relevant measures in the February 2009 American Recovery and Reinvestment Act stimulus legislation. Also included in the reference case is the advanced timetable for future automobile fuel economy standards, signed into law by President Obama in May 2009.

3. Study Methodology

As noted, a defining feature of this study is its use of the same economywide model across all policy simulations, leading to the development of a consistent set of quantitative metrics from that model.

Policy effects and costs are computed against a Reference case developed in NEMS–RFF, based on data included in DOE's *Annual Energy Outlook 2009,* or *AEO2009* (EIA 2009d), and including relevant measures in the February 2009 American Recovery and Reinvestment Act (ARRA) stimulus legislation. Also included in the Reference case is the advanced timetable for future automobile fuel economy standards, signed into law by President Obama in May 2009.

Compared with *AEO2008*, one of the most notable changes in *AEO2009* is a much higher temporal profile for oil prices, peaking at $131 per barrel in 2030. The recently released *AEO2010* (EIA 2010) also differs from *AEO2009*, most notably by the inclusion of more optimistic estimates of natural gas resources. We also update NEMS–RFF to reflect more optimistic natural gas resource estimates, with results reported in Chapter 4, Box 4.2.

3.1 About NEMS

Consistent evaluation of the policies compared in this study requires a comprehensive and detailed energy–economic model that can handle policies covering a wide range of fuels, technologies, and sectors. It is also essential that the model be well understood and widely accepted by the energy policy community. For these reasons, the project team selected NEMS, maintained and used by EIA, for much of their forecasting and policy analyses. Nearly all modeling efforts of U.S. policies rely on EIA for baseline forecasts and, although a number of other energy–economic models are available, only NEMS has the sectoral disaggregation and detail needed to model the diverse range of policies considered here.

NEMS is an energy systems model, also often referred to as a *bottom-up* model. Such models incorporate considerable detail on a wide spectrum of existing and emerging technologies across the energy system, while also balancing supply and demand in all (energy and other) markets of the economy.

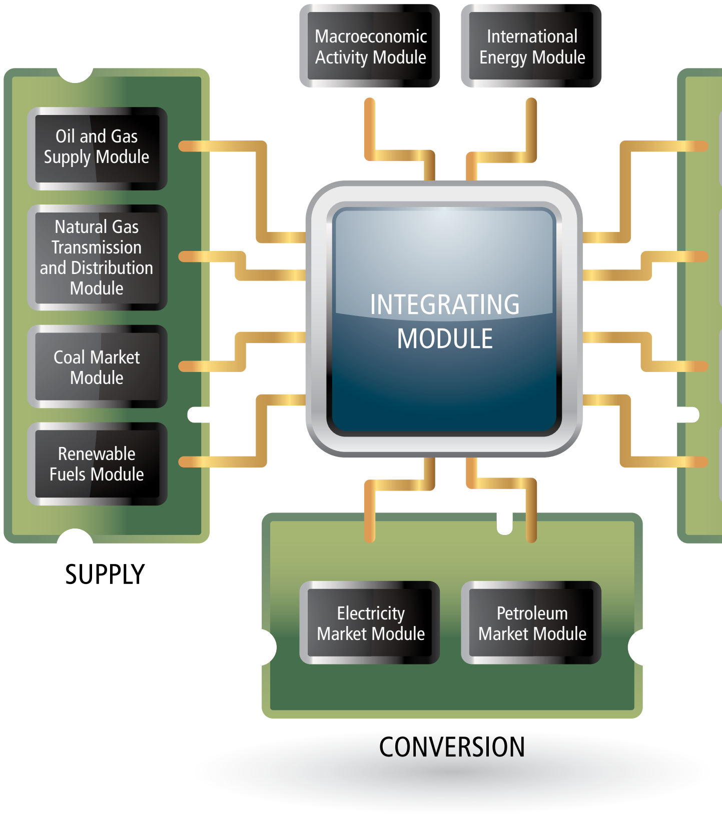
NEMS is modular in nature (Figure 3.1), with each module representing individual fuel supply, conversion, and end-use consumption for a particular sector. The model solves iteratively until the delivered prices of energy are in equilibrium. Many of the modules contain extensive data: industrial demand is represented for 21 industry groups, for example, and light-duty vehicles are disaggregated into 12 classes and distinguished by vintage. The model also has regional disaggregation, taking into account, for example, state electric utility regulations.

It also incorporates existing regulations, taxes, and tax credits, all of which are updated regularly; this is another reason that NEMS was selected for this study. The detail in the model allows for scrutiny and interpretation of specific policies, such as a production tax credit for a particular renewable fuel or a change in appliance efficiency standards.

3.2 How NEMS Models Policies

To model the effects of specific policies, researchers change various "levers" within NEMS. For example, automobile fuel economy standards are incorporated into the NEMS transportation

Figure 3.1: Visual Representation of NEMS Modules



Source: EIA (2009c).

module, along with costs of various technologies to achieve higher fuel efficiency. The costs incurred to meet a tighter standard will be captured as the model solves for a new equilibrium with altered vehicle stock, miles traveled, gasoline consumption, and prices.

In other cases, the project team made modifications to underlying assumptions in the model to represent policy changes. A good illustration is the *return on equity* (ROE) required for investments in new nuclear plants. The ROE can be altered in NEMS to simulate the impact of a federal loan guarantee policy that would reduce the risk premium required by investors associated with investments in nuclear plants.

Finally, for some scenarios, we adjusted underlying assumptions in NEMS that affect the Reference case. These changes are explained and justified in more detail in individual policy chapters or in the accompanying technical reports.

3.3 Understanding the Limitations of NEMS

Although NEMS is a powerful and flexible tool, like any model, it has limitations.

One weakness (for the purposes of this study) is that NEMS does not provide estimates of welfare costs associated with policy scenarios. Although we used NEMS output to estimate welfare costs, these were “offline” calculations that we made outside of the model.

Another drawback is that NEMS does not always adequately represent the full range of behavioral responses to policies. For our purposes, an important example of this is the limited possibilities for conserving oil use in the freight truck, air travel, and industrial sectors. In evaluating policies that raise the price of all oil products, we made adjustments to the model results to reflect greater price responsiveness in these sectors.

The transportation side of the model faces limitations, including issues with substitution between vehicle size classes and the treatment of hybrid vehicles in compliance with CAFE standards. In addition, although NEMS is updated regularly, it may nonetheless include assumptions that seem out of date or too conservative. The experts involved in the project were given the option to modify various parameters in NEMS to better represent, in their judgment, more realistic assumptions.

As an example, although natural gas prices and oil prices have historically moved together (Brown and Yücel 2008), in NEMS, these two prices are decoupled, with projected natural gas prices that are well below projected crude oil prices. This is most influential when considering fuel switching between natural gas and oil in the industrial sector; NEMS shows little opportunity for substitution, whereas other studies (e.g., Huntington 2007) find that this substitution is more sensitive to price differentials than NEMS suggests. Another example concerns the residential module in NEMS. Some restrictions are placed on the types of space-heating and -cooling equipment that are chosen in response to price changes. These restrictions are incorporated to better reflect the observed behavior of consumers, but they limit the responsiveness of some of our policies. For our case study of GHP policies, included in our EE analyses, we alter these assumptions to make the model more responsive.

Finally, NEMS, like any other model, is most reliable at predicting the effects of incremental changes. The effects of revolutionary policies and large technological breakthroughs are probably not well captured in NEMS (or most other models).

3.4 Assumptions in NEMS–RFF

Below are several key assumptions in NEMS–RFF; some of these stem directly from NEMS and others were put in place by the study team.

- The time period for policy implementation and the baseline is 2010–2030, although not all policies begin in 2010 and some ramp up over time.
- The version of NEMS that we refer to as NEMS–RFF includes the impacts of the ARRA and moves the deadline for meeting new CAFE standards from 2020 to 2016.
- Projected GHG emissions do not include full life cycle emissions.
- Revenues from auctioned carbon allowances or taxes are recycled to individuals (lump-sum), with recycling in amounts intended to produce deficit neutrality.
- Imported oil prices are projected to rise to $131 per barrel by 2030.
- Electricity prices are set by a combination of cost-of-service regulation and competitive markets, depending on the region.
- The demand modules use a variety of methods to evaluate energy equipment and energy efficiency. The net effect is generally equivalent to a discount rate of 10 to 40 percent or more.
- Vehicle fuel-saving technologies are evaluated assuming a three-year payback period at a 15 percent discount rate.
- In terms of vehicle choice (over vehicles of different size classes and fuels), the model considers multiple vehicle attributes, including price, cost of driving, vehicle range, and performance.
- For this study, we modified NEMS to allow (but not force) greater penetration of hybrid vehicles than EIA's reference case for passenger vehicles.
- In the oil tax and other cases, we adjusted the elasticity of oil demand in the industrial sector to be roughly equal to –0.2.
- Some runs use EIA's high-tech assumptions for energy efficiency technologies.
- Some runs substitute battery costs that are below those found in NEMS.
- Some runs include modified *switching costs* between heating system technologies to allow for more flexibility in consumer choice when purchasing new heating systems.

In the reference case, total oil consumption is predicted to drop by just under two million barrels per day by 2030, compared to 2007 levels. Total imports of crude oil and associated products are predicted to drop to 8.2 million barrels per day in 2030, compared with imports of 12.1 million barrels per day in 2007, and total U.S. greenhouse gas emissions are predicted to rise by 9 percent.

4. The Reference Case in NEMS–RFF

Examining the effects of any particular policy requires comparison to a baseline. For the purposes of this study, policies were compared to a business-as-usual Reference case that closely resembles *AEO2009* + Stimulus. In addition, a key variant of the Reference case includes updated information on natural gas supply (see Box 4.2).

This section describes some of the key baseline data and trends in the Reference case.

4.1 Oil Consumption, Oil Imports, and GHG Emissions

In 2007, the United States consumed just under 20 million barrels of petroleum per day. The transportation sector was responsible for 69 percent of this consumption in 2007, with light-duty passenger vehicles and freight trucks using 61 percent and aircraft using 8 percent (Figure 4.1(a)). Outside of transportation, industry is currently the major consumer of petroleum products, accounting for 24 percent of the nationwide total.

How does oil consumption fare in the Reference case? As noted, total oil consumption is predicted to drop by just under 2 mmbd by 2030, compared to 2007 levels. Total imports of crude oil and associated products are predicted to drop to 8.2 mmbd in 2030, compared with imports of 12.1 mmbd in 2007. Besides reduced consumption, this decline also reflects projected increases in domestic production in response to rising oil prices.

Diesel fuel use by trucks increases by 33.5 percent during 2010–2030, and jet fuel increases 40 percent (neither of these transportation modes is currently subject to fuel economy regulations). On the other hand, industrial uses of petroleum fall 10 percent over the period, reflecting the relatively larger scope for adoption of energy-saving technologies in that sector in response to higher oil prices. Consequently, the sources of petroleum use look somewhat different in 2030, with industry's share falling to 20 percent and the light-duty vehicle share to 38 percent, whereas the shares for freight trucks and jet fuel rise to 20 and 10 percent, respectively (Figure 4.1 (b)).

Figure 4.2 shows trends in oil consumption, imports, and oil intensity beginning in 1975 and continuing through the end of the project period. Unless otherwise noted, all figures in this chapter refer to the Reference case.

4.1.1. Comparing Oil Consumption in *AEO2009* vs. *AEO2010*

This study is built on data from *AEO2009*, which was the most recent *AEO* available when this study was launched. More recently, a new version—*AEO2010*—has been released, which includes different assumptions about oil price paths, biofuels consumption, natural gas inputs, and more. A comparison of oil consumption trends between this study's Reference case (similar to *AEO2009*) and *AEO2010* illustrates how different assumptions—many of which are highly uncertain—can have a significant effect on key metrics.

Figure 4.1(a): Total Oil Consumption by Sector, 2007

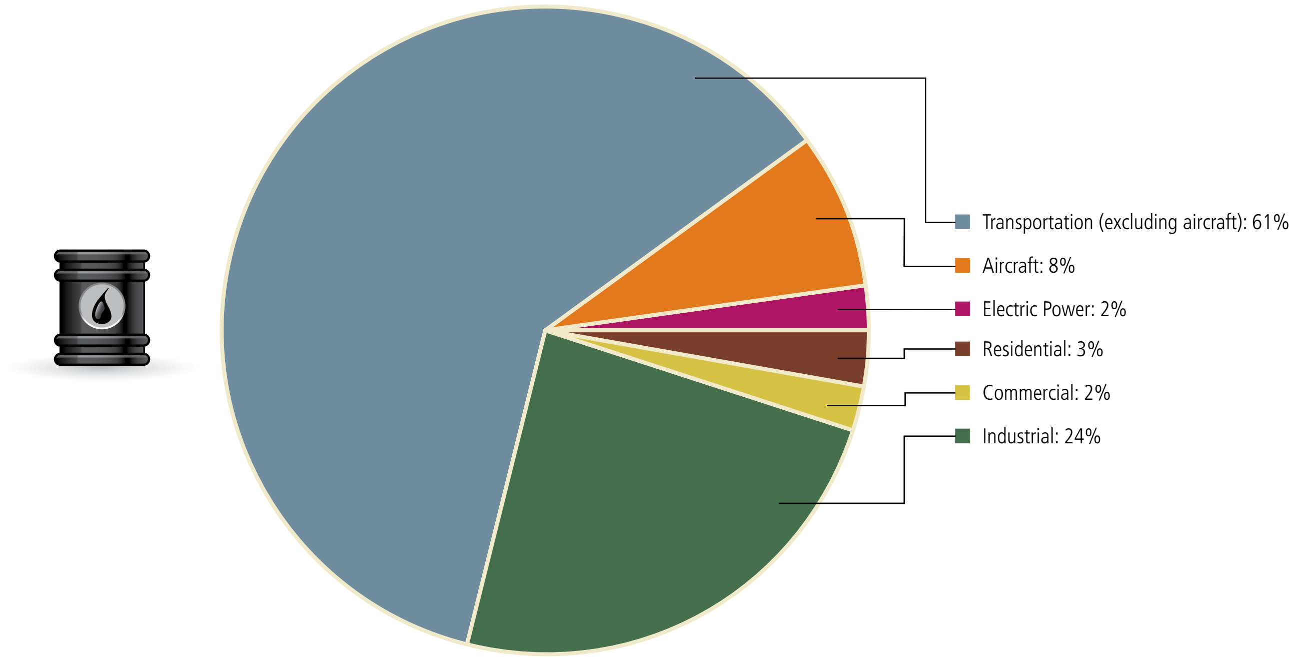


Figure 4.1(b): Total Oil Consumption by Sector, 2030

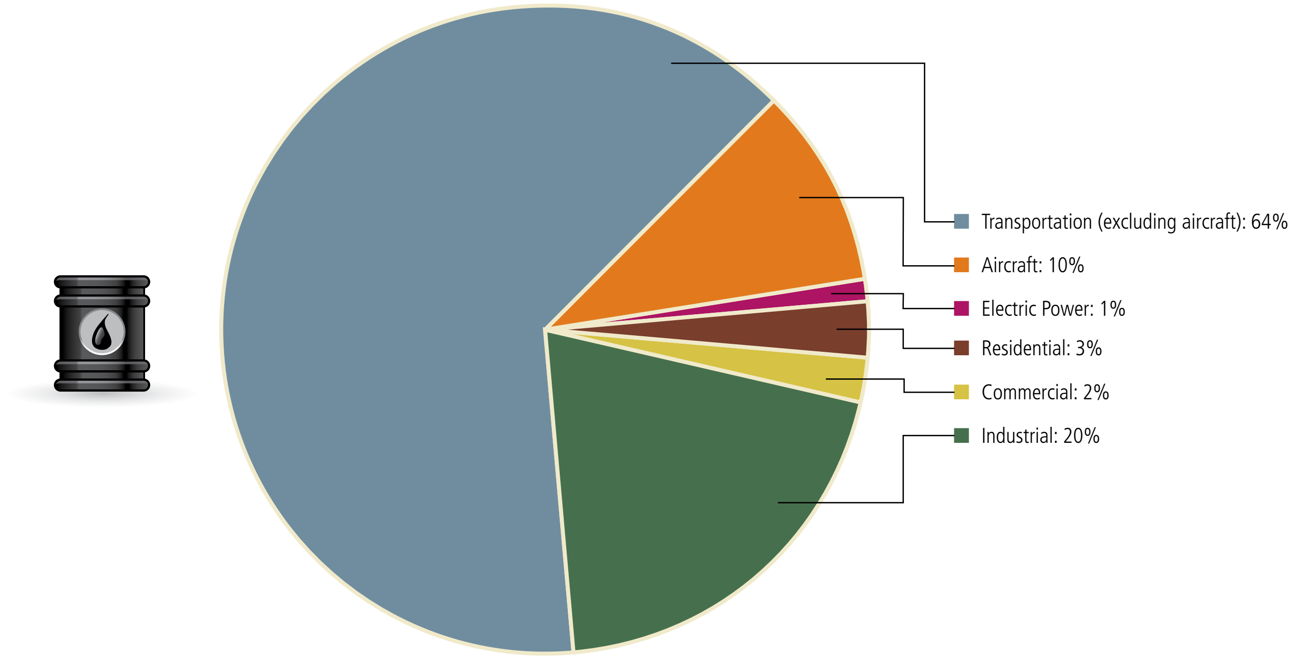


Figure 4.2: Trends in Oil Consumption, Oil Imports, and Oil Intensity

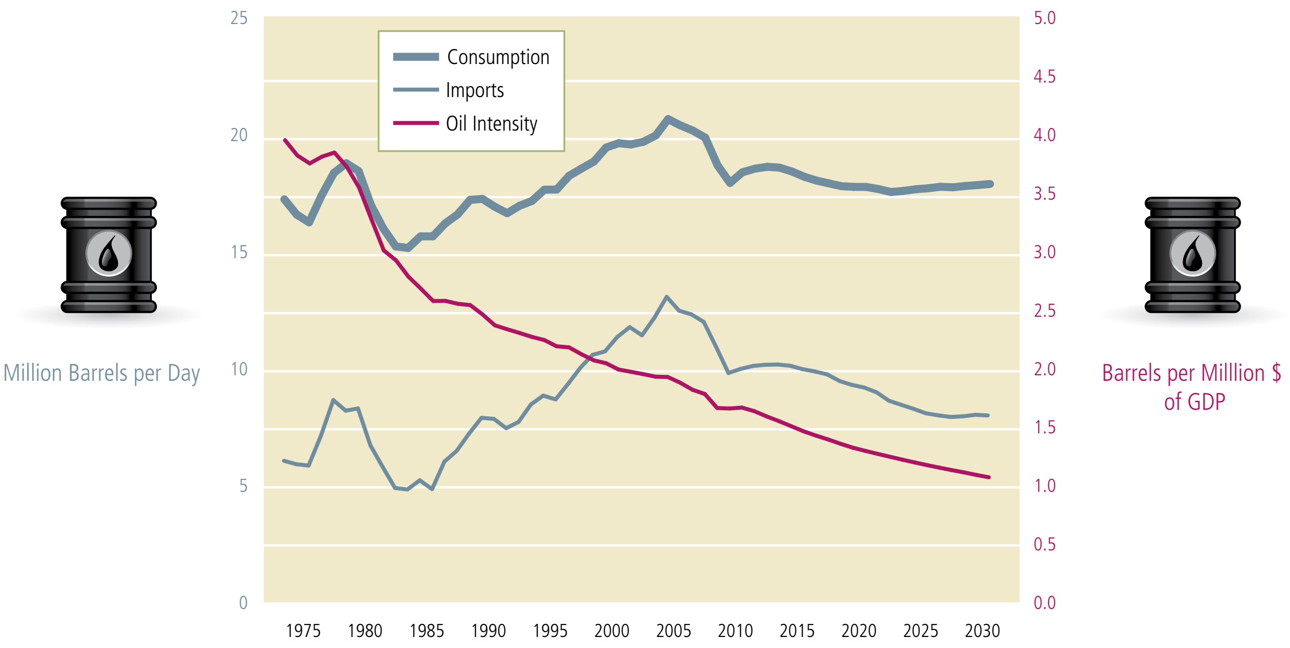
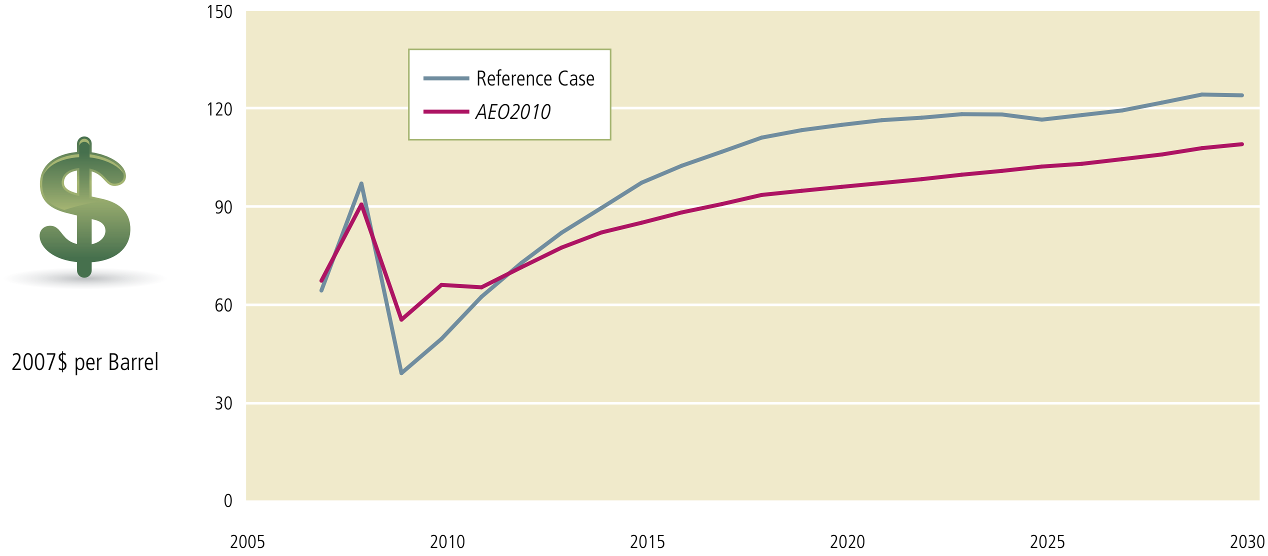


Figure 4.3: Oil Price Paths in the Reference Case (based on *AEO2009* and *AEO2010*)



For example, *AEO2010* shows a reduction in total petroleum consumption between 2007 and 2030 of about 1.1 mmbd compared to a reduction of 2 mmbd found in our Reference case. Given this study's target reduction of 4 mmbd, under *AEO2010* assumptions, the burden of reductions in oil use on *new* policies would be significantly larger: 0.77 mmbd more to meet the target in 2020 and 0.86 mmbd more to meet the target in 2030. One contributing factor is the different price path of oil found in the two cases, as shown in Figure 4.3.

Overall, the differences between the Reference case and *AEO2010* illustrate the reality of dealing with fluid projections in long-term modeling exercises. The policy comparisons contained in this study remain useful, especially in terms of policies' relative impact when compared to each other, but they may result in different absolute reductions when interacted with a different projected future.

4.2 GHG Emissions

Total U.S. GHG emissions are predicted to rise by 9 percent in the Reference case, from about 7,280 mmtons of CO_2e in 2007 to about 7,950 mmtons in 2030. Similarly, energy-related CO_2 emissions are predicted to rise from around 5,990 mmtons in 2007 to 6,190 mmtons in 2030. The electricity sector accounts for 42 percent of CO_2 emissions (or 33 percent of total GHGs) at this date, and the transportation sector accounts for 33 percent (or 28 percent of total GHGs). Direct fuel consumption in the industrial, residential, and commercial sectors accounts for a further 15, 6, and 4 percent, respectively. Non-CO_2 GHGs (e.g., methane and nitrous oxides from agricultural sources) contribute a further 22 percent to total GHGs.

Figures 4.4, 4.5(a), and 4.5(b) summarize key trends in energy-related emissions of CO_2 and other GHGs in the Reference case.

Figure 4.4: Trends in U.S. Energy-Related CO_2 and GHG Emissions, 1975–2030

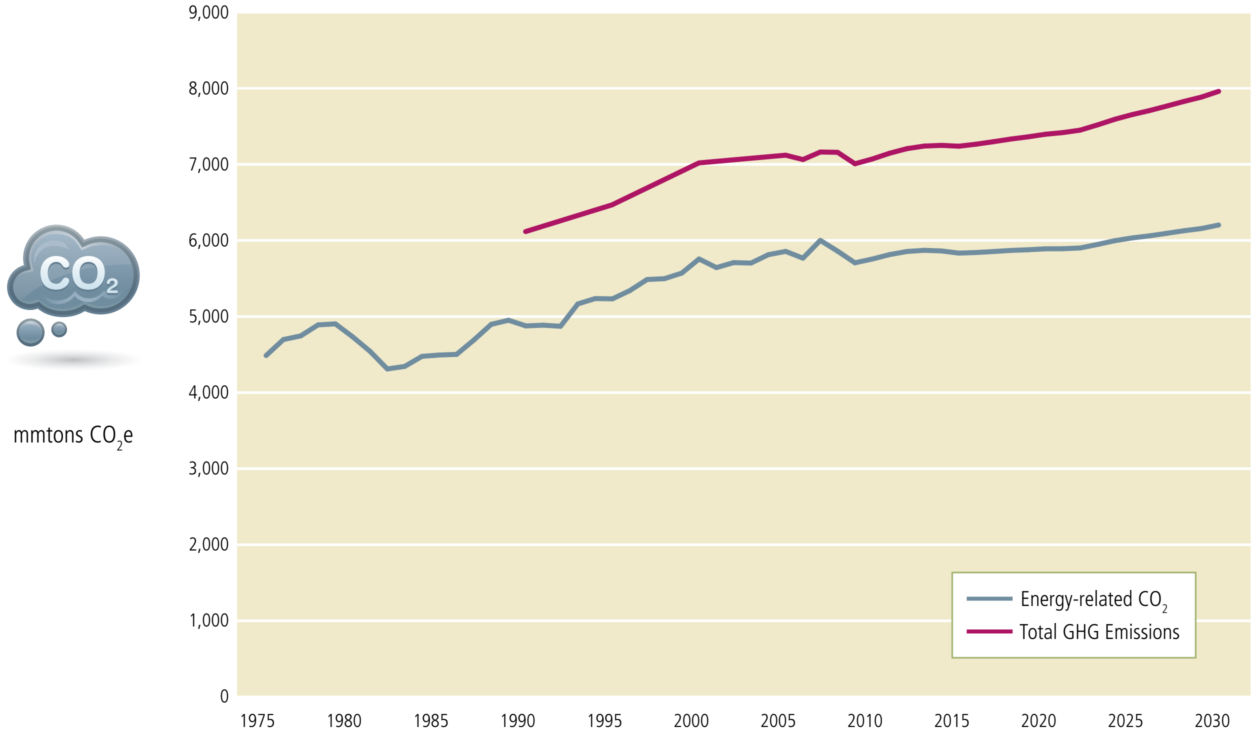


Figure 4.5(a): GHG Emissions by Sector, 2007

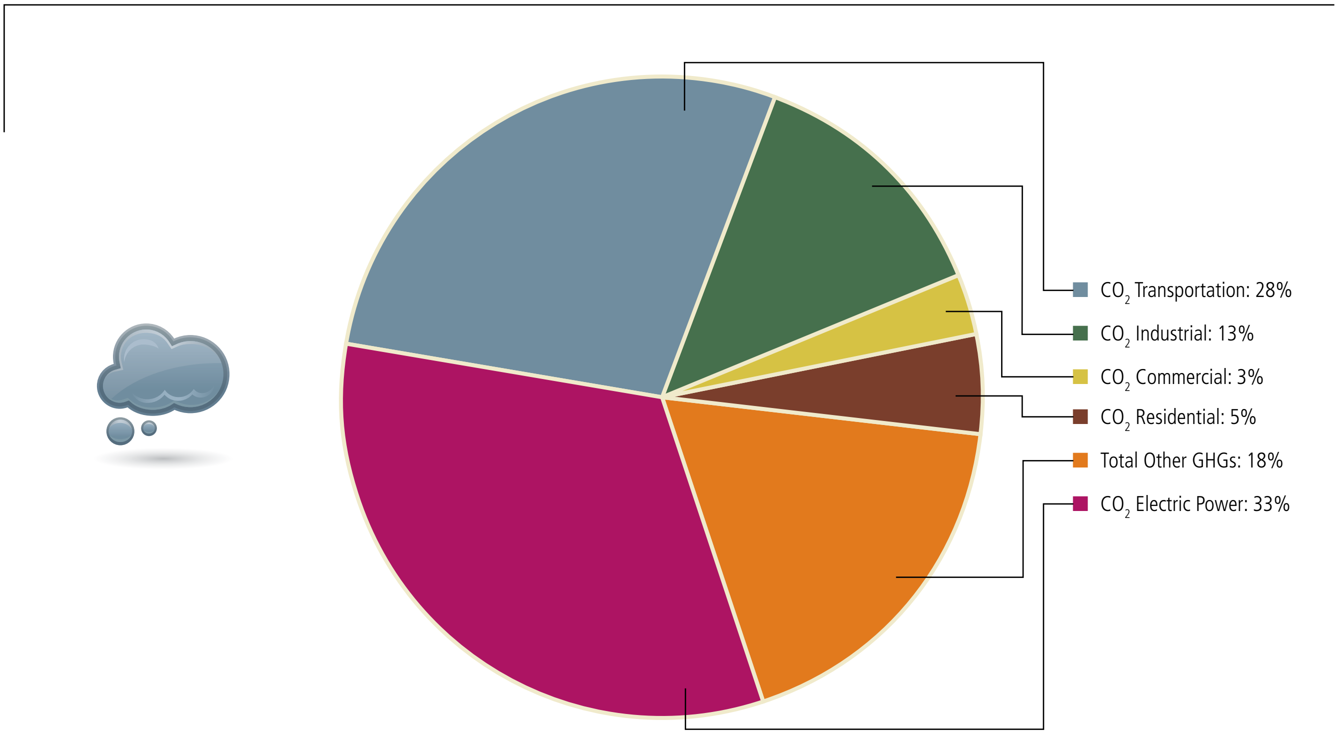
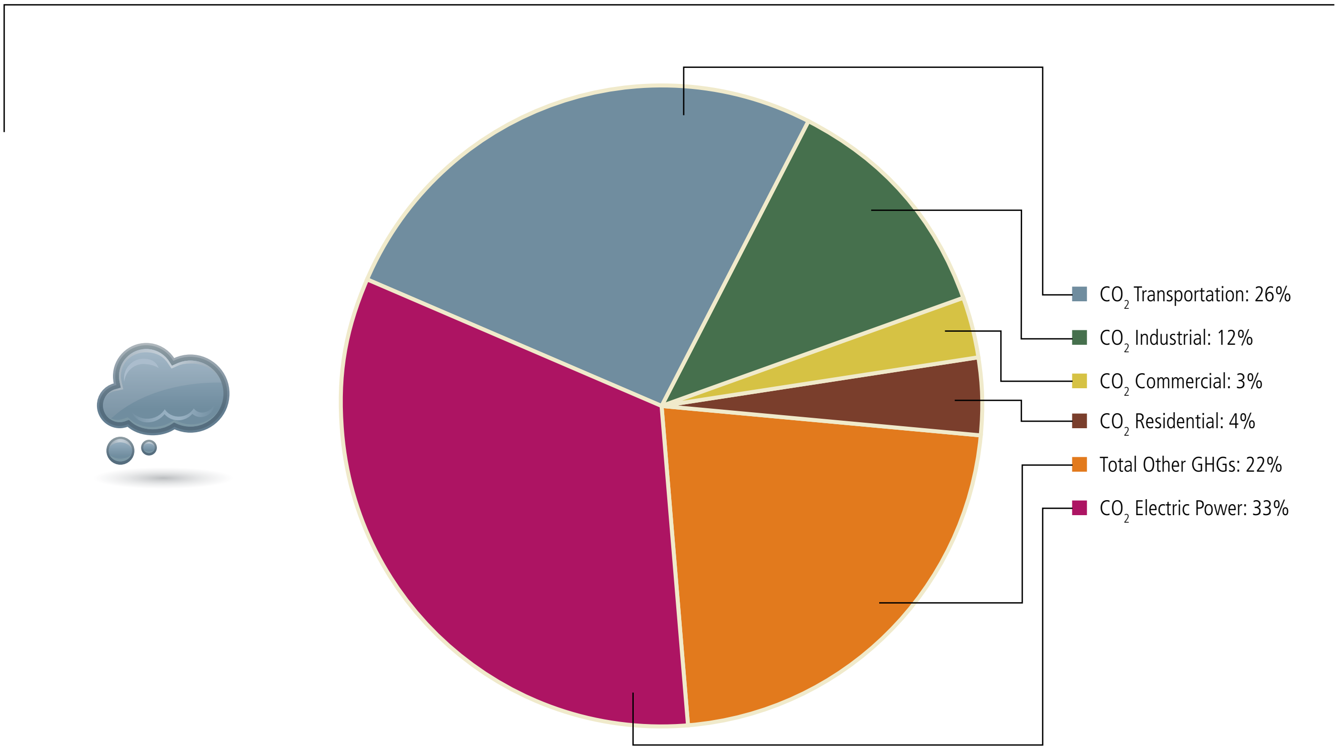


Figure 4.5(b): GHG Emissions by Sector, 2030



4.3 Transportation Trends

Although the number of vehicle-miles traveled (VMT) by light-duty vehicles is projected to grow by 42 percent between 2010 and 2030 (as a result of continued growth in population and real income), the extra fuel demand required for this travel is largely offset by an improvement in vehicle fuel economy over the period.

The share of light-duty trucks (sport utility vehicles, minivans, and pickups) in new-vehicle sales in the reference case falls from 51 percent to 37 percent over the project period, as rising fuel prices increase cars' attractiveness to consumers and new fuel economy requirements are more onerous for light trucks.

Another notable trend is the rising penetration of HEVs, which increase from 2.3 percent of combined car and light truck sales in 2010 to 21.1 percent by 2030, encouraged by a combination of higher fuel prices and tightening fuel economy standards. The penetration of PHEVs is far more limited, reaching only 2.7 percent of sales by 2030.

4.4 Electricity Generation Trends

Total electricity generation is predicted to grow steadily in the Reference case throughout the project period, from 4,159 billion kilowatt-hours (kWh) in 2007 to 5,058 billion kWh in 2030 (Figure 4.7). Figures 4.8(a) and 4.8(b) show the mix of fuels used to generate electricity in 2007, and in the Reference case in 2030. One particularly notable feature is the growth in nonhydro renewables predicted over the period, spurred in part by state renewable portfolio standard (RPS) regulations.

Figure 4.6(a): Vehicle Sales by Vehicle Type, 2007

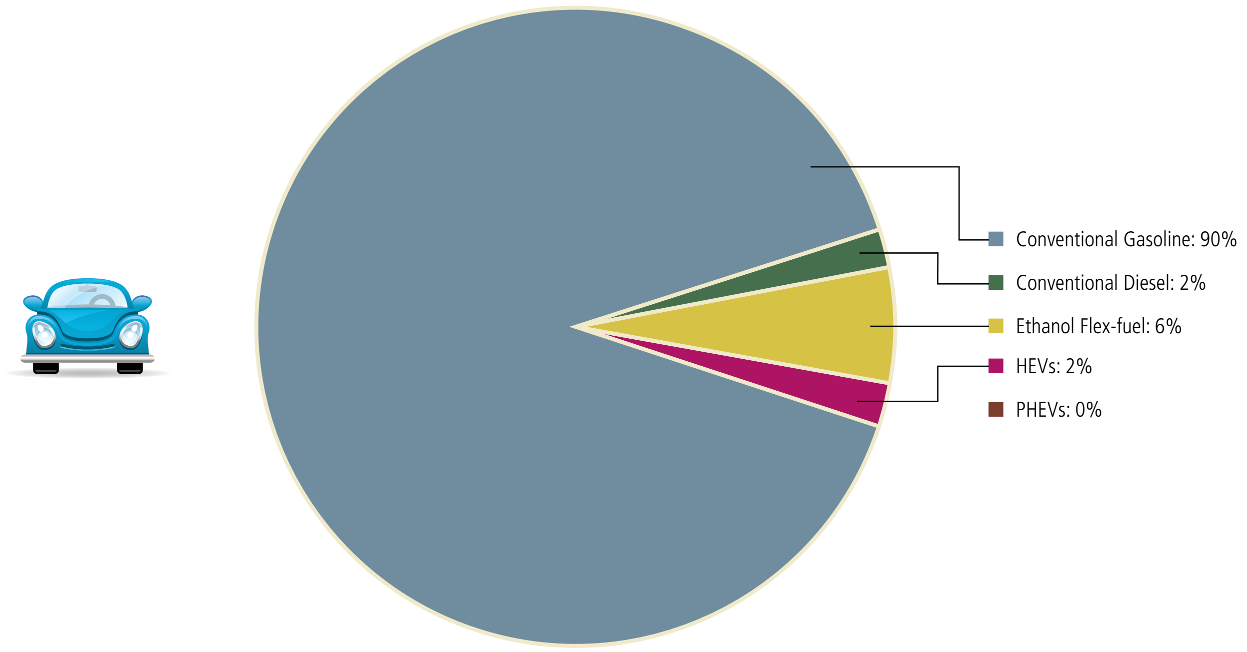


Figure 4.6(b): Vehicle Sales by Vehicle Type, 2030

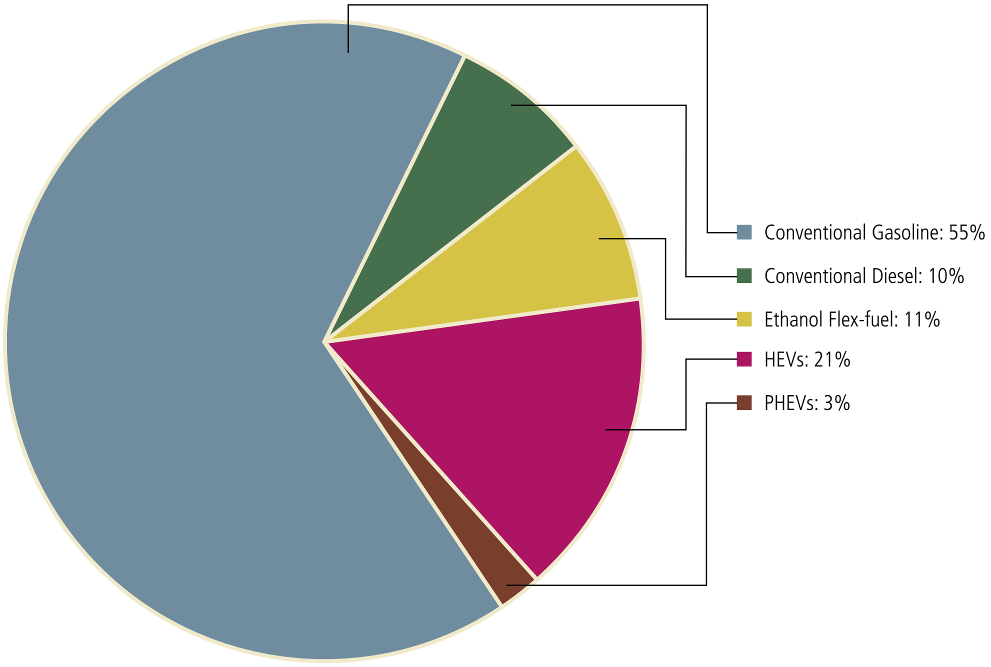


Figure 4.7: Total Electricity Generation, 2001–2030

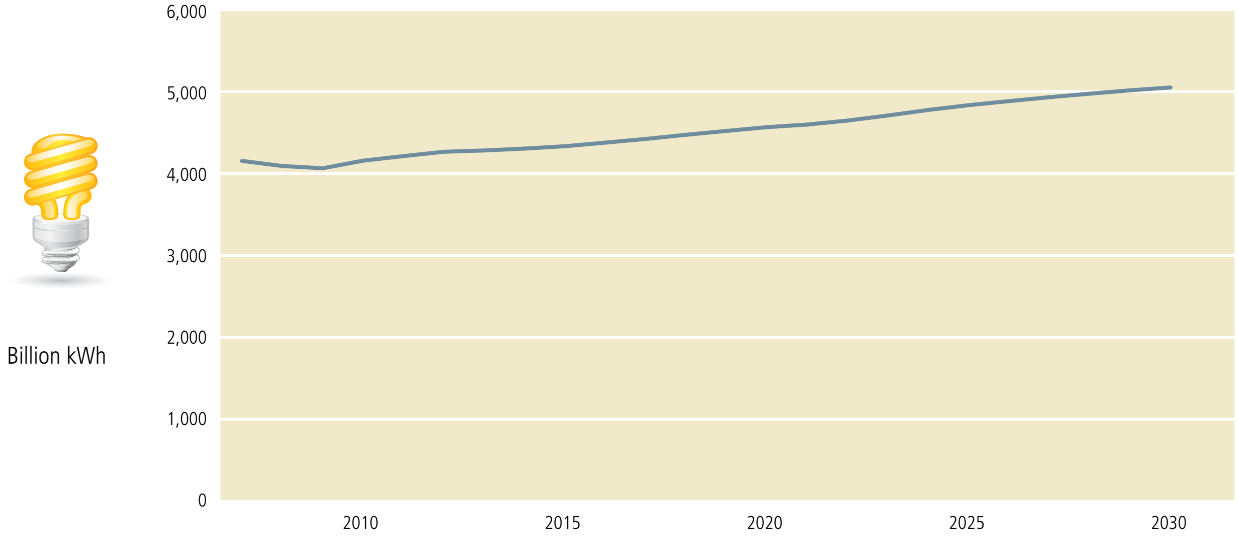
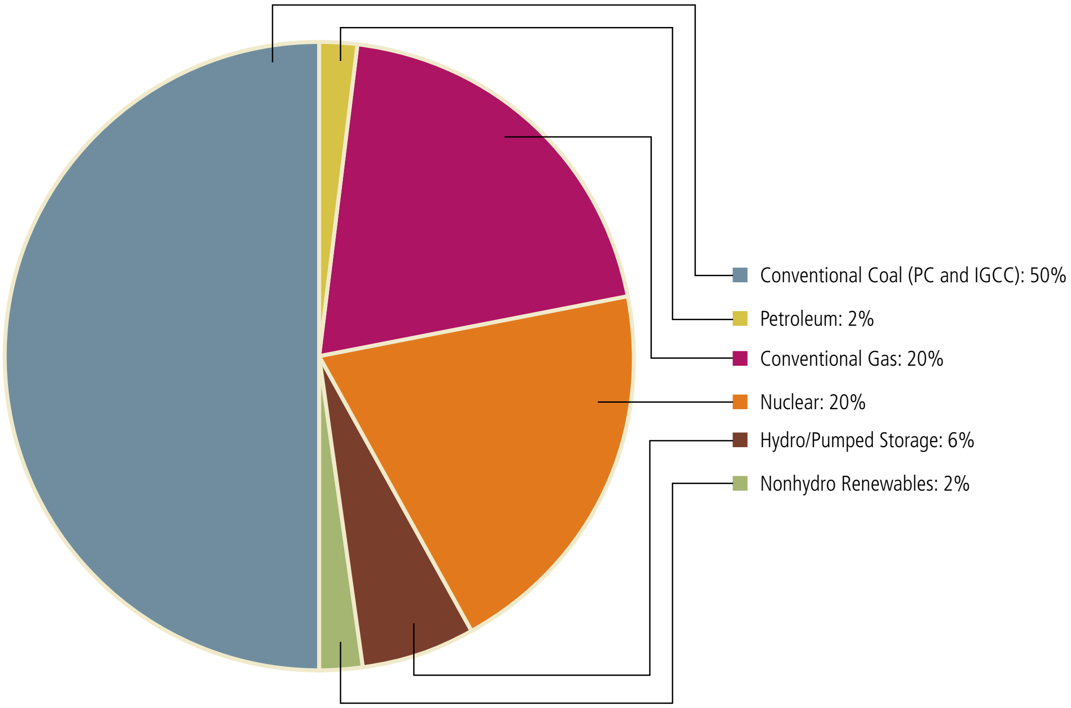
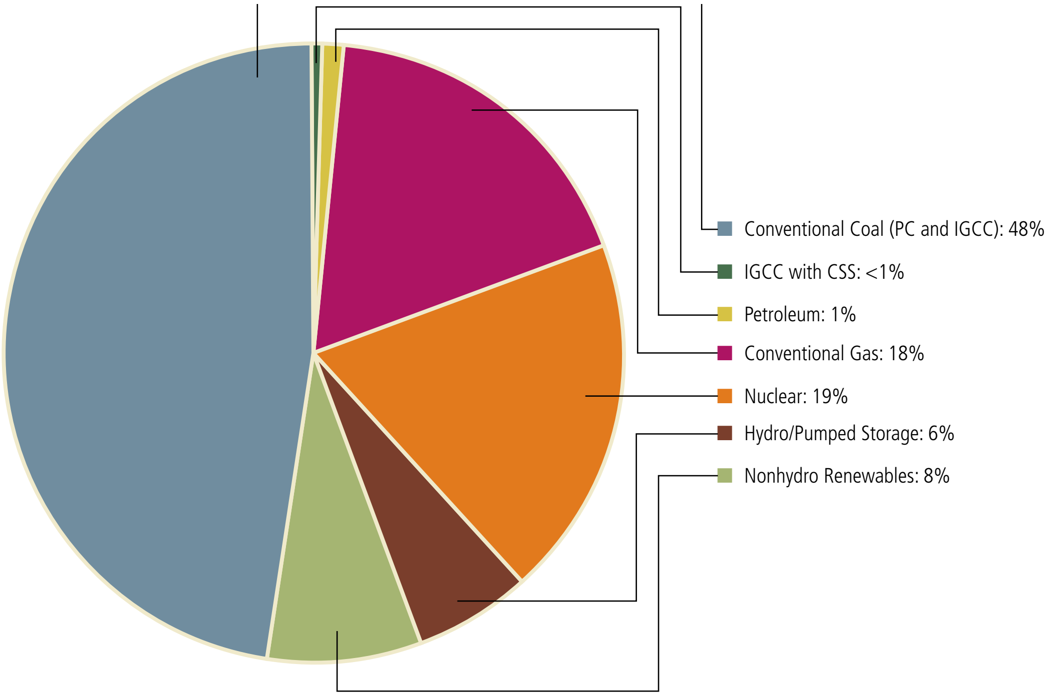


Figure 4.8(a): Electricity Generation (Power Sector) by Fuel, 2007



Notes: IGCC, integrated gasification combined cycle; PC, pulverized coal.

Figure 4.8(b): Electricity Generation (Power Sector) by Fuel, 2030



Notes: IGCC, integrated gasification combined cycle; PC, pulverized coal.

4.5 Addressing Uncertainties

Although the Reference case results presented above represent a realistic set of assumptions about future trends in oil consumption, GHG emissions, vehicle share, electricity generation, and more, all forecasts contains some level of uncertainty. This study in particular faces two types of uncertainties: those inherent in the NEMS–RFF model (model uncertainties), and those that spring from the intrinsic challenges of predicting the future (projection uncertainties). Model uncertainties concern the data and underlying relationships, such as consumer behavior in technology adoption, portrayed in the NEMS–RFF model. Estimates of natural gas supply are one illustration of data uncertainty, where newly economic shale gas plays are changing resources estimates (see Box 4.2). Projection uncertainties concern the obvious difficulties of predicting the future, and in particular, we call out technological, regulatory, and economic uncertainties for special scrutiny.

Box 4.1: A Sensitivity Analysis: The Effect of Low Oil Prices

Increasing oil price is a key factor in spurring reductions in oil use and VMT, yet there is considerable uncertainty about this projected price over the next few decades. To test the effect of a significantly lower world oil price, we developed a sensitivity analysis in which oil prices only climb to $81 per barrel in 2030, compared to $131 per barrel in 2030 in the Reference case. We can gain further insight by looking at results from Gallagher and Collantes (2008), who use an even lower price path for oil, peaking at only $52 per barrel in 2030.

In 2030 in the sensitivity analysis, total petroleum supply is predicted to be higher by 1.9 mmbd compared to that in the Reference case. Indeed, in a world with such low oil prices, oil consumption *increases* from 2010 to 2030 (from 18.5 to 19.9 mmbd), even with CAFE and other policies in place to reduce oil consumption.

Under the sensitivity analysis, a low world oil price also causes the United States to shift away from domestic oil production (dropping from 9 mmbd in the Reference case to 7.7 mmbd in the sensitivity analysis in 2030) and toward more imports (increasing from 8.2 to 11.2 mmbd).

As expected, low oil prices also lead to greater VMT by light-duty vehicles (6.4 percent, or 250 billion additional miles) in 2030 compared to the Reference case. In the sensitivity analysis, where gasoline prices only reach $2.63 (compared to $3.81 in the Reference case), growth in VMT averages 2.1 percent per year from 2008 out to 2030. A low oil price also slows the uptake of alternative liquid fuels, particularly ethanol, and leads to additional challenges in meeting CAFE standards.

Gallagher and Collantes (2008) find that in their low-oil-price case—which includes EISA 2007 CAFE standards—oil imports steadily increase, rising 20 percent by 2030. Transportation carbon emissions increase about 19 percent and, at best, with steep carbon and fuel taxes, CO_2 emissions still increase 10 percent over the 2010–2030 period.

These results illustrate the relevance of high oil prices to projected decreases in oil consumption and the difficulty in meeting any targets for reductions in total oil consumption and GHG emissions in a low-price environment.

Technological uncertainties concern the cost and efficacy of future technologies. Technological characterization is the stock-in-trade of NEMS–RFF, but ultimately it relies on extrapolations from current trends to project costs and efficacy in the future. This study addresses one such technological uncertainty by assuming more optimistic costs of HEV and PHEV batteries and comparing those results to Reference case assumptions. It also assesses EE policies in a NEMS-specified "high-tech" scenario (developed by EIA for the *AEO2009*), which assumes technological advances across a range of investments. In addition, Brown et al. (2010) examine the uncertainties over future improvements in the technology required to produce natural gas from coalbed methane or gas hydrates, which may have a significant impact on natural gas price.

Box 4.2: Enhancing Natural Gas Supply in Baseline Cases

EIA's estimates of U.S. natural gas supplies in *AEO2009* date from 2007. Given the more recent technological changes in extracting gas from shale deposits (termed *hydraulic fracturing*), the cost of recovering such shale gas has dropped significantly and has begun altering price and recoverable reserve forecasts in the United States and around the world. Thus, we felt it appropriate to create a sensitivity analysis for the Reference case that includes more recent estimates of natural gas reserves.

We chose to use data from PGC, a semiofficial body that carries out biannual surveys of natural gas reserves. In 2009, PGC estimated U.S. shale gas resources of 615.9 Tcf, a substantial increase over the *AEO2009* estimates of 269.3 Tcf. *AEO2010* contains more optimistic shale gas estimates, based on information obtained primarily from the U.S. Geological Survey and other government sources; these estimates of shale gas resources (317 Tcf) remain considerably lower than PGC's, however.

Comparing the Reference case with enhanced natural gas supply with the original Reference case shows that U.S. natural gas production and consumption are higher in 2030 (15.2 percent higher and 10.6 percent higher, respectively). These changes imply that the United States becomes a net exporter of natural gas rather than a net importer. Because natural gas prices are 22 percent lower in 2030 with the enhanced supply (a Henry Hub 2007$ spot price of $8.81 million British thermal units [Btus] in the Reference case versus $6.86 million Btus with enhanced supply), all sectors use more natural gas, with electric power seeing the biggest change; natural gas's share of electricity generation rises from 18 percent to 22 percent.

We also model the effects of this enhanced natural gas supply under a C&T program (see Brown et al. 2009), to explore how a price on carbon affects the use of this relatively low-carbon fossil fuel. In this scenario, the most important effect of enhanced supply is the increased use of natural gas in electricity generation—marking a reversal from the original C&T scenario. Comparing the Reference case and our *Central C&T* policy, natural gas's share of generation falls from 18 percent without C&T to 15.5 percent with it. With our enhanced reserve estimates, natural gas's share rises from 22 percent without C&T to 24 percent with it. Generation from nuclear and renewables loses a bit of advantage in the process.

Overall, we find that these enhanced natural gas resources are not a game changer in the sense that, without a carbon policy in place, they actually result in cheaper energy and more CO_2 emissions, and with a carbon C&T policy, they result in somewhat lower allowance prices and somewhat lower costs of meeting the cap.

Regulatory uncertainties concern future policies, as well as the future effectiveness of current policies. The Reference case reflects energy-related policies in place as of the beginning of 2009 and judgments about how those policies will perform in the future; other model runs look at the future effects of individual and combination energy policies. At the same time, policies that apply to other parts of the economy might have ancillary and important effects on the cost-effectiveness of energy policies. (Future trade policies, for instance, could alter the relationships in and results from the model.) For this reason, results should be interpreted as holding all other regulatory activities constant over the forecast period, except those we model.

Economic uncertainties concern a wide variety of future economic conditions: for example, the future price of oil (discussed in Box 4.1), or U.S. and world GDP growth. Results should be interpreted in the context of the business-as-usual economic conditions defined in the Reference case.

Ultimately, these various uncertainties suggest that some care should be taken in interpreting estimates of emissions, oil use, and costs as precise figures. Rather, it is safer to compare estimates across policy scenarios.

4.6 Introduction to Policy Analysis

Chapters 5 and 6 summarize the study's main policy analyses. Chapter 5 covers policies primarily targeted at reducing oil consumption, and Chapter 6 focuses on policies to reduce CO_2.

The term *primarily* is important. As illustrated in this and other studies, policies to reduce oil will probably include a focus on the transportation sector, and these policies will also have some ancillary impacts on reducing CO_2 emissions. Similarly, incentive-based policies to address CO_2 have some effect on reducing oil use. Thus, although in Chapters 5 and 6 we present these policies in two distinct categories, in Chapter 7 we model combinations that blend policies and illustrate their combined effects on both metrics.

Note that because NEMS–RFF only models policies up to 2030, we assume that all policies actually end in or, if appropriate, before 2030. By *end*, we mean that no new investments or behavior changes will take place after that date. Effects and costs and cost savings that extend beyond 2030 caused by long-lived investments made before or in 2030 are counted in cost-effectiveness calculations, however, where appropriate and feasible.

The various policies considered are listed in Appendix A. In general, we picked policy types for their salience in policy debates, whether in policy or academic circles. Policies were timed to generally start in 2010, although sometimes, for added realism, we ramped up the policies over time. Policy stringency, likewise, was driven by saliency in the debates as well as an eye for meeting the targets or guideposts we set for ourselves; for an example in which salience ruled, the specifics of RPSs were defined with reference to those currently being discussed in Congress. An example in which our targets helped set stringency was in our choice of the scope of the LNG truck mandate (10 percent LNG heavy-duty truck penetration of the new-vehicle fleet every year for 10 years, after which all new such trucks will run on LNG).

Defining policies in this way, while increasing salience and appropriateness to the policy debates and enhancing our ability to meet our targets, can create difficulties in comparing the policies across metrics. A standard academic approach is to set all policies to have equal effectiveness and then compare costs, enabling a cleaner comparison. In our case, both effectiveness (or scale) and costs vary, and often both costs and effectiveness are higher for one policy than another, making comparisons difficult. However, using cost-effectiveness measures—comparing a cost per ton or barrel reduced—permits such comparisons to be made.

Although we consider many of the major policy options, we do not model some policies, such as more stringent ethanol mandates, oil import tariffs, and feed-in tariffs for renewable energy. We explain the reasons for omitting these policies at the end of each chapter.

Policies that reduce driving are significantly more effective than policies that only increase automobile fuel economy, whereas gasoline or oil taxes and fuel efficiency policies combined are more effective than either one of these policies in isolation.

5. Policies to Reduce Oil Consumption

Substantially reducing oil consumption below future projected levels is challenging because the economy is heavily dependent on transportation, and our ability to quickly switch to alternative transportation fuels or to improve the energy efficiency of conventional-fuel vehicles faces technological and economic limitations. Evidence suggests that consumers are willing to pay for fuel economy improvements only if they quickly recoup the extra up-front costs in fuel savings. These real world challenges are also reflected in our policy modeling with NEMS–RFF. We consistently find that even aggressive policies have only limited effects on reducing oil use.

Transportation composes 70 percent of domestic oil use, with the other 30 percent primarily accounted for by industry. We focus largely on transportation policies given the difficulty of regulating diverse industrial uses of oil, though we examine various oil tax policies, covering all uses of petroleum products.

5.1 Policy Background

At present, some petroleum products are taxed and others are not. Federal and state excise taxes on gasoline and diesel (for heavy trucks) amount to about 38¢ and 45¢ per gallon, respectively, and the federal taxes alone on these fuels (last altered in 1993) are 18.4¢ and 24.4¢ per gallon (FHWA 2007, Tables 8.2.1 and 8.2.3). These taxes are low by international standards; for example, in many European countries, gasoline taxes exceed $2 per gallon and in some cases $3 per gallon. In addition, fuel tax revenues in the United States are largely earmarked for highway spending, whereas in other countries revenues typically fund general government spending. As in other countries, U.S. taxes on other oil products (e.g., jet fuel and industrial oil use) are small or nonexistent.

Currently, the centerpiece of attempts to boost U.S. automobile fuel economy is the CAFE program, introduced with the goal of reducing the nation’s dependence on foreign oil. This program requires manufacturers to meet separate standards for the average fuel economy of their car and light truck fleets. Initially, the car standard ramped up from 18.0 miles per gallon (mpg) in 1978 to 27.5 mpg in 1985 (and thereafter remained constant for 22 years), and the light truck standard has progressively risen from 16.0 mpg to 22.5 mpg in 2008.

As a result of legislation in 2007 and administrative action begun in 2009, CAFE requirements are being raised and fully integrated with new targets for limiting CO_2 emissions per mile. By 2016, CAFE standards will rise to 35.5 mpg across the light-duty transportation fleet (which reflects a requirement slightly higher than 35.5 mpg for cars, and slightly lower for light-duty trucks), which conforms to requirements already adopted in California under the Pavley bill (California Assembly Bill 1463) for this time period. The Reference case scenario is updated for the announced 2009 changes.[7] New cars, but not light trucks, with low fuel economy are

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[7] As noted in Chapter 3, the Reference case includes an advanced timetable for future automobile fuel economy standards, moving the start date for these new standards from 2020 to 2016. This change was signed into law by President Obama in May 2009.

also subject to a "gas guzzler" tax that rises from $1,000 to $7,000 per vehicle as fuel economy falls from 22.5 to 12.5 mpg.

HEVs and PHEVs offer a potentially promising alternative to traditional gasoline vehicles.[8] In HEVs, an electric motor, using energy stored in rechargeable batteries, replaces the use of gasoline for propulsion at low driving speeds. Most PHEVs operate in a similar way but have a much larger battery and can be plugged into the electrical grid (see McConnell and Turrentine [2010] for more details). PHEV 10 and PHEV 40 vehicles can be driven up to 10 and 40 miles, respectively, without using gasoline. Although PHEVs reduce CO_2 emissions from gasoline combustion, they can increase emissions from power generation.

HEVs currently account for 2.5 percent of new-automobile sales, and PHEVs will be introduced in the next few years. HEV purchases had been eligible for federal income tax credits ranging from $250 to $3,150, depending on their fuel economy improvement over gasoline vehicles (these credits, introduced in 2005, replaced previous, less generous incentives). A special income tax credit for PHEVs was introduced in the 2009 federal stimulus bill, varying with the size of the battery and reaching as much as $7,500. However, all of these tax credits phase out after manufacturers have reached certain targets for cumulative vehicle sales (60,000 for HEVs, and 200,000 for PHEVs).[9] Moreover, federal HEV tax credit provisions expire in 2010 and are therefore not in the Reference case baseline.

Natural gas is another possible alternative to traditional transportation fuel. Although there is limited interest in using natural gas broadly for light-duty vehicles,[10] there is some logic behind promoting its use by heavy-duty trucks. Freight trucks account for 16 percent of U.S. oil consumption, and most of the fuel is used by the heaviest vehicles. The combination trucks (Class 8) alone are responsible for more than 50 percent of diesel consumption. The large tanks required for natural gas storage are less of a concern for heavy trucks than for smaller vehicles, and only a limited network of refueling stations would be required (relative to the number required for light-duty vehicles), given that trucks typically refuel at truck stops, on interstates, and so forth. Further, their very low fuel economy (between 5 and 6 mpg for Class 8 trucks) and high mileage means that conversion to natural gas can back out a large amount of oil per vehicle. Finally, if these vehicles are fueled by LNG, rather than compressed gas, they have acceptable long-haul ranges of 350 miles on one tank.

5.2 Policies Modeled

We evaluate 10 main policies to reduce oil consumption, involving either strengthening existing policies or introducing new policy instruments.

5.2.1 Broad Pricing Policies

Gasoline Taxes

Raising the federal excise tax on gasoline would help to address energy security and (to a lesser extent) climate concerns by encouraging motorists to drive less and use more efficient vehicles. In addition, raising this tax would reduce other adverse side effects, or externalities, particularly highway congestion, traffic accidents, and local tailpipe emissions. These additional benefits are important, as discussed in Chapter 9, though the central focus of this study is on the efficiency of different policies in exploiting opportunities for oil and CO_2 reductions.

We consider a relatively high *Gasoline Tax*, where the tax increase charges motorists for an estimate of these broader external costs (but not energy security and climate change) and accounts for

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[8] We do not discuss all-electric vehicles here as their market penetration is very small in the policy simulations. Another potential alternative is the hydrogen fuel cell vehicle; however, even if the technology is successfully developed, it is unlikely to penetrate the market in significant numbers prior to 2030.

[9] The Prius, for example, no longer receives a tax credit.

[10] Some have suggested that natural gas could be a valuable alternative for light-duty fleet vehicles, such as those used by local governments, that refuel at prescribed stations.

their growth over time (Small 2010). This involves raising the tax by $1.27 per gallon in 2010 and increasing it in real terms at an annual rate of 1.5 percent per year, adding $1.73 to the cost of a gallon by 2030.[11]

Oil Taxes

Taxing *all* oil uses (rather than just gasoline) would be a cost-effective way to generate more substantial reductions in oil consumption. Such a tax would exploit all of the potential margins of behavior for reducing oil use, including, for example, opportunities to conserve air travel, truck freight, and industrial oil uses, besides reducing gasoline. We modeled this policy by applying the above gasoline tax, on a Btu-equivalent basis, to all refined oil products (imported petroleum products are covered by the tax, whereas exported products are exempt).

The prospects for a large, immediate tax increase in the United States anytime soon are remote, and even if a gasoline or oil tax increase were implemented, it would probably be phased in progressively over time. Therefore, we also consider a variant of the oil tax that eventually reaches $1.73 per gallon of gasoline equivalent (in real terms) on all oil products by 2030. This tax begins at 8¢ per gallon in 2010, and rises by (approximately) 8¢ per gallon each year out to 2030.

The two oil tax policies just described are referred to as the *Oil Tax* and *Phased Oil Tax*, respectively. Even the Phased Oil Tax would be challenging to implement, however. No other country has a comparable tax on all oil products—in fact, taxes on international aviation fuel might face legal challenges as they run counter to an international agreement (known as the Convention on International Civil Aviation) designed to prevent such taxes.

In the Reference case, fuel prices are already increasing steadily as the world oil price rises from $64 per barrel in 2007 to $131 per barrel by 2030. The tax policies all serve to reinforce, often quite considerably, these price increases (tax increases are largely passed forward into higher retail prices for oil products). For example, under the Oil Tax and Gasoline Tax policies, the retail gasoline price reaches $5.47 per gallon by 2030, which is 45 percent higher than in that year without the tax increase, and about 150 percent larger than the 2007 gasoline price.

Attempts to levy new taxes consistently face tough political challenges—particularly for taxes on commodities that are as fundamental to the American economy as oil. To make such a tax more politically and socially palatable, tax revenues might be returned or *recycled* back to the public. Economists often recommend using new tax revenues to offset existing taxes, like income taxes, that distort labor supply and capital investment decisions. Another option would be to return revenues in the form of rebate checks—for example, if the total present value of revenue generated under the Phased Oil Tax over the project period ($2,366 billion) were evenly divided among each of the current 309 million individuals in the United States, it is estimated that each American would receive more than $7,600 in rebates over the next 20 years.

How the revenues from all of the tax policies are used has very important implications for the overall costs of these policies, the burden they impose on different household income groups, and their feasibility. However, the NEMS model is not set up to fully analyze the cost and distributional implications of recycling revenues in different ways, such as through reductions in personal income taxes (the NEMS–RFF model assumes that revenues are returned in lump-sum rebates to households). As discussed in Chapter 9, this analysis would require a detailed treatment of how the broader fiscal system distorts economic behavior in various ways, and the pattern of energy consumption and tax burdens across different households. Based on other studies, Chapter 9 provides

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[11] In this policy scenario, we also applied the tax to ethanol and diesel fuels to avoid a large shift in the light-duty sector from gasoline to these fuels. Although the diesel tax also affects heavy trucks, as discussed below, NEMS assumes very little response from the trucking sector. In the Oil Tax scenarios, we apply expert judgment to better represent responses outside of the light-duty sector. Therefore, it is most accurate to describe our Oil Tax scenario as applicable to all oil products and to call the fuel tax a Gasoline Tax applicable primarily to light-duty vehicles.

a broad sense of the trade-offs involved in alternative revenue recycling options.

5.2.2 Energy Efficiency Policies

Fuel Economy Standards

Some would argue that fuel economy standards are more feasible than gasoline or oil taxes, not least because they do not require a large revenue transfer from motorists to the government. Indeed, CAFE standards have already had an impact on reducing oil use: according to an NRC (2002) report, fuel use in 2001 was roughly one-third lower than it would have been in the absence of CAFE standards (rising oil prices are likely to have contributed, as well).

As noted, federal CAFE standards were tightened in 2008, and the timeline for these standards was further advanced in 2009. Here we consider a highly aggressive policy change that extends the pending tightening of CAFE already enacted. We refer to this policy as *Pavley CAFE* because it is based on the targets tentatively adopted by California under the Pavley bill beyond 2016—namely, an increase of 3.7 percent per year in both the car and light truck standards for 2017 through 2020. From 2021 to 2030, our Pavley CAFE policy further tightens standards by 2.5 percent per year, reaching 52.2 mpg (averaged across cars and light trucks) in 2030. Figure 5.1 compares this policy with existing regulations, where the car and light truck standards are weighted using their respective vehicle shares in the Reference case (these shares will change somewhat in response to the new policy). As we discuss below, we find that the actual fuel economy of new vehicles eventually falls short of the rising legal requirements under the Pavley CAFE policy, as manufacturers run out of fuel-saving technologies and must pay fines instead.

From the perspective of minimizing the costs of meeting a given, industrywide, fuel economy target, it makes sense to induce some manufacturers (with relatively low compliance costs) to exceed the industry standard and allow others (with relatively high compliance costs) to remain below it. Provisions in the recent CAFE legislation allow this flexibility as manufacturers now have individual standards that vary according to vehicle size—standards are therefore less stringent for those manufacturers specializing in relatively large cars or large light trucks.[12] Further flexibility is being incorporated into the CAFE program through provisions that will allow firms to trade credits among themselves and over time.

Despite these improvements, CAFE policies still have two significant drawbacks:

- They do not discourage driving—in fact, by reducing fuel costs per mile, they encourage more vehicle use. The amount of fuel savings from greater efficiency that is offset by extra driving, termed the *rebound effect*, is approximately 17 percent in NEMS–RFF.[13]
- CAFE standards can undermine the effects of other policies. In particular, fuel savings from policies that increase the sales share of vehicles with high fuel economy, like hybrids, can be largely offset. This is because manufacturers that sell more hybrids do not need to increase the fuel economy of their conventional gasoline vehicles by as much to meet the average fuel economy requirements for their fleets.

Feebates

Feebates avoid this last problem associated with CAFE standards. These policies combine a fee for low-fuel-economy vehicles and a rebate for high-fuel-economy vehicles. Usually, feebates are imposed at the manufacturer level (like CAFE regulations). Alternatively, they could be imposed at the consumer level, though either would be equivalent within the NEMS–RFF modeling framework (as

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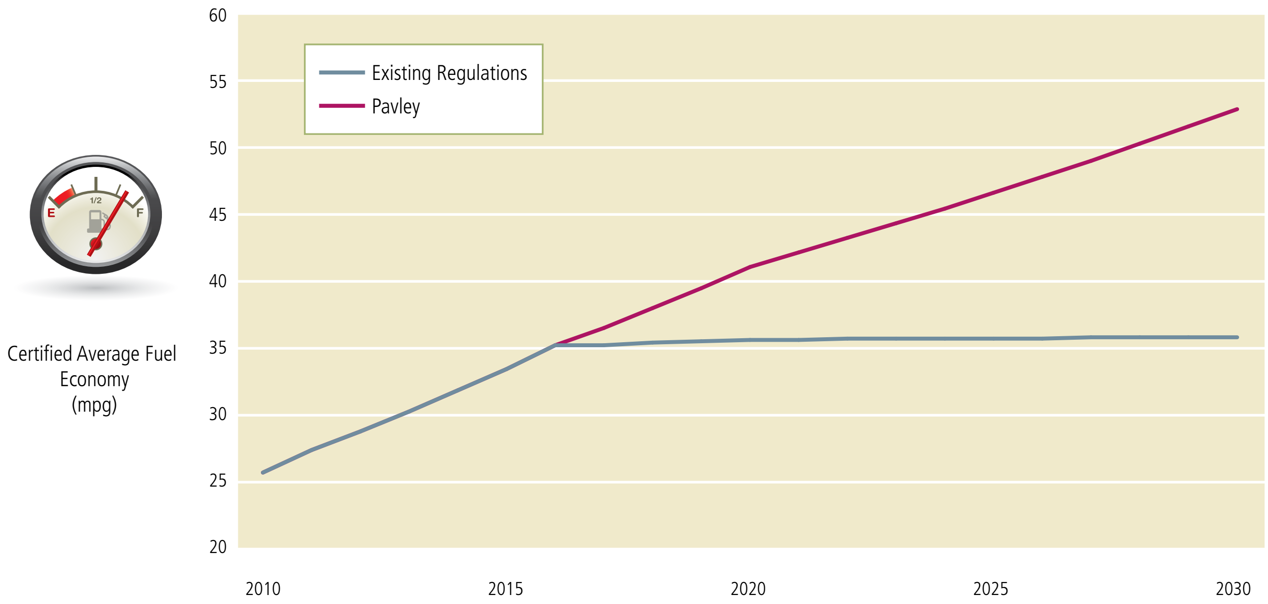
[12] Vehicles are grouped into one of six size categories as defined by their *footprint* (i.e., the distance between the centers of the wheels multiplied by the distance between the front and rear axles). Within each class, a mathematical function is defined that maps the footprint of individual models into fuel economy targets, which are used to calculate a sales-weighted standard for each manufacturer's car and light truck fleet. This removes the incentive for downsizing vehicles to comply with regulations, given that the fuel economy functions are higher for smaller vehicle classes (i.e., the smaller the vehicle, the more stringent the standard).

[13] Some experts believe that CAFE standards will be continually tightened to compensate for this rebound effect. Given the uncertainty over this potential change, we model such a progressive tightening only in the Pavley CAFE policy, not the Reference case scenario.

Figure 5.1: Pavley CAFE Policy



would some combination of consumer and manufacturer feebates). The policy represents an extension of the gas guzzler tax, which discourages the purchase of fuel-inefficient cars through a progressively rising penalty reflected in the sales price. The feebate effectively applies a similar tax penalty scheme to relatively fuel-inefficient light trucks and cars, and it adds a rebate that effectively lowers the price of cars and trucks with relatively high fuel economy. The point at which the *fuel intensity* of a vehicle—expressed in gallons per mile[14]—changes from an assignment of a fee to eligibility for a rebate is called the *pivot point*.[15]

Like CAFE standards, feebates do not transfer revenue to the government—at least if they are revenue-neutral, as considered here.[16] They also promote cost-effectiveness by rewarding manufacturers with low compliance costs to go beyond the pivot point while allowing other firms with high compliance costs to fall short of the pivot point. And feebates do not undermine the effectiveness of incentives for hybrid vehicles. If manufacturers raise the sales share of hybrids in their fleets, they have no incentive to offset this by lowering the fuel economy of their conventional gasoline vehicles.

We consider two feebate policies, one labeled *High* and the other *Very High*. The High Feebate rates are set so that this policy yields fuel economy outcomes each year that are approximately comparable to those of the Pavley CAFE policy. It has a basic rate of $2,000 per 0.01 gallons per

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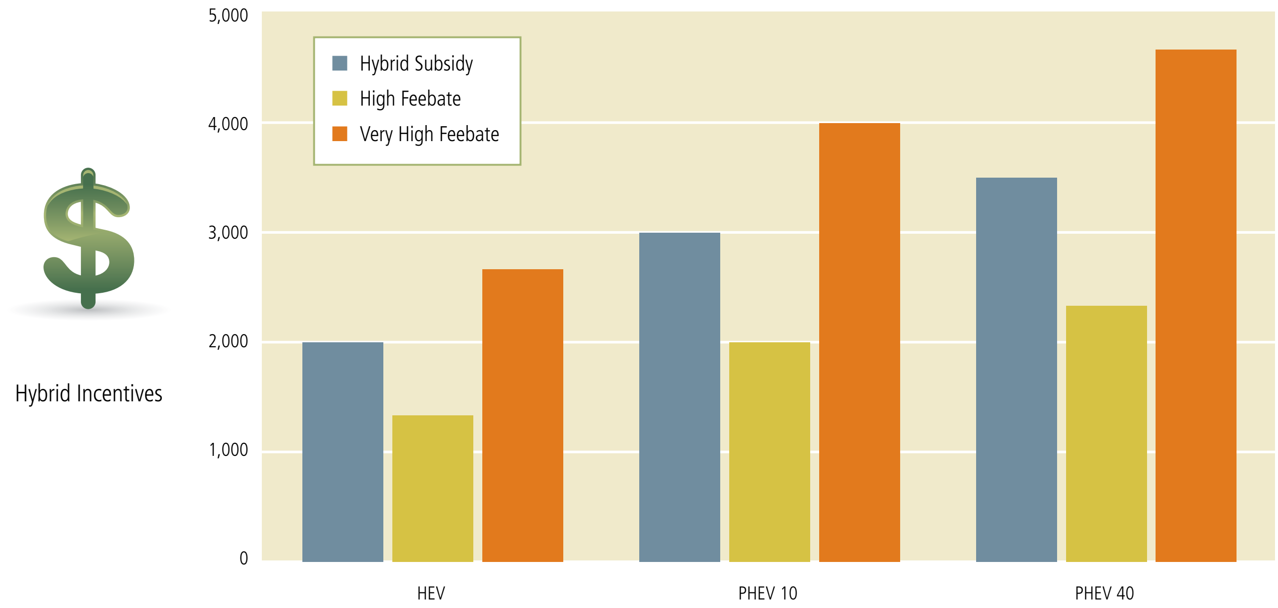
[14] The rationale for making the tax or subsidy proportional to fuel intensity rather than fuel economy is that it provides a constant incentive rate for each gallon of fuel saved, regardless of whether those improvements are in small or large cars (for the same reason, fuel economy under the CAFE program is calculated using a harmonic average). If the payment schedule were instead based on fuel economy, it would give a disproportionately small subsidy to fuel savings in vehicles with low mpg, where the potential for fuel economy improvements is greatest.

[15] Feebates are proposed in S. 1620, a bill introduced by Senator Bingaman in August 2009. They have been implemented in Canada and proposed in California and France.

[16] Approximate revenue neutrality can be achieved by setting the pivot point in one year slightly below the average fuel intensity of new vehicles in the previous year.

Figure 5.2: Hybrid Incentives under Hybrid Subsidy and Feebate Policies



Note: Figures are for a typical midsize car. Feebate rates are for those applying in year 2021.

mile (that is, for each 10 gallons of fuel saved on 1,000 miles of driving).[17] This rate is phased in progressively between 2017 and 2021 and thereafter rises (in real terms) at 2.5 percent per year, so that it reaches $2,969 per 0.01 gallons per mile in 2030.[18] The Very High Feebate scenario sets the feebate rates in each year such that they are exactly twice as large as those in the High Feebate case. The feebate policies have multiple pivot points—one for each vehicle class represented in NEMS–RFF. This leads to much smaller fees and rebates than when only one pivot point applies to all vehicles and should therefore help with feasibility. The difference between feebates with single and multiple pivot points is that the former lead to more shifting in demand among vehicle classes, although simulations with NEMS–RFF indicated that the additional fuel savings from this effect were relatively small.

5.2.3 Incentives for Specific Technologies

Hybrid Subsidies

To encourage additional hybrid penetration, we consider a vehicle purchase subsidy of $3,000 for each 0.01 gallon per mile saved between the HEV or PHEV and its gasoline equivalent vehicle, with the subsidy constant in nominal terms from 2010 to 2030.[19] This would amount to about $2,000, $3,000, and $3,500 for a typical midsize HEV, PHEV 10, and PHEV 40, respectively, at current fuel economy levels. These subsidies are initially about midway between the basic rate subsidies for hybrids provided under the High and Very High Feebate policies, respectively, and are more

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[17] Thus, it would be become worthwhile for a manufacturer to adopt technology raising fuel efficiency from 30 to 31 mpg if the cost were less than $2,000 x (0.0333 – 0.0323)/0.01 = $200 per vehicle.

[18] To get an idea of the magnitude of this fee–rebate schedule, consider that in our Reference case in 2010, the average fuel economy of compact and midsize cars is 33.8 and 30.0 mpg, respectively, implying a difference in fuel economy of 3.7 gallons per 1,000 miles driven. A feebate of $2,000 per 10 gallons saved on this driving distance would create a price difference of $740 between the two vehicles.

[19] Purchase subsidies are thought to be more effective than personal income tax credits, in part because they reach all consumers, regardless of their taxable income (e.g., Gallagher and Muehlegger 2008).

Box 5.1: Hybrid Battery Costs

The NEMS–RFF model assumes that nickel metal hydride (NiMH) batteries are used in HEVs and lithium ion (Li-ion) batteries in PHEVs (NiMH batteries do not have sufficient storage capacity for PHEVs). A number of different approaches to designing Li-ion batteries for use in PHEVs are under development, with different combinations of storage capacity, battery life, and weight. Several vehicles are coming to the market in 2010 and, although observers are optimistic about the likelihood that PHEV batteries will meet performance and endurance goals, they are less optimistic about costs, which remain high (McConnell and Turrentine 2010).

In the Reference case, the costs of the two types of batteries in 2010 are assumed to be $650 per kWh for NiMH and $1,500 per kWh for Li-ion, implying a total battery cost of $650, $1,500, and $6,000 for an HEV, PHEV 10, and PHEV 40, respectively (HEVs and PHEV 10s generally require battery capacities of 1 kWh, whereas PHEV 40s generally require a capacity of 4 kWh). Projected costs fall over time in the Reference case, with technology improvements and economies of scale, to $500 and $600 per kWh, respectively, for NiMH and Li-ion batteries by 2030. However, McConnell and Turrentine (2010, Figure 7) develop a more optimistic scenario, based on the views of some analysts in the industry, in which the costs of Li-ion batteries are initially much lower, at $600 per kWh, and fall to $250 per kWh by 2030. In this scenario, all hybrids use Li-ion batteries by 2020, as NiMH batteries are phased out.

In addition to battery costs, hybrids cost more than their gasoline counterparts because of additional system costs, such as integrated electric and internal combustion drive trains and computer systems to manage the battery systems. The optimistic battery scenario assumes that systems costs fall to about half of those in the Reference case by 2030 (McConnell and Turrentine 2010, Figure 8).

than twice the value of fuel savings (relative to gasoline vehicles) over the first three years of vehicle life (see Figure 5.2). Thus, for example, the midsize PHEV 40 would be economical to buy if the difference in price compared with its gasoline counterpart were less than $5,000.

Batteries are the key determinant of the cost of PHEVs. However, as discussed in Box 5.1, considerable uncertainty surrounds future battery costs, particularly for PHEVs. The NEMS–RFF assumptions are similar to those in a recent NRC (2009e) report. McConnell and Turrentine (2010) develop an alternative scenario for hybrid battery costs that is quite optimistic but still consistent with what some analysts believe about future technology opportunities (Box 5.1). We discuss the implications of this alternative scenario below.

LNG Trucks

This study examines the impact of a progressive conversion of Class 7 and 8 heavy trucks to run on LNG rather than diesel; we modeled this by assuming that 10 percent of new trucks sold in 2011 and 20 percent of new trucks sold in 2012 run on natural gas and that this rises to 100 percent of new trucks sold in 2020 and beyond. We recognize that the implementation of such a policy in such a short time frame is highly aggressive, but wanted to test the maximum effect achievable as early as possible within the project period. We modeled assumptions about the penetration rate (rather than policies that would result in such penetration) because alternative fuel shares for trucks in NEMS–RFF are primarily driven by user assumptions, which lead to a small number of heavy-duty natural gas vehicles in the Reference case (20,000 in 2007, up to 120,000 by 2030).

Box 5.2: Representation of Oil-Using Sectors in NEMS–RFF

The light-duty transportation sector in NEMS–RFF is represented by six size classes for cars (minicompact, subcompact, compact, midsize, large, and two-seater vehicles) and six size classes for light trucks (small and large minivans, small and large pickup trucks, and small and large sport utility vehicles). Within each size class, various fuel types are represented (e.g., conventional gasoline, ethanol–gasoline, hybrid, and diesel). For a vehicle of a given size and fuel type, manufacturers choose which technologies, from a large set of possibilities, are cost-effective in terms of whether consumers' willingness to pay for fuel cost savings and other possible benefits of the technology outweighs the extra production costs. Manufacturers are competitive and set vehicle prices equal to the production costs per vehicle.

Consumer preferences for vehicles are chosen so that the model matches vehicle sales shares observed in recent years. Households as a group choose how many new vehicles of each type to purchase in a given year and how much to use new and existing vehicles (the vehicle lifetime is fixed). Higher fuel prices increase consumer willingness to pay for the adoption of fuel-saving technologies, though consumers only value the resulting fuel savings over the first 3 years (and discount them at 15 percent) rather than over the entire 14-year vehicle life. Changes in the prices of new vehicles in response to technology adoption affect the demand for those vehicles.

The model's technology sets and parameters lead to little penetration of energy-saving technologies in the freight, aviation, and industrial sectors in NEMS–RFF. Moreover, there is little responsiveness to higher fuel prices in terms of reduced demand for air travel, substitution of rail for truck freight, and substitution of natural gas for oil. Based on consultations with our outside experts, fuel reductions in these sectors in response to oil taxes (and oil taxes in the crosscutting policy combinations discussed below) were scaled up in offline calculations such that each 10 percent increase in fuel prices is associated with (approximately) a fuel reduction of 2 percent.

Implicitly, the assumed penetration could be brought about by a minimum sales requirement for these vehicles in new-truck fleets or by subsidies.[20]

5.2.4 Policy Combinations

CAFE/Gasoline Tax

Gasoline taxes primarily reduce fuel use through reduced driving, whereas strengthened CAFE standards push fuel economy beyond future requirements currently in law, with a modest increase in vehicle mileage. Combining the two policies potentially has more impact on reducing gasoline use than either policy on its own (although the impacts are not additive because of the rebound effect). We explored this possibility by jointly implementing the Gasoline Tax and Pavley CAFE policies. Because both policies are aggressive, this combination might be viewed as an upper limit on achievable gasoline savings—at least under policies that (conceivably) might be feasible, and given the assumed technological possibilities in NEMS–RFF.

Phased Oil Tax/Feebate/Hybrid Subsidy Combination

This second policy package, combining the Phased Oil Tax with the High Feebate and Hybrid

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[20] We do not consider the purchase of smaller fleet vehicles and buses fueled by compressed natural gas because such vehicles have already made their way into the marketplace, given the existing government incentives and judgments about their economic viability. In fact, NEMS assumes a 666 percent increase in medium-duty compressed natural gas trucks between 2007 and 2030 (from 30,000 to 200,000 vehicles). Also, the greater fuel economy and smaller number of such vehicles compared with heavy-duty trucks make them a less attractive target for reducing oil consumption. Finally, in the analysis, we combined Class 7 and 8 trucks because NEMS–RFF does not consider these two classes separately.

Subsidy, has the advantage of broader coverage of the margins affecting oil use and allows a more flexible approach to encouraging energy efficiency.

We did not examine a variety of other policy options for reducing transportation-related oil use and CO_2 emissions, including, for example, automobile insurance reform, incentives for nonconventional oil, and oil import tariffs. Section 5.5 below provides the justification for these choices.

The following two subsections evaluate the effectiveness and costs of the above policies using the NEMS–RFF model. Box 5.2 briefly describes how the major oil-using sectors are represented in the model. Although it contains a comprehensive representation of light-duty vehicle use, fleet turnover, and technology adoption, the model includes considerably less detail on behavioral responses to fuel prices for other oil-using sectors because less is known about future technological possibilities. We therefore adjusted fuel responses for these sectors from the two Oil Tax runs based on expert judgment. Later, we discuss the sensitivity of model results to other key assumptions.

5.3 Key Metrics: Effectiveness of Alternative Policies

This section discusses reductions in oil use and CO_2 emissions when the above policies are imposed on the Reference case. We also briefly comment on the sensitivity of these findings to alternative assumptions.

5.3.1 Reductions in Oil Use

The two panels in Figure 5.3 show the effectiveness of the above policies at reducing oil use below Reference case levels in 2020 and 2030, where the horizontal lines indicate the study goals for oil reductions.

In 2020, the most effective policy is the Oil Tax, which reduces oil consumption by 1.6 mmbd, or 9.0 percent below Reference case levels. Next most effective are the Phased Oil Tax, Gasoline Tax, LNG Trucks policy, CAFE/Gasoline Tax combination, and Phased Oil Tax combination, which reduce oil use by between 0.8 and 1.1 mmbd below Reference case levels, or 4.3 to 6.2 percent. By 2030, the LNG Trucks policy and the Phased Oil Tax combination (just) achieve the target reduction of 2.0 mmbd; the next most effective policies, the Oil Tax cases alone and the CAFE/Gasoline Tax, achieve reductions of 1.4 to 1.5 mmbd.

These findings underscore the difficulty of addressing the problem of oil dependence, even with aggressive tax policies. The modest responsiveness of oil use to higher prices reflects a combination of three general factors. First, the availability of substitutes for oil-based fuels in the transportation and other sectors is very limited. Second, higher prices have a limited effect on encouraging further adoption of energy-saving technologies, given improvements that must already be made to satisfy preexisting CAFE requirements. And third, demand for travel and other oil-using activities—given the need for people to commute, shop, and so on—is relatively insensitive to higher prices. The considerable time required for vehicle stock turnover also slows the responsiveness.

About half of the reductions in oil use under the Oil Tax policies come from reductions in gasoline. Not surprisingly, therefore, significant oil reductions are forgone by policies that focus exclusively on automobiles. Even raising the gasoline tax by $1.26 immediately, and by $1.73 in 2030, reduces petroleum use by only 0.8 mmbd in 2030, less than half of the target reduction. The Oil Tax reduces petroleum use by 70 percent more by that date as it reduces demand for all petroleum products rather than gasoline alone. The CAFE/Gasoline Tax combination achieves larger reductions, however, given its stronger impact on automobile fuel economy.

The Pavley CAFE and Feebate policies initially generate very little savings as they are introduced progressively after 2016, and it takes around 15 years for their effects to fully permeate the in-use vehicle fleet. By 2030, these policies reduce oil use by about 0.7 to 0.9 mmbd below Reference case levels. And the Hybrid Subsidy policy has no

Figure 5.3(a): Reductions in Oil Use Relative to Reference Case Levels, 2020

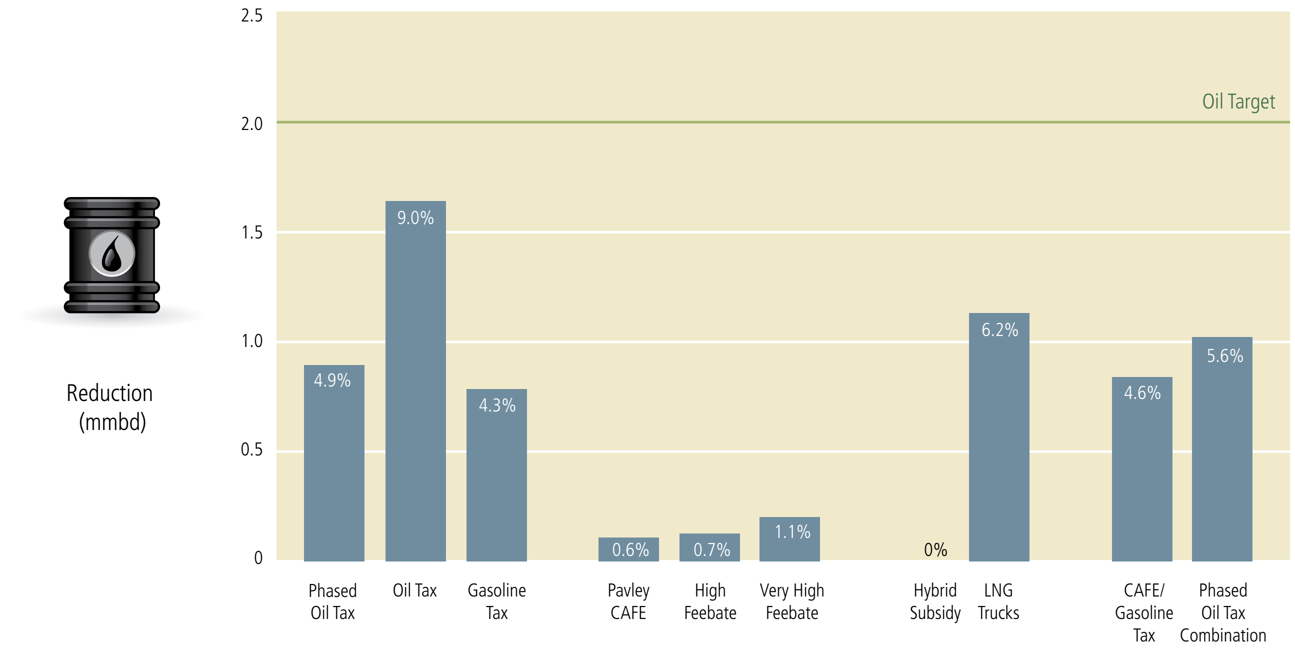


Figure 5.3(b): Reductions in Oil Use Relative to Reference Case Levels, 2030

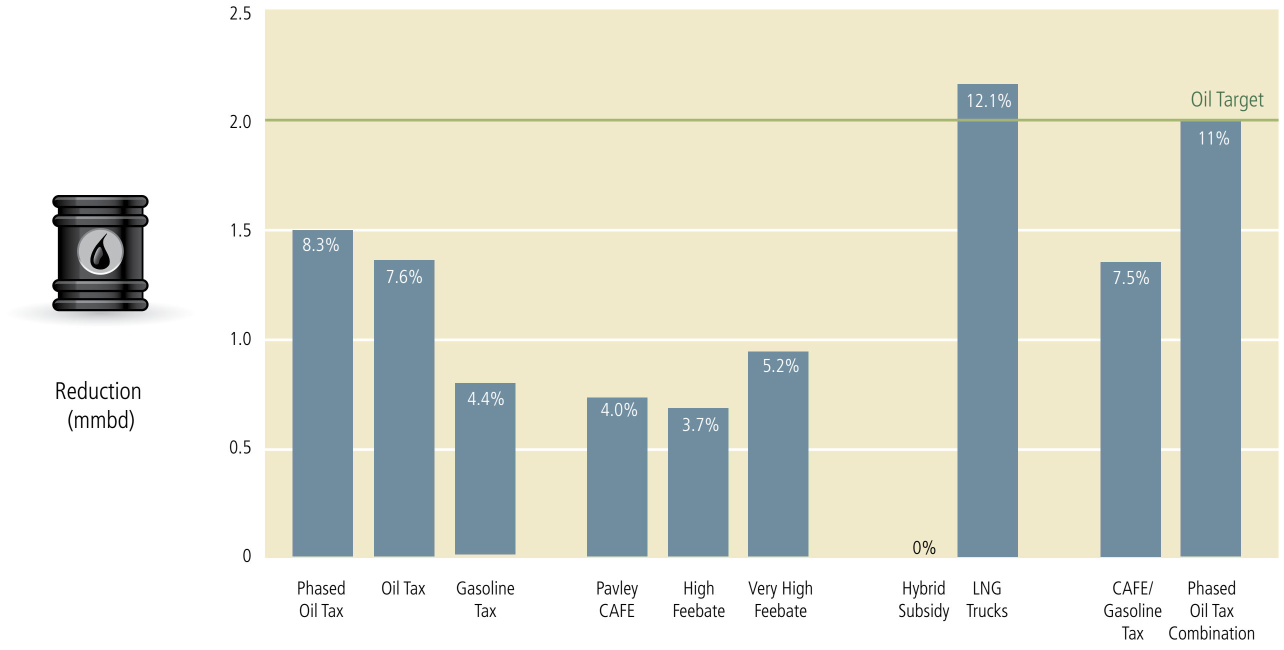
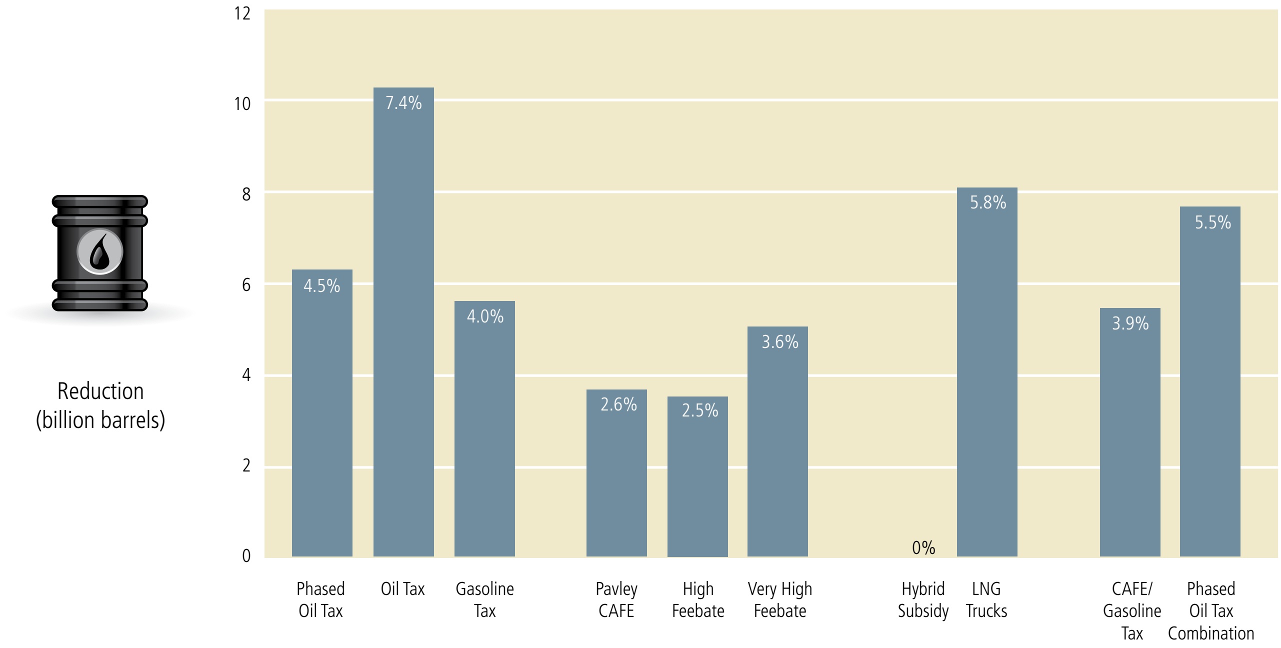


Figure 5.4: Cumulative Reductions in Oil Use Relative to Reference Case, 2010–2030



effect on total oil consumption because manufacturers selling more hybrids can lower the average fuel economy of other vehicles in their fleet and still meet existing CAFE requirements. Nonetheless, the Hybrid Subsidy policy may offer other benefits not captured by NEMS–RFF, such as driving down production costs for hybrids, promoting consumer acceptance of new technologies, and potentially spurring additional vehicle innovation.

The LNG Trucks scenario reduces oil use by 1.2 mmbd in 2020 and 2.2 mmbd in 2030. Under this policy, about 75 percent of the Class 7 and 8 heavy-duty truck fleet uses LNG by 2030, eliminating most of the 3 mmbd consumption of oil by these trucks in the Reference case.

Figure 5.4 shows the cumulative reduction in oil consumption over the period 2010 to 2030 (this excludes oil reductions occurring beyond 2030 as a result of policy-induced fuel economy improvements during the study period). The Oil Tax achieves the largest reductions—10.3 billion barrels, or 7.4 percent below the level of oil use found in the Reference case over the period. This policy has an immediate effect, unlike the phased taxes and the fuel economy and LNG Trucks policies, and it covers all oil uses. The LNG Trucks policy is the next most effective, reducing cumulative oil use by 8.0 billion barrels. Cumulative oil reductions under the other tax policies are between 4.7 and 7.6 billion barrels, whereas reductions under the EE policies in isolation are on a smaller scale still, between 1.8 and 2.4 billion barrels.

5.3.2 Reductions in CO_2 Emissions

Figures 5.5 and 5.6 show CO_2 reductions relative to the Reference case in 2030 (as a snapshot of policy achievement at the end of the project period), and cumulated over the period 2010–2030. For almost all policies, the percentage reduction in CO_2 is about half of the percentage reduction in oil use. The exception to this is the LNG Trucks scenario, in which CO_2 reductions in 2030 are 2.8 percent even though oil reductions in this scenario in 2030 are 12.1 percent. One reason for this is that natural gas itself produces emissions, which, according to Krupnick (2010), are 70 to 80 percent of those from diesel on a per-mile basis. In addition, nationwide prices for

Figure 5.5: Reductions in CO_2 Relative to Reference Case Levels, 2030

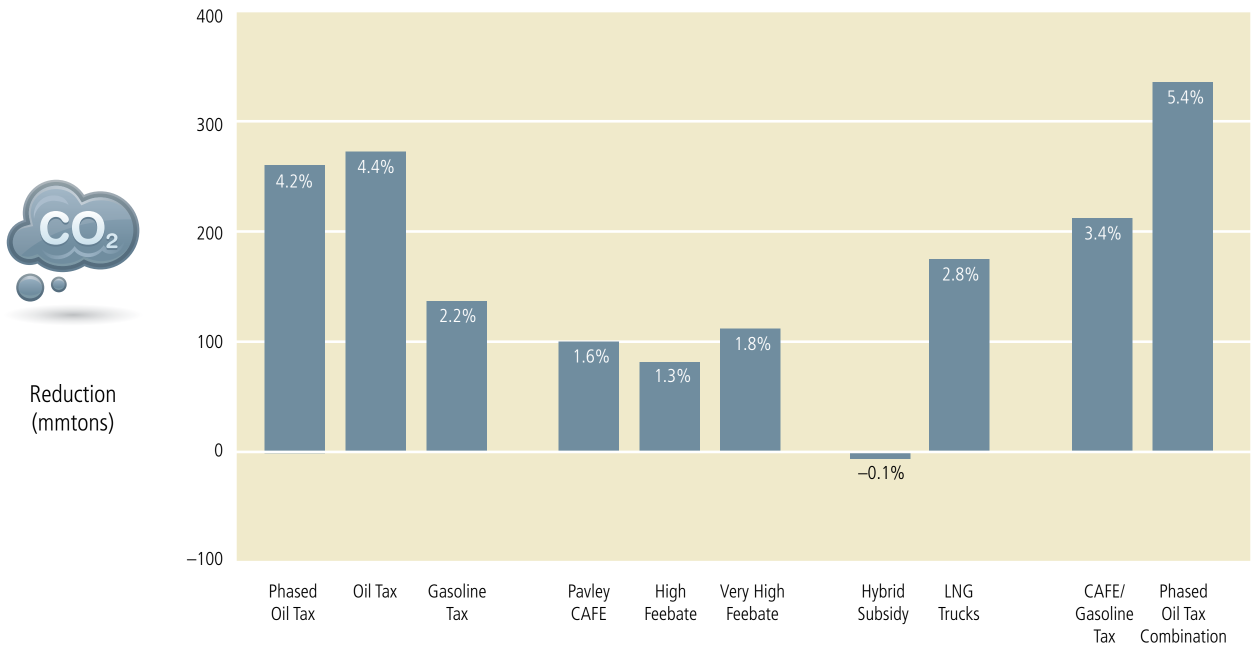


Figure 5.6: Cumulative Reductions in CO_2 Relative to Reference Case Levels, 2010–2030

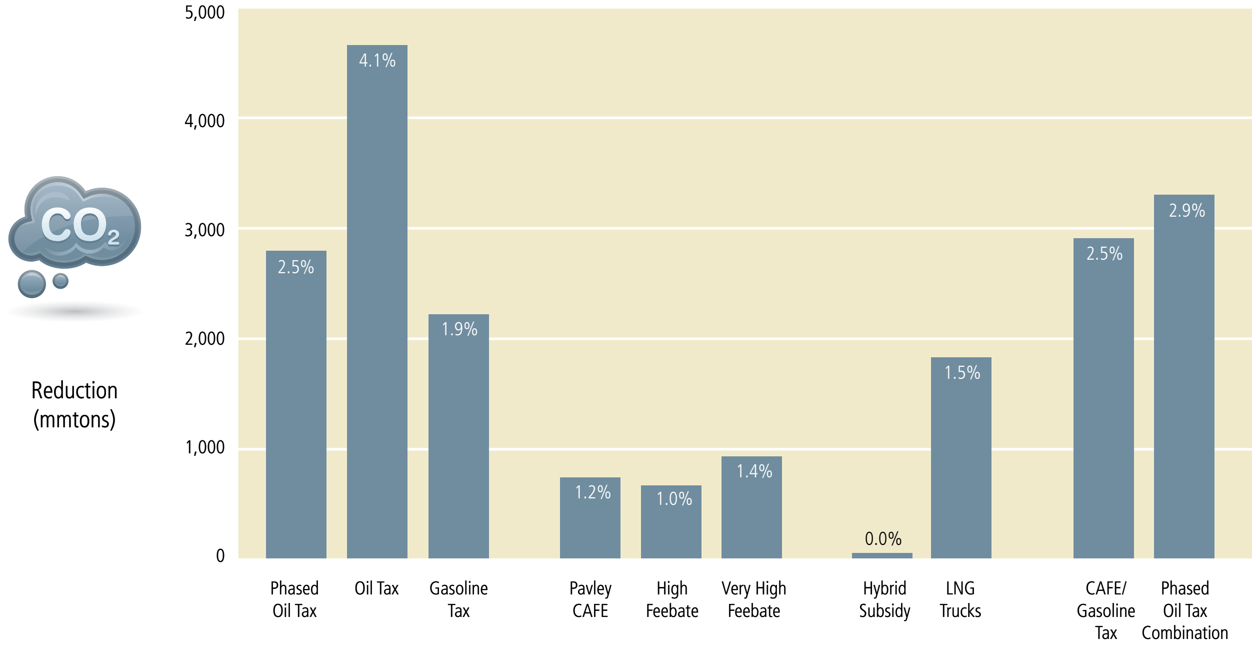
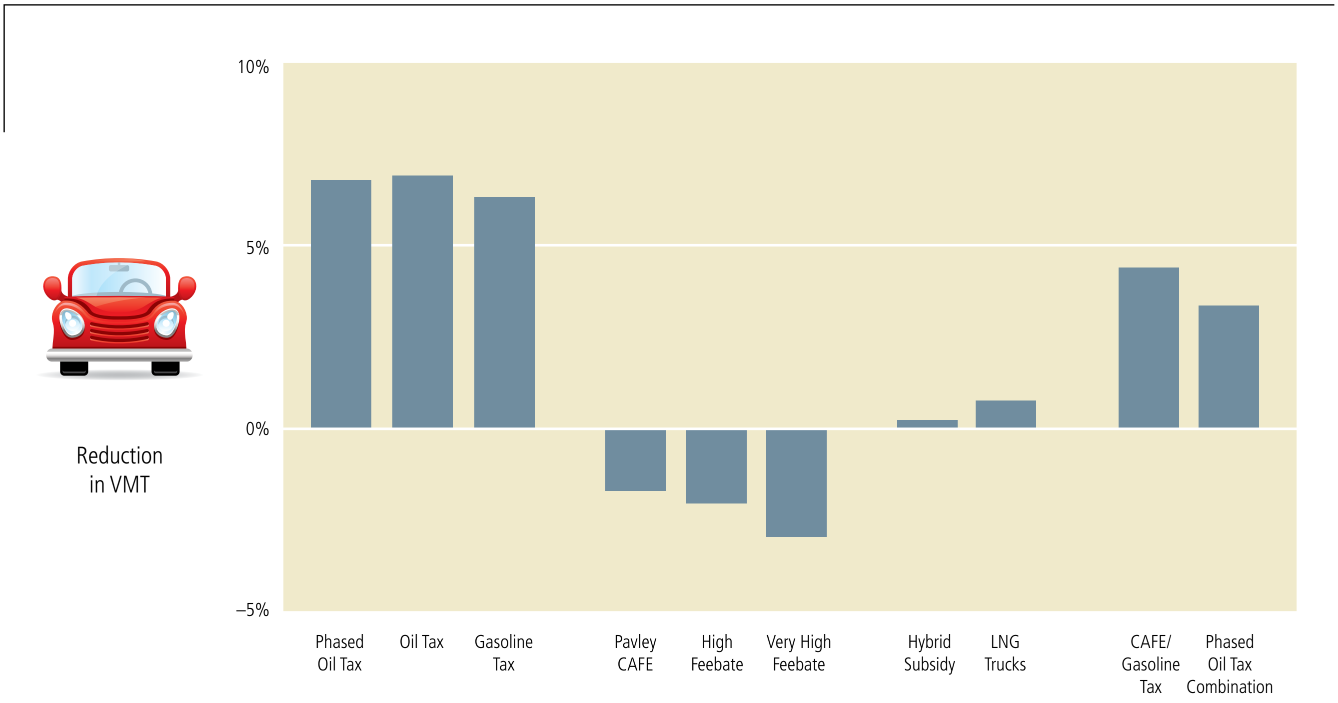


Figure 5.7: Reductions in VMT Relative to Reference Case, 2030



Note: A negative percentage indicates an increase in VMT.

natural gas are 16 percent higher in 2030 as a result of extra demand, and this causes some substitution away from natural gas to other fuels in the power sector, with a resulting increase in CO_2 emissions.

None of the policies or policy combinations meets the cumulative energy-related CO_2 reduction target. For example, even the most effective policy, the Oil Tax, reduces CO_2 by 4,715 million tons over the study period, which is less than 40 percent of the target reduction.

5.3.3 Impacts on the Light-Duty Transportation Sector

Figures 5.7 to 5.9 show, for light-duty vehicles in 2030, the impacts of the policies on VMT, fuel economy, and hybrid penetration rates.

Approximately two-thirds of the gasoline reductions under the (noncombination) Oil and Gasoline Tax policies in 2030 are due to reduced driving, and one-third are due to improvements in light-duty fuel economy. The Oil Tax, Phased Oil Tax, and Gasoline Tax reduce VMT in 2030 by 6.3 to 6.9 percent below Reference case levels (Figure 5.7). On the other hand, these policies only have modest impacts on fuel economy. Even in the Oil Tax cases and the Gasoline Tax case, the average fuel economy of new vehicles rises to about 40.5 mpg in 2030, up from the Reference case level of 38.8 mpg (Figure 5.8).[21] The reason for the modest impact, as already mentioned, is that fuel economy requirements already in law remain binding for many manufacturers, even at much higher fuel prices. Consumers are also somewhat more willing to buy hybrids with higher fuel taxes, as reflected in hybrid sales shares rising to about 27 percent in 2030 compared with about 23 percent in the Reference case (Figure 5.9).

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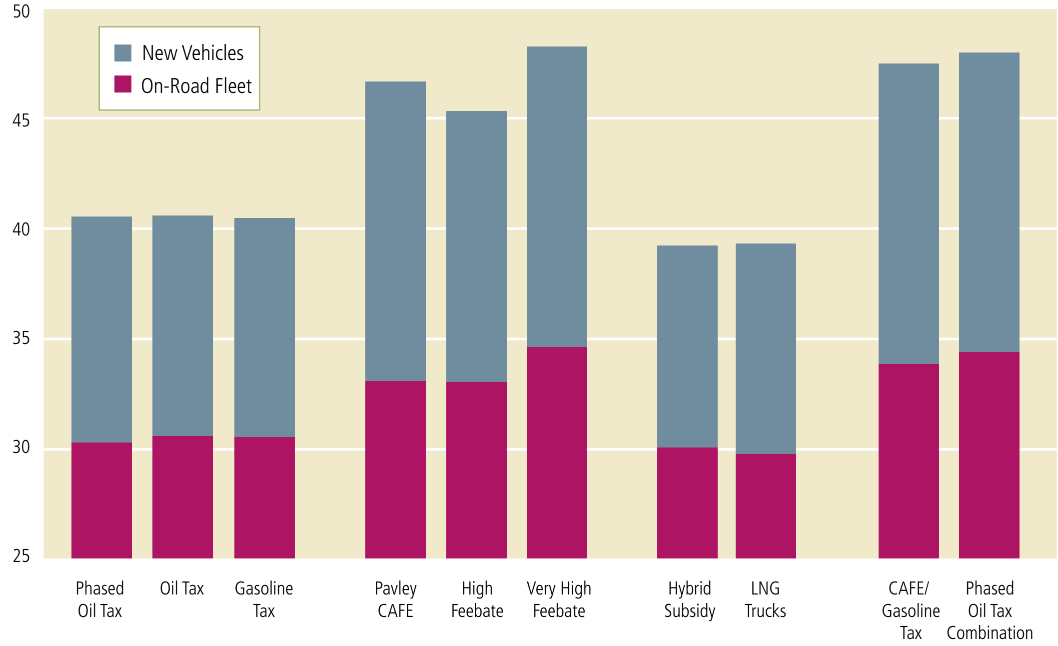
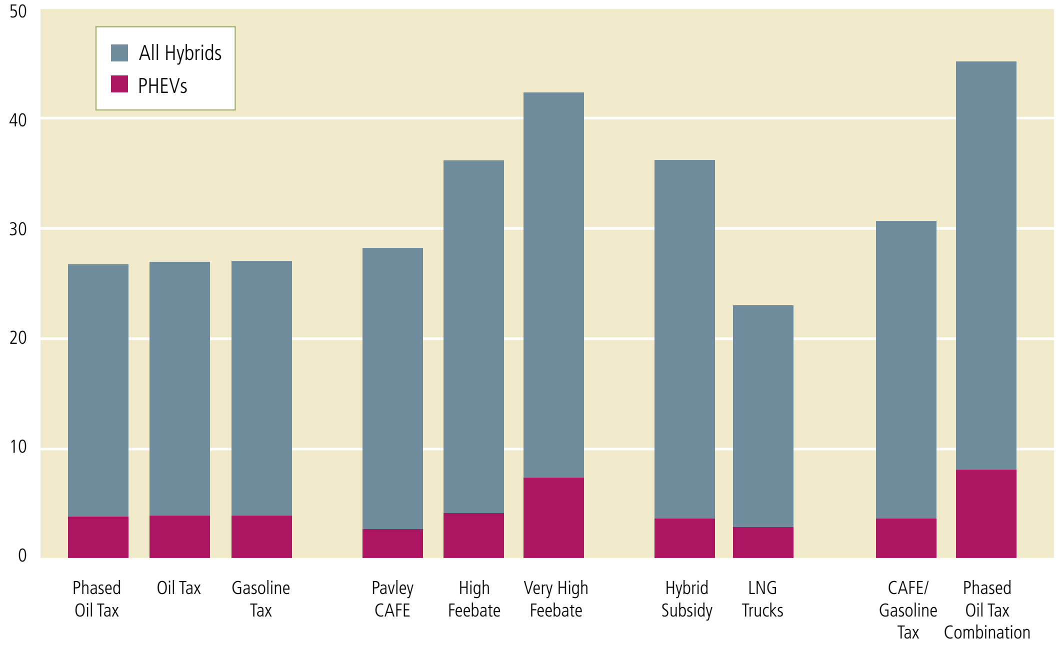
[21] The average fuel economy of the in-use light-duty fleet is about 25 to 30 percent smaller than these figures. This is because used vehicles have somewhat lower fuel economy than newer vehicles, and even for new vehicles, on-road fuel economy is about 20 percent lower than the certified, lab-tested level (Small 2010).

Figure 5.8: Light-Duty Vehicle Fuel Economy, 2030



Note: Light-duty fuel economy of new vehicles is projected to be 39.1 mpg in 2030 in the Reference case.

Figure 5.9: Sales Shares of Hybrid Light-Duty Vehicles, 2030



Note: Sales shares of hybrid light-duty vehicles are projected to be 23 percent in 2030 in the Reference case. LDV, light-duty vehicle.

EE policies, including CAFE policies and Feebates, achieve more substantial gains in fuel economy. Average new-vehicle fuel economy in 2030 is 45.4 to 48.3 mpg under these policies. Some of this increase reflects a higher market share for hybrid vehicles, but the majority comes from manufacturers incorporating advanced fuel-saving technologies into new vehicles (only a minor portion comes from higher sales shares for smaller gasoline vehicles). Hybrid penetration is greatest under the two Feebate policies, reaching 36 to 42 percent by 2030 (although the share of PHEVs remains fairly small). Under these policies, some manufacturers choose to exceed the fuel intensity pivot point, in part by selling more hybrids, whereas others opt to pay the fee, as this gives them more flexibility to use new technologies to improve horsepower rather than fuel economy. The penetration of hybrids also reaches 36 percent by 2030 under the Hybrid Subsidy case.

Nonetheless, the overall potential for CAFE and Feebate policies to reduce gasoline consumption is limited by two key factors. First, manufacturers are increasingly unable to find technologies sufficient to meet the Pavley CAFE standard or to go beyond the existing standard under a Feebate policy. Existing CAFE policies are already aggressive, and it is difficult to make further improvements, given that many of the fuel-saving technologies available in the future are already adopted under the Reference case. Under the Pavley CAFE policy, this is reflected in the increasing willingness of manufacturers to pay penalties rather than fully comply with progressively more stringent regulations.[22] Under the Feebate policies, it is reflected in the fairly modest difference in oil reductions between the High and Very High cases. The Very High Feebate case achieves oil reductions 40 percent greater than the High Feebate case, even though the tax and rebate rate under the first policy is twice that under the second. Second, CAFE and Feebate policies fail to exploit fuel savings from reductions in driving—in fact, they increase VMT by 2 to 3 percent in 2030, undercutting about one-sixth of the savings from higher fuel economy.

The Hybrid Subsidy has about the same effect on the penetration of these vehicles as the High Feebate policy, but fuel economy averaged over all light-duty vehicles is essentially unaffected (Figure 5.8).[23] (The LNG Trucks case has essentially no impact on the light-duty vehicle sector.)

The CAFE/Gasoline Tax and Phased Oil Tax combination achieve about the same fuel economy increase as the CAFE policy alone (Figure 5.8). However, these policies have a somewhat weaker effect on VMT than the tax policies alone, as the higher fuel economy under these policies leads to a larger offsetting rebound effect.

5.3.4 Sensitivity Analyses

Here we briefly discuss the implications of varying some key assumptions in the NEMS–RFF model.

Under more optimistic assumptions about future battery costs (see Box 5.1), the NEMS–RFF model projects the PHEV share of new light-duty vehicle sales rising to 14 percent by 2030 (versus 3 percent with Reference case assumptions), and the overall sales share of hybrids rising to 38 percent (from 23 percent), even with no subsidy. Nonetheless, the same problem applies—any savings in oil use or CO_2 from increased hybrid penetration (as a result of lower battery costs and/or purchase subsidies) are undone because manufacturers can lower the fuel economy of gasoline vehicles and still meet the CAFE standard. Moreover, economywide CO_2 emissions increase (albeit slightly) in this scenario, as gasoline consumption is unaffected, and enhanced use of PHEVs puts greater demands on the power system.

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[22] Even under existing policies in the Reference case, manufacturers pay a fine on 36 percent of vehicles sold in 2015, but this problem cures itself over the next several years, as rising fuel prices and falling technology costs make fuel-saving technologies progressively more attractive. In contrast, under Pavley CAFE, the share of new vehicles for which manufacturers opt to pay some level of fine continues to rise to 69 percent in 2020 and to 100 percent in 2030. As a result, the actual fuel economy of the average new light-duty vehicle in 2030 (46.2 mpg) is well below the official standard (51.8 mpg).

[23] We also modeled a Hybrid Subsidy policy in combination with the stricter Pavley CAFE policy, where manufacturers pay fines rather than fully meet the stricter standards. In this case, as more hybrids are sold, fewer fines are paid and overall fuel economy rises. Nonetheless, the reduction in oil use due to the subsidy is still very modest, about 0.1 percent.

The availability and cost of future fuel-saving technologies out to 2030 are difficult to project with accuracy—in fact, some analysts believe that NEMS (and therefore, NEMS–RFF) is unduly pessimistic about future technology development. Small (2010) investigated the effectiveness of the CAFE policy under more optimistic assumptions about automotive technology embedded in EIA's "high-tech" scenario. The projected average fuel economy of light-duty vehicles under the policy is greater, but not dramatically so—48.8 mpg, compared with 46.2 mpg.

5.4 Welfare Costs of Alternative Policies

This section briefly describes how the economic costs of policies are measured and the main results from NEMS–RFF comparing the total welfare costs and cost-effectiveness of policies. (As noted, adjustments to these costs to account for broader societal impacts, like reduced road congestion and local air pollution, as well as linkages with the broader fiscal system, are discussed in Chapter 9.)

5.4.1 Issues in Welfare Cost Measurement

Policies affecting the automobile sector may impose costs by inducing people to drive less, or to use different vehicles, than they would otherwise prefer. Welfare costs also arise to the extent that vehicle production costs are higher as manufacturers are induced to incorporate fuel-saving technologies, though offsetting this are the resulting fuel savings over the vehicle life. Appendix D provides details on how costs are measured.

Measurement of net economic costs, or benefits, from fuel economy improvements is especially contentious. Based on available evidence, consumers in the NEMS–RFF model are assumed to take into account fuel savings that accrue over the first three years of a vehicle's life. In contrast, the societal benefits from higher fuel economy extend over the vehicle's entire life, discounted at the social (or market) rate, which is taken to be 5 percent in this study.

One interpretation of the NEMS–RFF assumption is that consumers are myopic and that they undervalue, or excessively discount, the full benefits from higher fuel economy. An alternative interpretation is that consumers are reluctant to demand more fuel-efficient vehicles because of hidden costs; for example, people might face high costs to borrowing more for higher-priced vehicles. Hidden costs may also arise if emerging technologies could be used either to increase fuel economy or to enhance other vehicle attributes, such as horsepower, that consumers would value more highly than fuel economy. In this case, the opportunity cost of using the technologies to increase fuel economy is greater than the pure up-front vehicle installation cost.

We consider three cases below. In one case, fuel savings from fuel economy improvements are valued, or discounted, in our cost calculations according to how consumers in the NEMS–RFF model value them. This case, termed the No Market Failure case, assumes that the entire discrepancy between the societal value of fuel savings and the value attributed to these savings by consumers in the NEMS–RFF model is explained by hidden costs. In the second case, termed the Partial Market Failure case, these savings are valued based on the central estimate of Small (2010), who assumes that market failure accounts for half of the discrepancy between the societal value of fuel savings and the value attributed to these savings by consumers in the NEMS–RFF model. In the third case, we assume that market failures are fully responsible for this discrepancy (the Complete Market Failure case).

In our first case, there is no actual discrepancy between the private valuation of fuel economy and the social valuation, because the apparent discrepancy is due to other social costs. Therefore, if left to its own devices, the market would provide the economically efficient level of fuel economy (leaving aside energy security and climate change concerns). In the second case—Partial Market Failure—in the absence of any policy, investment in fuel economy would be inadequate because consumers value it less than society does. In this setting, up to a point, policy-induced improvements in fuel economy can produce net economic benefits in the sense that the social value of fuel savings exceeds the upfront costs of incorporating fuel-saving technologies into new vehicles. However, existing CAFE standards already in law go a long way toward addressing this market failure, so further improving fuel economy still results in some positive cost (albeit a lower cost because of market failures).

It is important to emphasize that our first case provides an upper-bound estimate of costs—that is, when hidden costs account for the entire discrepancy between the societal value of fuel savings and the value attached to those savings by consumers in the NEMS–RFF model. On the other hand, our third case represents a lower-bound estimate of costs, when hidden costs account for none of the discrepancy (or, said another way, market failure accounts for the entire discrepancy). The second case, therefore, represents a compromise between two extreme views of hidden costs. Comparing our three measures of cost clarifies the extent to which the costs of policies may decline as a result of their ability to address market failures associated with decisions about energy efficiency.

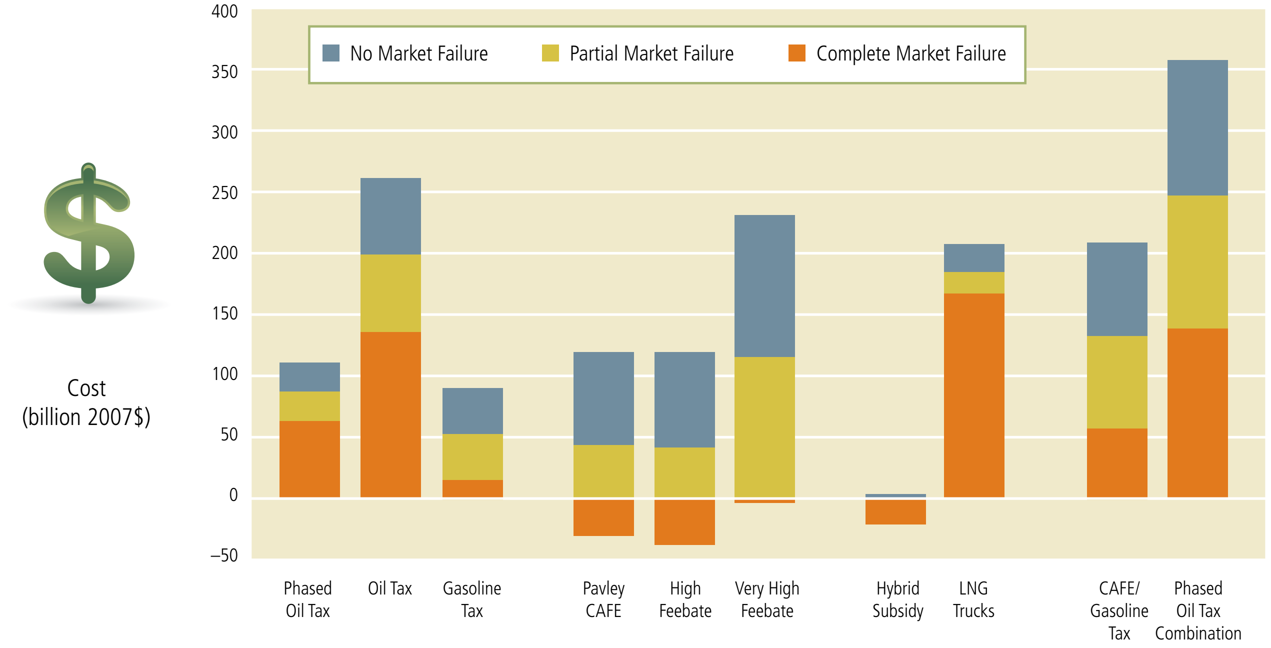
5.4.2 Cost Metrics

Figure 5.10 shows the total PDV of policy costs added up over the 2010–2030 period with fuel economy improvements valued according to the three assumptions mentioned above. The value of fuel savings beyond 2030 from fuel economy improvements made prior to that date are netted out from these costs.

Costs are highly sensitive to assumptions about possible market failures associated with energy efficiency—especially for policies targeted at improving fuel economy. For the Pavley CAFE, High Feebate, and CAFE/Gasoline Tax combination policies, costs fall by more than half in the case with partial market failures. For example, for the Pavley CAFE policy, PDV costs are $45 billion and $121 billion in the Partial and No Market Failure cases, respectively. In the Complete Market Failure case, some policies actually have negative costs; in particular, costs of the Pavley CAFE, High Feebate, and Hybrid Subsidy drop below zero.

Naturally, costs increase with the effectiveness of a policy at reducing oil and CO_2 emissions. For example, the Oil Tax, which immediately reduces

Figure 5.10: PDV of Policy Costs, 2010–2030



the use of all oil products, costs $138 to $263 billion over the study period, compared with $64 to $112 billion for the Phased Oil Tax, and $16 to $91 billion for the Gasoline Tax.

The Pavley CAFE and High Feebate cases have very similar costs, given that they have similar impacts on average fuel economy and fuel use and that increased flexibility in the CAFE standards moving forward exploits much of the potential cost savings from feebates.

The cost of reducing an extra barrel of oil, or an extra ton of CO_2, also rises with the scale of the policy in any given year, as the lower-cost options or technologies are progressively exploited. This shows up somewhat in the cost-effectiveness of the policies, as summarized in Figure 5.11. Cost-effectiveness is the PDV of costs (from Figure 5.10) divided by the (undiscounted) cumulative reductions in oil or CO_2, where the latter takes into account savings in oil and CO_2 beyond 2030 that occur as a result of policy action during the study period. These cost-effectiveness metrics provide a measure of the average cost per barrel of oil, or ton of CO_2, reduced as a result of policy intervention between 2010 and 2030.

In panel (a) of Figure 5.11, the Oil Tax reduces oil use at an average cost of $13 to $24 per barrel over the period 2010 to 2030. Average costs for the Phased Oil Tax are $10 to $17 per barrel, but this policy reduces cumulative oil use over the study period by 40 percent less than the (immediate) Oil Tax. The Phased Oil Tax has a higher cost per barrel reduced than the Gasoline Tax, averaged across the whole study period. The former policy imposes lower costs, and achieves smaller oil reductions, out to about 2020. However, the converse applies after 2020 as the level of this policy catches up to that of the (immediate) Gasoline Tax and it reduces all oil products, rather than just those in the light-duty vehicle sector.

In the absence of market failures related to energy efficiency, the CAFE and Feebate policies have relatively poor cost-effectiveness as average costs exceed $30 per barrel. That is, if the market correctly values fuel economy improvements, policies targeted at fuel economy are costly relative to policies that also exploit other options for fuel savings, especially given the stringent CAFE policies already in place. The Very High Feebate policy has especially poor cost-effectiveness ($47 per barrel) because of the rapidly escalating costs to manufacturers of additional fuel economy improvements beyond those in the Pavley CAFE and High Feebate scenarios, as technological possibilities are exhausted. However, under the scenarios with market failures related to energy efficiency, policies targeting fuel economy can be reasonably cost-effective—for example, at the Partial Market Failure rate, the costs of the Pavley CAFE and High Feebate policies are $12 per barrel. Nonetheless, average costs are still (moderately) above those for the Gasoline Tax, even though the latter produces greater cumulative oil reductions. Moreover, according to our results, feebates are no more cost-effective than CAFE policies, given the increased flexibility recently introduced into the CAFE regulations. The CAFE/Gasoline Tax combination has average costs ($7 to $26 per barrel) that fall within the range of its policy components.

The LNG Trucks policy appears to score well on cost-effectiveness grounds—average costs are $13 to $16 per barrel. However, this estimate should be viewed with some caution given that it omits any effect on the price of LNG of expanded fuel distribution infrastructure,[24] the possible lack of a market for used (natural gas) engines that can only be refueled at specific locations (diesel engines from used trucks are commonly used for agricultural or other off-road activities), and safety risks posed by the use of liquefied gas.[25]

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[24] We assume, simply, that the price of this infrastructure would be reflected in the price of LNG at the "pump," and that this price is the same per Btu as that of compressed natural gas—the current situation in California.

[25] On the other hand, the above estimate is based on future natural gas reserves as predicted by EIA (2009d). As discussed in Box 4.2, projected reserves are now much larger, implying somewhat lower natural gas prices in the future. In Krupnick (2010) for the central case, the net costs of an LNG truck relative to a diesel-fueled truck falls slightly under this alternative bounding case for future gas prices.

Figure 5.11(a): Cost-Effectiveness: Cost per Barrel for Reducing Oil Use, 2010–2030

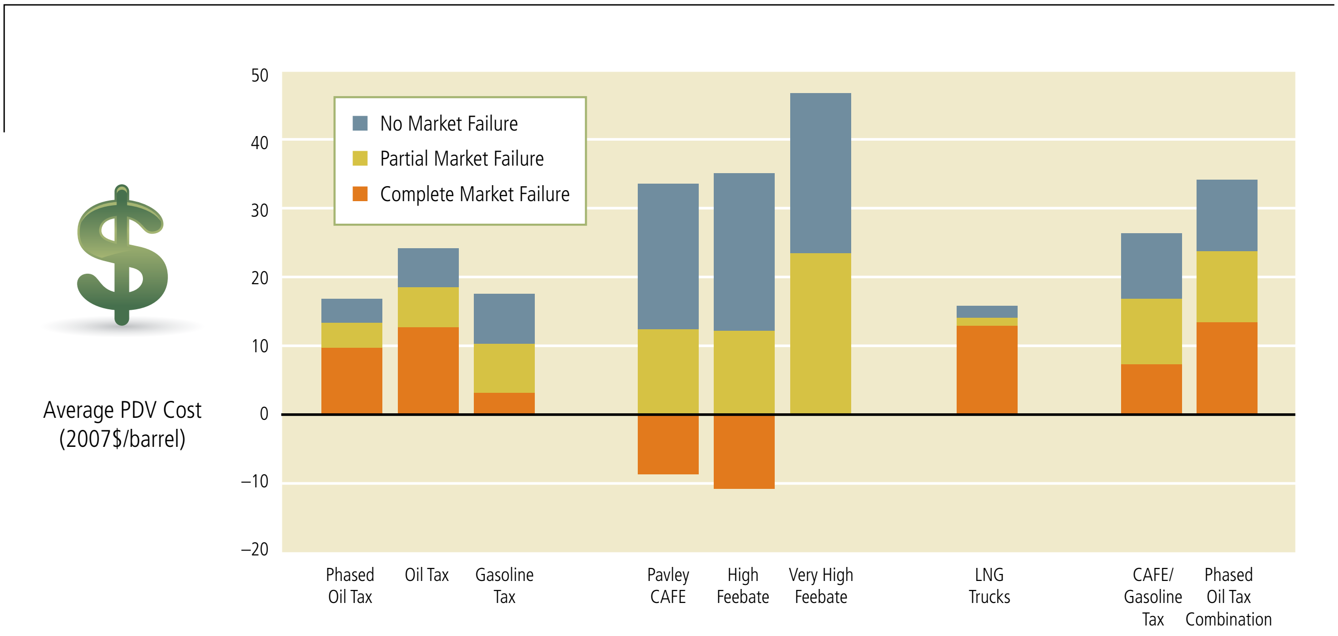
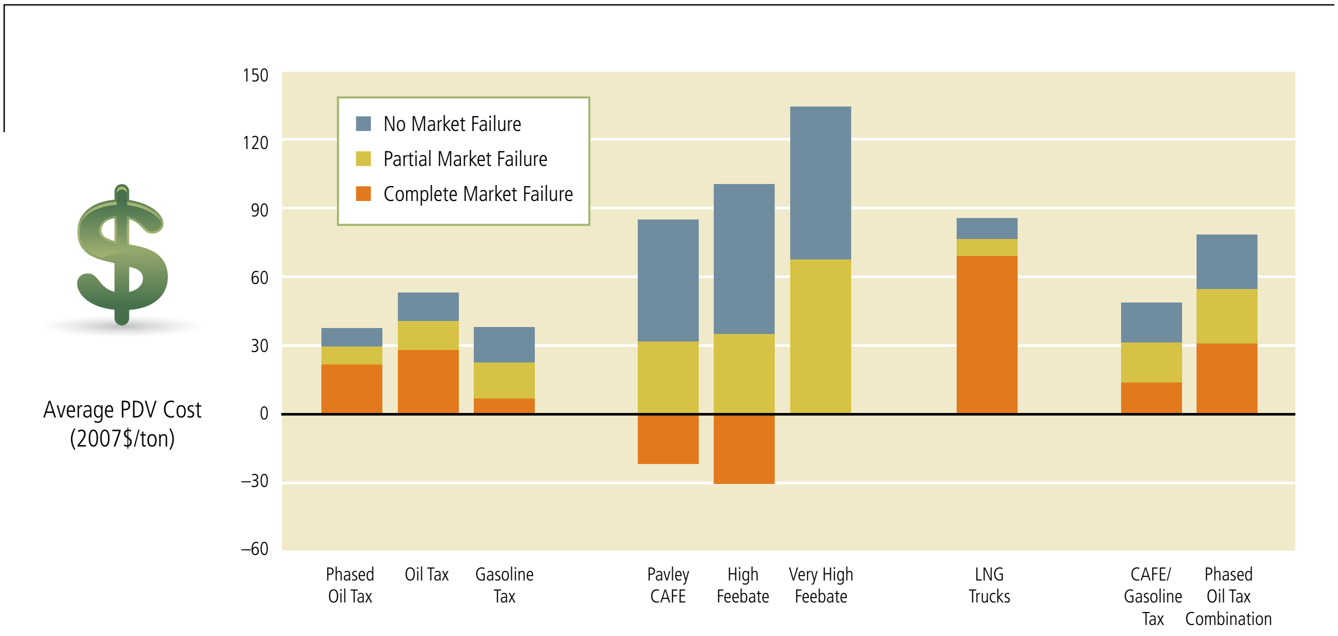


Figure 5.11(b): Cost per Ton for Reducing CO_2 Emissions, 2010–2030



Note: The cost-effectiveness of the hybrid subsidy is not shown as it does not reduce oil or CO_2.

The average cost of the Phased Oil Tax combination is \$24 per barrel in the Partial Market Failure case. This is about what we would expect given that it is more effective than the gasoline policies and that average costs rise with scale. Because this combination policy also pushes hard on the fuel economy margin, it is significantly more expensive (\$34 per barrel) if no market failures are associated with fuel economy choices (i.e., using the high discount rate).

In panel (b) of Figure 5.11, the oil-focused policies tend to perform relatively poorly in terms of cost-effectiveness at reducing CO_2 emissions, when compared with policies that exploit low-cost abatement opportunities in the power sector. For example, with no market failures, the average cost-effectiveness of the oil-focused policies would range between \$37 and \$134 per ton of CO_2 reduced.

In terms of relative cost-effectiveness, the policies display a pattern that is broadly similar to that in panel (a). One difference is LNG Trucks, in which cost-effectiveness relative to other policies deteriorates somewhat in terms of CO_2 reductions given that, as noted above, some of the savings from reduced oil consumption are offset through new emissions sources.

An important caveat to the interpretation of NEMS–RFF outputs is needed. With stringent policies and appropriate incentives, it is possible that manufacturers will adopt strategies or develop technologies a number of years from now that go beyond the ability of a model like NEMS–RFF to predict. In this regard, the analysis may understate the future effectiveness of aggressive policies.

5.5 Policies Not Modeled

This chapter includes discussion of a broad range of policy options; nonetheless, other policies that were not modeled as part of this study could produce significant oil reductions. We describe several of these policies below.

Insurance Reform

An alternative to higher fuel taxes is incentives to encourage pay-as-you-drive automobile insurance. This involves replacing the current system of fixed annual insurance premiums with premiums that vary in direct proportion to a motorist's annual mileage (scaled by his or her insurance rating factor). Effectively, the policy imposes a charge on VMT, but without a transfer of revenue to the government, which helps with feasibility, as the average motorist is fully compensated for the variable charge through the elimination of current (fixed) insurance premiums. According to Bordoff and Noel (2008), fully implementing pay-as-you-drive insurance would impose a charge of almost 7¢ per vehicle mile for the average motorist, which is equivalent in scale to a gasoline tax increase of around \$1.50 per gallon (given that the average vehicle currently drives about 22 miles on a gallon of gasoline). We did not specifically model insurance reform as it does not provide incentives for higher fuel economy (though it could be implemented in conjunction with EE policies). The potential impact of insurance reform on vehicle travel, and fuel savings from reduced mileage, can be inferred approximately from the effect of the Gasoline Tax on VMT.

Incentives for Unconventional Oil

On paper at least, nonconventional sources of oil might be economic at oil prices of around \$80 per barrel or more (Darmstadter 2010), though the extent to which practical constraints like environmental impacts will inhibit their development over the next 20 years is highly uncertain (see Box 5.3). We did not consider policies to promote domestic sources of nonconventional oil, however, given the difficulty of projecting their future penetration rate, and the controversy that would surround any such incentives.

Oil Import Tariff

An oil import tariff would be more effective at reducing imports than a tax on all crude oil supply, as it encourages more domestic oil production by increasing the market price of oil above the world price. We did not model this policy, however, as it is probably precluded by international trade law.

Box 5.3: Exploring the Potential of Unconventional Liquid Fuels

Unconventional liquid fuels, also referred to as synthetic fuels or synfuels, have long been recognized as a potential alternative to conventional oil. The three main synthetic fuels currently, or prospectively, in development in North America are oil sands, coal-to-liquids (CTL), and oil shale.

Oil sands, also known as tar sands, are sand formations containing considerable hydrocarbon content in the form of bitumen, which can be recovered through modifications to traditional mining techniques. CTL refers to the chemical process (the Fischer-Tropsch method) that converts coal into an intermediate gaseous product that is then condensed and refined into transportation fuel. Oil shale contains kerogen, a type of organic matter that, when heated to very high temperatures, can yield a fuel with properties similar to those of crude oil.

These synfuels (or their base materials) are highly abundant and can be found in great quantities in secure locations (including within U.S. borders, or in neighboring Canada). Although oil sands in Canada have developed rapidly, according to assessments in Toman et al. (2008) and Darmstadter (2010), oil shale and CTL might be produced in the United States at costs on the order of $60 to $80 per barrel, though for any number of reasons, actual costs may turn out to be much higher.

One concern about synthetic fuels is that their production is more CO_2-intensive than for conventional oil, from roughly 25 percent more intensive on a well-to-wheel basis for tar sands, to about 75 percent more intensive for CTL. According to Darmstadter (2010), even if CO_2 emissions were priced at $50 per ton, tar sands and CTL could still be competitive with oil (the competitiveness of shale is more uncertain as the technology is less mature and much depends on whether in situ recovery, rather than surface recovery, will prove viable).

Despite their potentially favorable economics, CTL and oil shale are predicted to supply at most only a tiny fraction of U.S. oil needs out to 2030. One reason is that these technologies remain unproven in the United States, which deters major up-front investments in them, especially given uncertainty over future oil prices. In addition, given uncertainty over potentially serious environmental impacts, firms may require a long lead time to obtain the required permits and leases prior to the construction of production facilities. These environmental concerns include the disposal of tailings, implications for water quality and quantity in fragile ecosystems, and the destruction of landscapes from oil shale extraction. Even the development of oil sands has raised concerns about the destruction of boreal forests in western Canada, as well as the diversion of substantial water flow from Alberta's Athabasca River and the management of toxic waste byproducts.

Several other unconventional liquids are discussed in Darmstadter (2010), including the conversion to liquids of a combined coal-and-biomass-to-liquids (CBTL) resource feedstock. This approach is deemed particularly worthy of additional investigation, as CBTL (even at a ratio of 92 percent coal to 8 percent biomass) can lead to significant reductions in CO_2 emissions compared to CTL alone. More recently, large-scale natural gas discoveries have spurred interest in gas-to-liquids as still an additional possibility for a domestic unconventional-fuel industry.

Biofuels Policies

We did not consider any change in biofuels policies. Policies in place to promote biofuels are already highly aggressive—the federal Renewable Fuel Standard program requires 36 billion gallons of biofuels to be produced by 2022. Moreover, experts have expressed doubt about whether even existing targets will be achievable, let alone more stringent mandates, given the difficulty of producing biofuels profitably in light of, for example, high corn prices. A further discussion of biofuels policies is included in Chapter 8.

Low-Carbon Fuel Standard

This policy would impose a limit on the average amount of carbon in refined transportation fuels. Given current technologies, the main option for meeting the standard would be to increase the amount of ethanol-based or blended fuel. However, the maximum potential for ethanol may already have been induced by the renewable fuel standard, implying a possible redundancy for low-carbon fuel standards.

Fuel Economy Regulations for Other Transportation Vehicles

Fuel economy regulations might be introduced for heavy-duty trucks. However, according to NRC (2010b), the potential fuel savings appear to be relatively modest, given already strong incentives among competitive trucking companies to minimize fuel costs.[26] The same would apply to the regulation of aviation fuel economy.

5.6 Summary

The main findings of this chapter can be summarized as follows:

5.6.1 Effectiveness

A tax on all oil use is much more effective at reducing oil use than a tax on gasoline alone because it reduces a much broader array of oil products.

Policies that reduce the amount vehicles are driven are significantly more effective than policies that only increase automobile fuel economy, whereas gasoline or oil taxes and EE policies combined are more effective than either one of these policies in isolation.

Tightening fuel economy regulations beyond already enacted standards has a limited effect because such approaches begin to run up against technological constraints, even under more optimistic technology assumptions.

Binding CAFE standards undermine fuel savings from subsidies designed to promote the penetration of hybrid vehicles because hybrids are included in the pool of vehicles for which CAFE standards are measured; therefore, pressure is reduced on conventional gasoline vehicle fuel economy. Feebates do not lead to the same undermining effect, nor does a policy progressively converting heavy trucks to natural gas, which could achieve substantial oil reductions (though natural gas trucks are an emerging, rather than proven, technology).

Phased oil taxes over the next 20 years yield about 60 percent of the cumulative oil reductions that would be induced under a large, immediate, and sustained oil tax increase. More reductions could be achieved by combining phased taxes with feebates and hybrid subsidies.

5.6.2 Costs

The most cost-effective measures are taxes on all oil products, and next are taxes on gasoline fuels.

The CAFE or Feebate policies modeled in this study perform poorly on cost-effectiveness grounds if the market values fuel economy appropriately. If the market substantially undervalues fuel economy, the cost-effectiveness of these policies improves substantially. In the case of partial market failure, the average cost per barrel of oil reduced is smaller under the Gasoline Tax policy than under the EE policies, even though the

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[26] Moreover, in contrast to cars, the cabin and trailer are interchangeable, which complicates the design of fuel economy regulations for a vehicle.

Gasoline Tax produces significantly greater cumulative oil reductions. Assuming complete market failure, however, turns these costs of the EE policies negative.

Any cost advantage of feebates over fuel economy regulations appears to be small, given new flexibility provisions in the CAFE program. But, unlike CAFE, feebates do not undermine the fuel savings from incentives for hybrid vehicles.

Combining progressively rising oil taxes with additional EE policies makes sense on cost-effectiveness grounds only if a substantial market failure is associated with fuel economy decisions.

Although not as effective and cost-effective as carbon pricing policies, a broad portfolio standard that includes all generation types cleaner than coal (this study's CEPS-All policy) is better at reducing CO_2 emissions than other types of portfolio standards—and it achieves these reductions at a relatively low cost.

6. Policies to Reduce CO_2 Emissions

About 40 percent of current and projected CO_2 emissions in the United States come from the electricity sector, with the remainder from transportation, heating, and industrial sources. Although the potential for reducing CO_2 in the power sector is greater than elsewhere in the economy (because of the wider availability of alternatives to carbon-intensive fuels), substantially reducing electricity-related emissions will still be very challenging for several reasons: (a) power generation is heavily dependent on cheap but carbon-laden coal; (b) there are limits to expanding carbon-free alternatives like nuclear, wind, and solar; (c) methods for capturing power plant emissions of CO_2 are still in their infancy; and (d) consumers and producers appear reluctant to adopt energy-saving technologies.

At the same time, policymakers throughout the world are discussing (and in some cases, implementing) market-based approaches to reducing CO_2—namely, cap and trade (C&T) or emissions tax systems. The European Union has a C&T system, applied to utility and industrial sources and covering about half of total CO_2 emissions, and carbon taxes have been introduced in Scandinavian countries, Ireland, and British Columbia. In the United States, a C&T system applied to the power sector has been introduced in the northeastern states (though with little effect on emissions to date), and larger-scale programs are envisioned for California and for six states and four Canadian provinces covered through the Western Climate Initiative. At the federal level, C&T legislation in the Waxman–Markey bill (WM, or H.R. 2454) passed the House of Representatives, and variants of it have been proposed in the Senate. However, final implementation of a nationwide C&T program faces significant challenges and currently seems unlikely, particularly given intense opposition to large energy price increases and debate over who will receive valuable emissions allowances.

This chapter therefore examines a variety of emissions pricing policies, as well as alternatives to direct pricing that may prove more politically palatable. The latter include energy efficiency (EE) policies and incentives for low-carbon technologies like nuclear and renewables. We also discuss fiscal and other considerations where appropriate.

6.1 Emissions Pricing Policies

6.1.1 Policy Background

Economic theory is clear that economywide pricing policies—in this case, carbon taxes or C&T programs that price CO_2 through the allowance-trading market—have the potential to reduce a given amount of CO_2 emissions at the lowest economic cost, relative to other policies. As the emissions price is reflected in the price of fossil fuels, electricity, and energy-using products, firms and households have incentives to switch toward low-carbon fuels, adopt energy-saving technologies, and cut back on energy-intensive products and activities. Moreover, emissions pricing achieves an efficient pattern of emissions reductions across many different margins, as firms and households have incentives to adjust their behaviors until the cost of those behaviors (per ton of CO_2 reductions) equals the emissions price. In this way, the economywide costs of all these individual decisions are kept to a minimum. Further, over the longer haul, innovators are rewarded for developing low-cost carbon technologies. A single alternative to (broad-based) emissions pricing policies generally acts only on a subset of the many margins for emissions reductions and rewards only specific types of technology developments.

A number of key design issues critically influence the effectiveness and costs of emissions pricing policies. Most obviously, these include the emissions sources covered, the extent and timing of required reductions, and whether firms can pay for emissions reductions in other sectors (not covered by the program) or other countries—typically referred to as *offsets*—instead of reducing their own emissions. Moreover, as already discussed for oil policies, the extent to which revenues are raised and how they are used critically affect the broader economywide costs of the policy.

6.1.2 Central C&T Policy

This chapter of the report looks at several variations on C&T policies with different design assumptions, beginning with a Central C&T case that includes or modifies several key features found in recent federal legislation.[27] This Central policy is defined as follows.

- *The aggregate cap:* The time profile of the aggregate cap reduces covered emissions of all GHGs by 17 percent below 2005 levels by 2020 and 40 percent below by 2030.

- *GHGs covered:* The cap covers all energy-related CO_2 emissions and selected non-CO_2 gases.[28]

- *Sectors covered:* The cap covers all major sectors (electric power, transportation, and industrial) as points of regulation. That is, emitters in each of these sectors must submit allowances to validate their emissions.

- *Availability of offsets:* Offsets enable domestic firms to take advantage of lower-cost emissions reduction opportunities in other sectors and countries. For example, a covered domestic firm may gain emissions reduction credits by paying for a project to reduce deforestation in Indonesia. However, offsets may be problematic in that reductions are not "real" if the project would have occurred anyway without the payment.[29] And even if project emissions reductions are genuine, they may be offset by increased emissions elsewhere; for example, reduced deforestation in one region may raise timber prices and encourage more deforestation in other regions. The WM bill allows for one billion tons of domestic offsets and another one billion tons of international offsets each year. However, given considerable uncertainty about the availability, validity, and cost of these offsets, our Central C&T policy instead allows 500 million tons each per year for domestic and international offsets.

- *Intertemporal allowance trading:* Banking and borrowing of allowances is permitted; that is, emitters can accumulate emissions credits in early years, which they can then *bank* for use in future years, and they can *borrow* emissions credits (without penalty) against future reductions. Bank balances must go to zero by 2030, meaning that each regulated entity must have used up all previously banked allowances by this date.

- *Allowance allocation and revenue use:* Emissions pricing policies often generate revenue that can be returned, or recycled, to the economy in various ways. Different revenue recycling options—such as cutting distortionary income taxes or providing cash rebates—have important implications for the overall costs of policies (Parry and Williams 2010) and the distribution of these costs across different households (Blonz et al. 2008). However, the NEMS–RFF model is not designed to analyze these issues; in fact, estimates of policy costs

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[27] The Central C&T program is referred to as a second reference case, or Core 2, in several of the technical papers accompanying this report.

[28] Other GHGs are converted into CO_2e based on their lifetime warming potential and are then priced at the same rate as CO_2. They include, among others, methane released from farm activities and sulfur hexafluoride, which is used in the electric power industry.

[29] In fact, a large fraction of projects qualifying for offsets under the Kyoto Protocol's Clean Development Mechanism may have been undertaken even without payments (Wara and Victor 2008).

from the model are very similar, regardless of the form of recycling and whether allowances are given away for free. For the emissions pricing policies considered here, all revenues are assumed to be returned to individuals as direct rebates. Chapter 9 discusses the cost and distributional implications of alternative possibilities for revenue recycling.[30]

6.1.3 Variants of C&T

We model several alternatives to the Central C&T program, reflecting different possibilities for policy stringency, offset availability, coverage, and the form of pricing instrument.

- *Less Stringent Cap:* In this scenario, required cumulative reductions for all GHGs are 33 percent lower than in the Central case. This implies that reductions in CO_2 will also be lower.

- *No Offsets:* Given uncertainty over offset availability, we model a policy with the same emissions cap as the Central case, but with no offsets available (implying a greater burden on domestic energy-related CO_2 reductions).

- *More Offsets:* For this policy, we double the allowable offsets to two billion, reflecting more optimistic assumptions about future offset availability and validity.

- *Transportation Sector Excluded:* Again, this policy imposes the same overall GHG cap, but excludes the transportation sector to provide some sense of the additional costs if the United States were to follow the European Union with a program focused on stationary emissions sources only. This variation provides interesting insight into a more sectoral-based approach, which has been considered in proposed Senate legislation.

6.1.4 An Additional Emissions Pricing Option: The Carbon Tax

We also model a *Carbon Tax* (which has various political, academic, and media proponents) that essentially mimics the time path of allowance prices under the Central C&T policy. Within the NEMS–RFF model, these two policies have equivalent effects and costs when implemented in isolation. However, other instruments have different effects when combined with one of these policies, given that a carbon tax fixes the emissions price (and allows emissions to vary) whereas C&T fixes the quantity of emissions (and allows the allowance price to vary).

Carbon taxes have two potentially important advantages over traditional C&T systems, though the latter can be designed to largely mimic the effects of taxes. One advantage relates to emissions price stability[31] and the other to fiscal considerations. Given that these issues cannot be examined with the NEMS–RFF model, they are taken up in Chapter 9.

6.1.5 Key Metrics: Effectiveness of Alternative Policies

Although most policies in this chapter impact energy-related CO_2 only (with essentially no impact on other GHG emissions and offsets), emissions pricing policies typically affect emissions more broadly. To ensure comparability across policies, in this section we focus on energy-related CO_2 emissions and the costs associated with their reduction under emissions pricing policies. However, Box 6.1 discusses the metrics associated with all GHGs and offsets for the Central C&T case.

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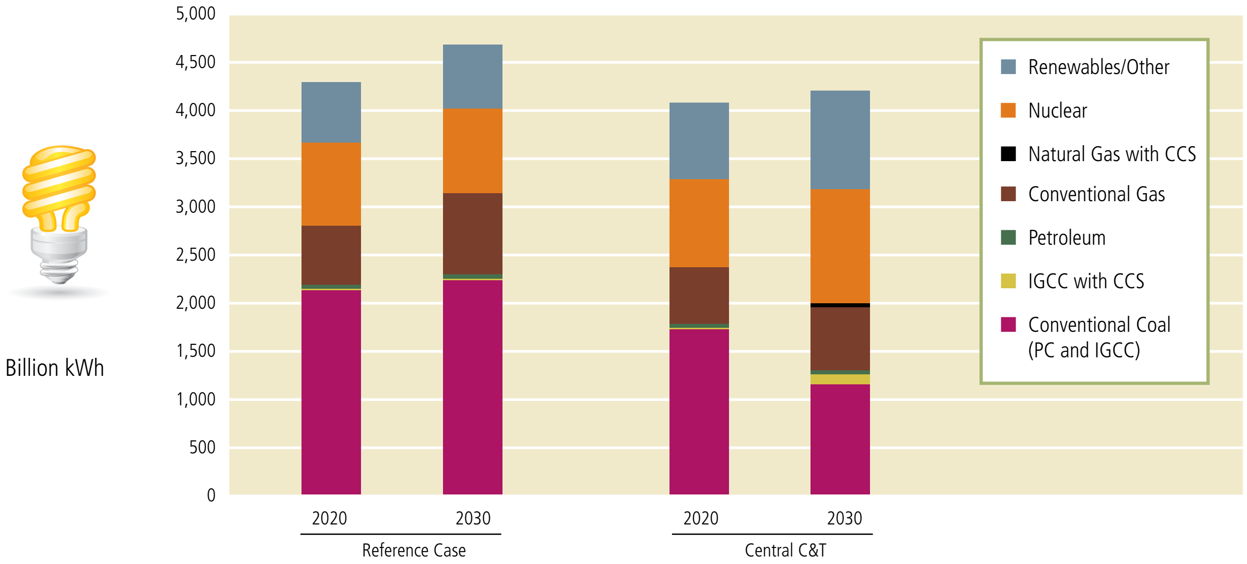
[30] A final key issue in the climate policy debate has been the implications for U.S. firms competing in global markets (e.g., steel, aluminum, and cement) and the extent to which emissions reductions at home might be partly negated by increased emissions elsewhere as production relocates to other countries. According to some models, as much as 15 to 25 percent of economywide U.S. CO_2 reductions could be offset by extra emissions elsewhere, although the majority of the leakage stems from changes in global fuel prices rather than relocation of capital (Gupta et al. 2007; Ho et al. 2008; Babiker and Rutherford 2005; Fischer and Fox 2007, 2009). To partly address this problem, some have proposed to charge importers for the CO_2 emissions associated with their production and provide compensation for U.S. exporters in energy-intensive industries. These issues are beyond our scope, however, given that NEMS–RFF is not designed to analyze international emissions leakage.

[31] Existing C&T systems have displayed considerable price volatility. For example, the price of NO_x allowances under the Regional Clean Air Incentives Market program varied between $400 and $20,000 per ton during California's energy supply crisis in 2000. And in the European Trading System, allowance prices varied between $1 and $30 per ton of CO_2 from 2005 to 2009.

Figure 6.1: Electricity Generation Mix, 2020 and 2030



Reductions in CO_2 Emissions

Figure 6.1 compares the electricity generation mix in the Reference case and the Central C&T case, illustrating the overall reduction in generation spurred by the pricing policy. This reduction in generation leads to a reduction in domestic energy-related CO_2 emissions, and Figures 6.2 (a) and (b) provide a breakdown of these reductions in 2020 and 2030 under the Central C&T policy. CO_2 emissions are reduced by about 500 mmtons below Reference case levels in 2020, and 1,400 mmtons below Reference case levels in 2030. The bulk of the reductions (about 89 and 87 percent, respectively) are in the power sector, mostly from fuel switching, though lower electricity consumption accounts for between 18 and 26 percent of the reductions. Electricity generation from nuclear power and renewables rises, largely at the expense of coal. By 2030, the share of generation from nuclear power increases from 18 to 26 percent; similarly, the share of generation from renewables rises from 16 to 26 percent. Use of natural gas in the power sector remains basically flat, as even though carbon pricing favors natural gas over coal, natural gas becomes more costly relative to zero-carbon fuels. Transportation accounts for approximately 8 percent of domestic CO_2 reductions.

Figure 6.3 shows the cumulative reductions in domestic energy-related CO_2 emissions from the Central C&T case (12,366 mmtons) and its variants (ranging from 6,404 mmtons to 28,475 mmtons). The variation in CO_2 reductions from the policies is wide, ranging from 5 to 23 percent below Reference case levels. By design, the Central C&T and Carbon Tax policies lead to very similar reductions, about 10 percent[32] below Reference case levels, whereas the Less Stringent Cap leads to a reduction only half as large. The 23 percent reduction arises because offsets are not permitted, and the cap must therefore be met mostly from domestic energy-related CO_2 reductions. The policy excluding transportation is still under the same cap; thus, the power and other covered sectors must make up for the loss of transportation as a source of domestic energy-related CO_2 reductions.[33]

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[32] In our Central case, energy-related CO_2 reductions are only 10 percent, not the 17 percent reduction commonly associated with C&T bills in Congress. The difference is that the 17 percent includes all GHG reductions, not just energy-related CO_2 reductions.

[33] CO_2 reductions are slightly higher in the case where transportation is excluded because of a small price response in the non-covered transportation sector.

Figure 6.2(a): Breakdown of Emissions Reductions in Central C&T, 2020

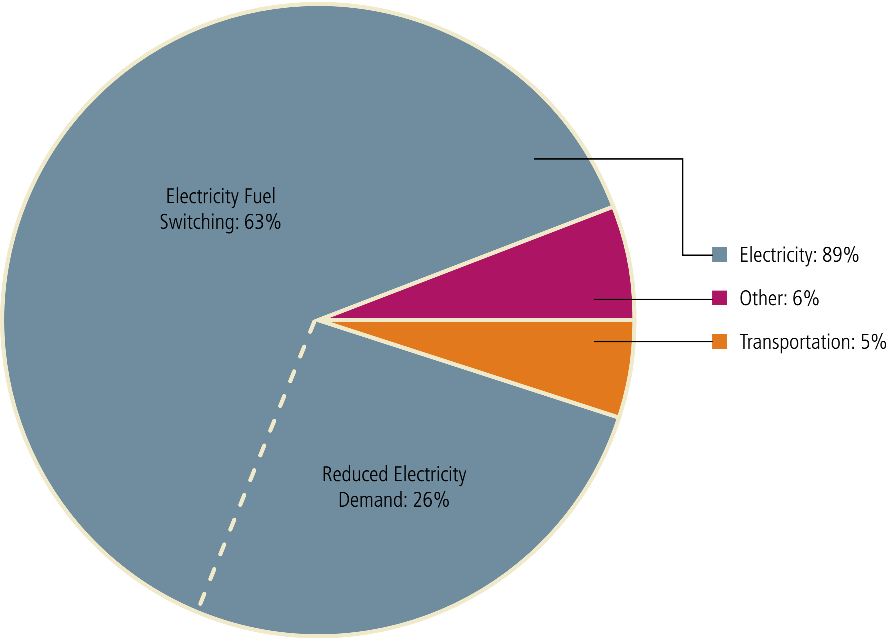


Figure 6.2(b): Breakdown of Emissions Reductions in Central C&T, 2030

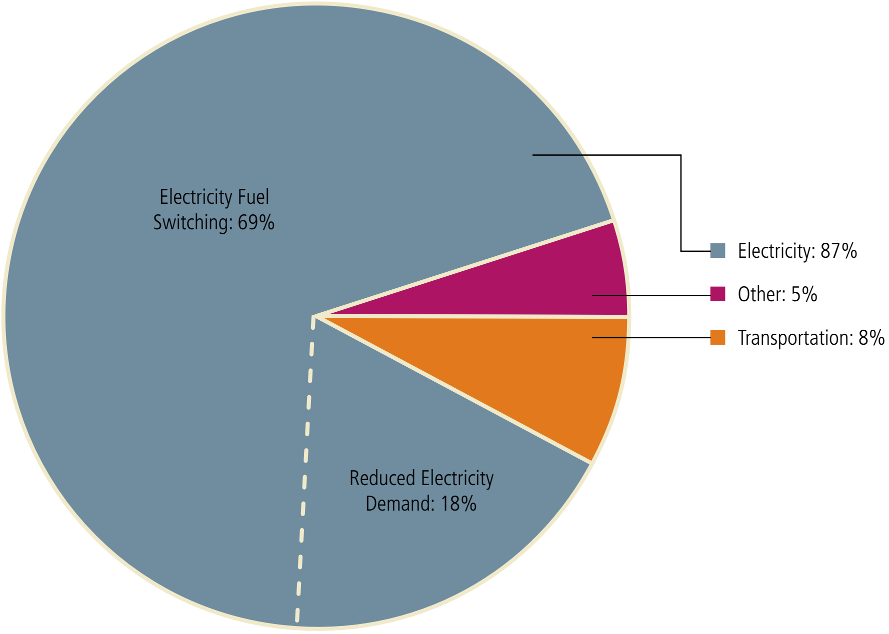
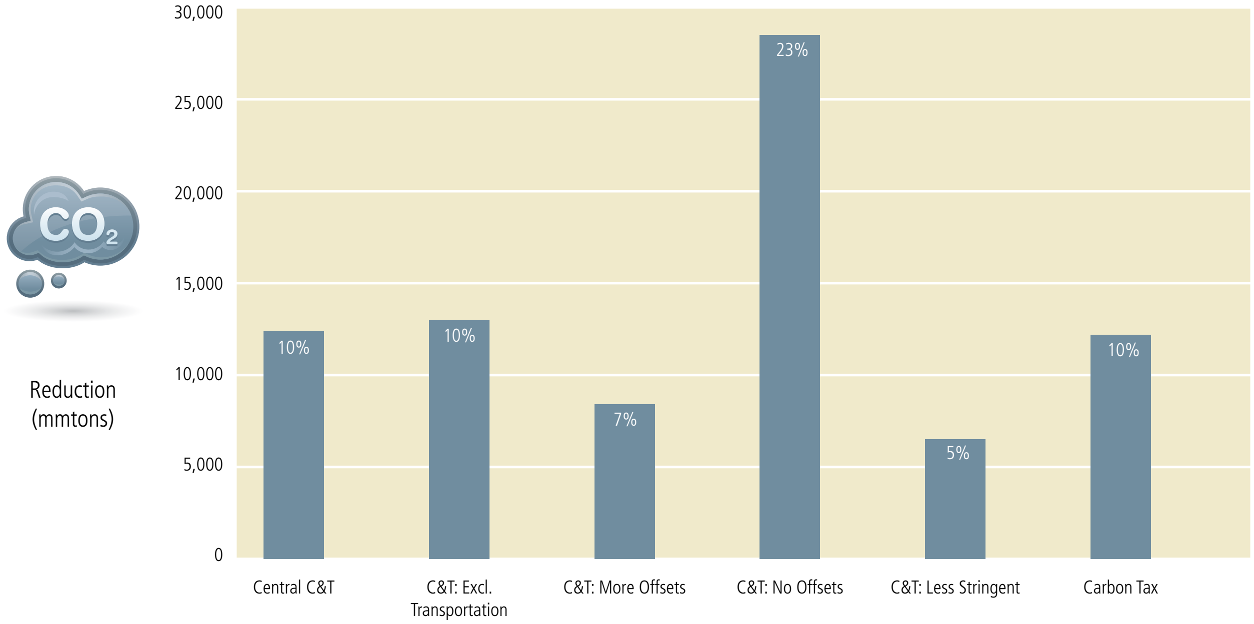


Figure 6.3: Cumulative Reductions in CO_2 Relative to Reference Case, 2010–2030



Note: Percentages noted are percentage reductions from the Reference case.

Reductions in Oil Use

Because the consumption of oil does entail some carbon emissions, C&T programs and carbon taxes do place an extra price burden on oil use, particularly if the transportation sector is included under the cap. This leads to a reasonably significant reduction in oil use over the project period, ranging from 0.2 to 0.6 mmbd in 2020 and 0.7 to 1.3 mmbd in 2030, as shown in Figures 6.4 (a) and (b).

Pricing Impacts

Pricing CO_2 emissions will raise electricity prices, which will cause consumers to use less energy than they would otherwise. To get some idea of these effects, we examine three variants that result in different cap stringencies: the Central case, the Less Stringent Cap case, and the No Offsets case. As illustrated in Table 6.1, the delivered price of electricity in 2030 varies from 10.0¢/kWh in the Reference case to 12.8¢/kWh in the Central C&T case, and usage drops by nearly 8 percent. Price and quantity changes are more pronounced in the No Offsets case and less pronounced with the Less Stringent Cap.

As expected, average electricity prices increase for all policy scenarios over the Reference case, up to more than 4¢/kWh by 2030 in the No Offsets case. These price increases result in less use of electricity for all consumers—up to 571 billion kWh less in 2030 for the No Offsets scenario—but overall electricity expenditures rise. In the No Offsets case, expenditures are $116 billion higher in 2030 than in the Reference case. Given a U.S. population forecast for 2030 of 364 million (U.S. Census Bureau n.d.), this implies an increase in average annual energy expenditures of $319/person. In our Central C&T case, higher electricity prices lead to an expenditure increase in 2030 of $213/person.

Different C&T scenarios result in different emissions prices as well, reflecting the varying costs of the last ton reduced; that is, switching to cleaner

Figure 6.4(a): Reduction in Oil Use Relative to Reference Case, 2020

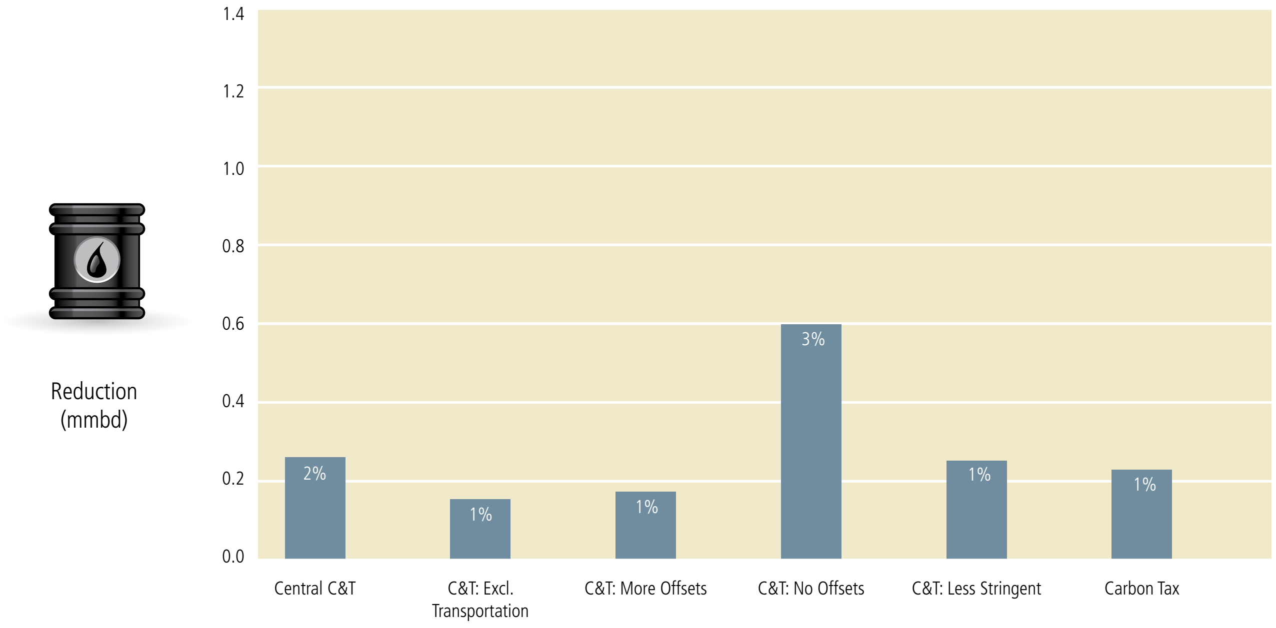
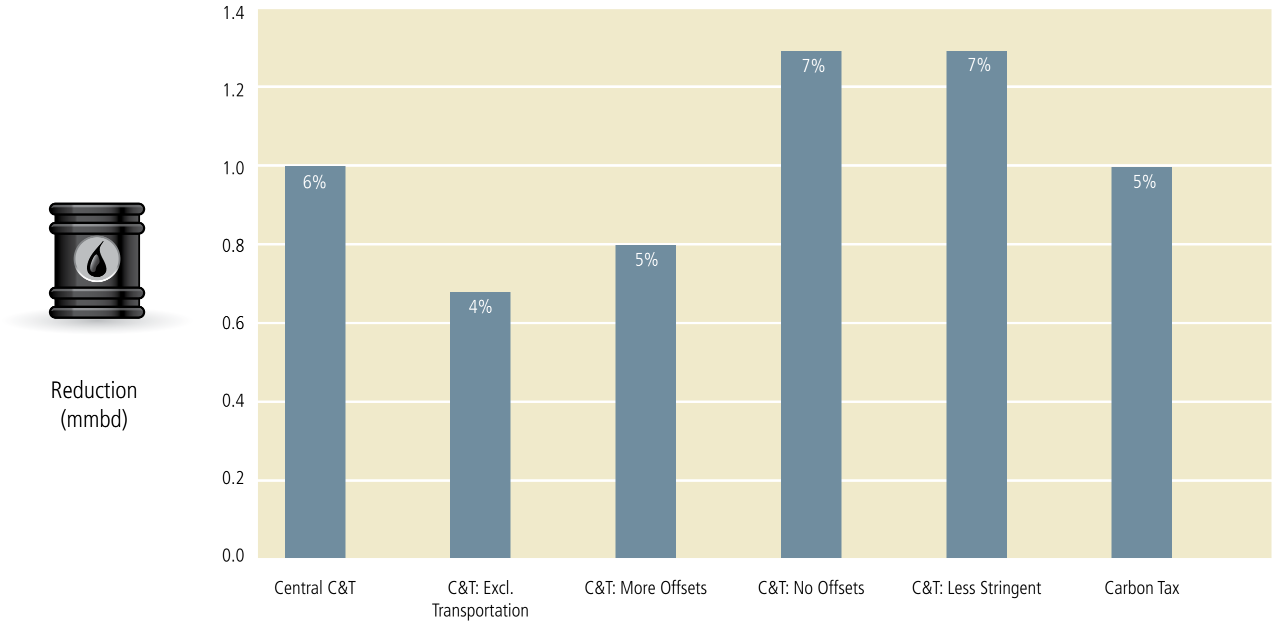


Figure 6.4(b): Reduction in Oil Use Relative to Reference Case, 2030

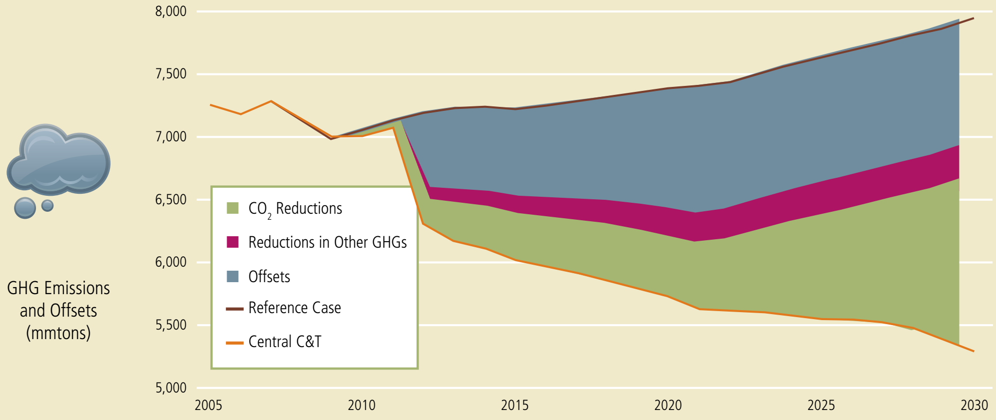


Note: The percentages indicate overall reductions from the Reference case.

Box 6.1: Measuring Overall GHG Emissions

Figure 6.5 provides a temporal breakdown of reductions in CO_2 and other GHGs as well as those from offsets in the Central C&T case over the 2010 to 2030 projection period. Cumulative U.S. GHG reductions amount to 52,316 mmtons compared to the Reference case.

Figure 6.5: GHG Emissions and Offsets in the Reference Case and the Central C&T Policy



Offsets account for 50 percent of these reductions in 2020 and 30 percent in 2030, cuts in domestic CO_2 account for 40 percent and 60 percent of the reductions at those dates, and the remainder reflects cuts in other GHGs. Actual GHGs are (moderately) below the emissions cap out to 2020 and exceeding the cap thereafter, reflecting banking of allowances in the earlier years of the program and the withdrawal of banked allowances later on. Under the variants to the Central C&T policy, the time profile of total GHG reductions is equivalent to that shown in Figure 6.5—with the exception of the Less Stringent Cap, which, by definition, results in 33 percent fewer reductions. The share of reductions composed of CO_2, other GHGs, and offsets varies under the different cases, as shown in Figure 6.6.

Figure 6.6: Cumulative Reductions in CO_2 and Other GHG Emissions Relative to Reference Case, 2010–2030

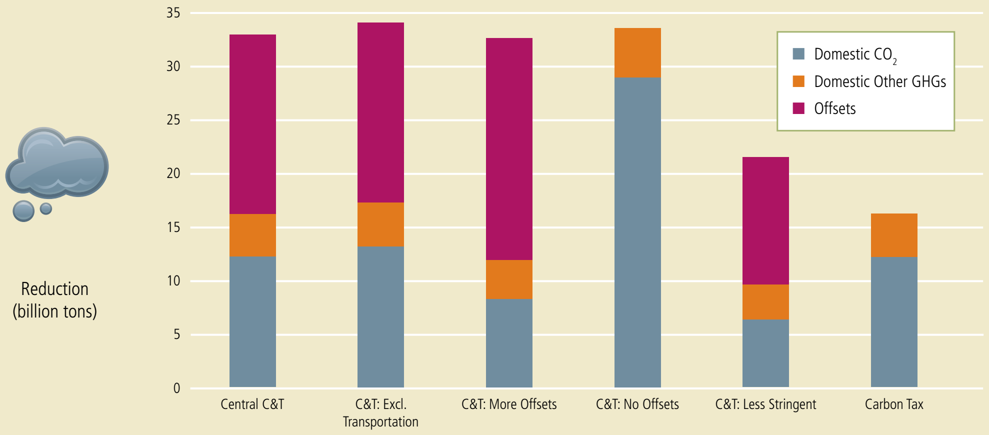
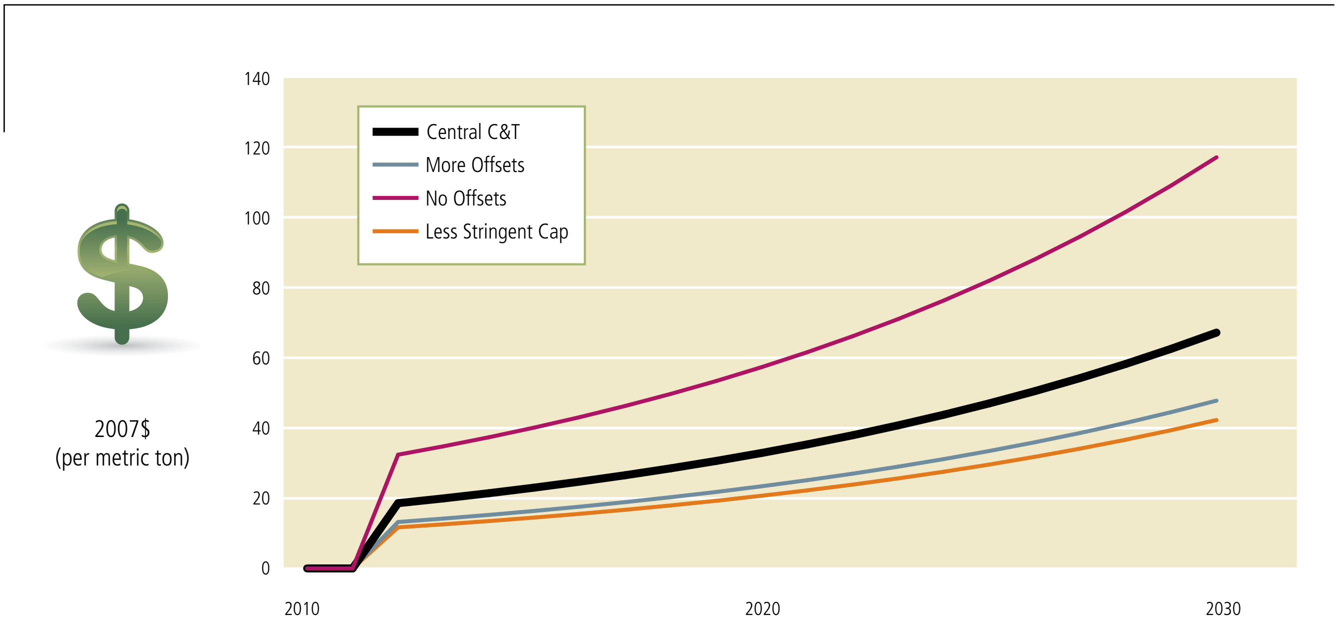


Figure 6.7: Allowance Prices for Selected C&T Scenarios



but more expensive fuels will occur until the extra cost equals the avoided tax payments, or avoided allowance purchases, to an entity from reducing emissions. As it is progressively more difficult to reduce emissions, the allowance price (or cost of the last ton reduced) rises with the level of emissions reduction, as shown in Figure 6.7. The emissions price rises from $18/ton of CO_2 reduced in 2012 (Central C&T case) to $33/ton in 2020 and $67/ton in 2030. Allowance prices are roughly 75 percent higher with no offsets.

6.1.6 Cost and Cost-Effectiveness of Carbon Pricing Policies

The welfare cost of carbon pricing policies in a given year can be approximated by one-half the

Table 6.1: Metrics Relevant to Electricity Consumers, 2030

	Tons of CO_2 emitted, 2030	Delivered price of electricity, 2030 (¢/kWh)	kWh used (billions)	National electricity expenditure (billion $)
Reference case	6,186	10.0	4,527	454.05
Less Stringent Cap	5,587	11.5	4,314	496.97
Central C&T	4,815	12.8	4,171	531.80
No Offsets	3,703	14.4	3,956	569.66

Table 6.2: Total Welfare Costs and Welfare Cost per Ton (Cost-Effectiveness) of C&T Policies, 2010–2030

	Total welfare costs, PDV (billion $)	Cost-effectiveness ($/ton)	Total CO_2 emissions reductions, 2010–2030 (mmtons)
Central C&T	142.3	12	12,366
More Offsets	68.1	8	8,320
No Offsets	559.4	20	28,745
Less Stringent Cap	47.2	7	6,404
Excluding Transportation	153.3	12	12,948
Carbon Tax	141.6	12	12,181

product of the emissions reduction and the emissions price (i.e., the price of allowances). This is the standard deadweight loss (Harberger) triangle in the carbon market (see Appendix C). In addition, because renewable energy is favored by existing subsidy programs (an investment tax credit and a production tax credit), and these programs expand under C&T, we must count the added government subsidies as an additional welfare cost to society.

Table 6.2 compares the present discounted value (PDV) cost and cost per ton of alternative C&T policies. Not surprisingly, the overall cost grows higher with fewer offsets, as this implies much greater reductions in domestic CO_2. For example, the PDV cost over the study period is $142.3 billion for the Central C&T case, rising to $559.4 billion with No Offsets and dropping to $68.1 billion with More Offsets.

The cost-effectiveness of the Central C&T policy is $12/ton of CO_2 emissions reduced, with the Carbon Tax (by design) showing a very similar cost per ton. Not surprisingly, given the large contribution of offsets to emissions reductions in the Central C&T case (Figure 6.5), cost-effectiveness varies considerably under the alternative scenarios for offset availability, from $8/ton to $20/ton. On the other hand, cost-effectiveness is considerably less sensitive to the exclusion of the transportation sector (also ~$12/ton), given the relatively small contribution of transportation to total CO_2 reductions in the Central C&T case.[34]

The Less Stringent Cap is an interesting case: the policy achieves 52 percent of the domestic energy-related CO_2 emissions reductions found in the Central C&T case (6,404 mmtons versus 12,366 mmtons), but the total PDV of welfare costs is reduced by a larger percentage (67

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[34] Readers may wonder why these costs per ton are so much lower than allowance prices. An allowance price at a moment in time represents the cost of reducing the "last" or marginal unit of emissions. Rather, we are measuring the total present discounted social cost of reducing emissions over an entire period, a period with changing allowance prices. When we measure cost-effectiveness, it is an average cost concept—in other words, total social cost divided by cumulative emissions reductions over the period—not a marginal concept. Allowance prices do figure into the calculation of welfare costs, however.

Box 6.2: Modeling C&T with Only CO_2 Covered

We model an additional variant of C&T in which the cap—set at the same level as in the Central C&T case—must be met by reductions only in domestic CO_2 emissions (rather than all GHGs) or through offsets. This variation reflects the potential difficulty of monitoring and verifying reductions of some non-CO_2 GHGs covered in the Central case (e.g., livestock emissions of methane, nitrous oxide from fertilizers, and soil practices).

As expected, this case results in significantly more domestic energy-related CO_2 emissions reductions over the project period (16,115 mmtons) than the Central C&T case, although by design the total combined number of emissions reductions (CO_2 and other GHGs) and offsets is the same in both cases. Total welfare costs of the policy are $219.1 billion, for a cost per ton of $14—thus, it is marginally more expensive than the broader variants but considerably less costly than the case with no offsets allowed. This type of C&T program might therefore be worth considering if verification of reductions in non-CO_2 GHGs proved challenging but policymakers still wanted to achieve significant measurable emissions reductions while offering low-cost offsets.

percent)—an indication that the less stringent cap avoids the most costly reductions in CO_2 emissions. With the Less Stringent Cap case, cost-effectiveness falls to $7/ton but only half of the CO_2 emissions reductions are achieved, illustrating the inherent trade-off between the effectiveness of a policy and its costs.

Sectoral C&T approaches—such as dropping transportation, and potentially industry,[35] from the trading system—involve trading off cost for simplicity. This study's analysis shows that dropping transportation raises overall costs of meeting the (unchanged) cap by almost 8 percent, because some low-cost sources of CO_2 reductions that could have been available for trading are no longer available.[36]

Finally, Box 6.2 describes a final C&T case modeled but not included in the broader analysis.

6.1.7 Summary

In general, our analysis shows that PDV costs rise at an increasing rate with CO_2 emissions reductions. This suggests that as policies become more stringent in terms of energy-related CO_2 reductions, these added reductions become more expensive—a fairly intuitive finding, but one that deserves emphasis again here.

Our findings also suggest that offsets play a vital role in keeping costs low—again, this is something that policymakers have long understood, but it is worth noting. As long as offsets are available at the price and quantity assumed in this analysis, and they are enforceable, the strategy of including offsets in C&T systems makes some economic sense on cost-effectiveness grounds. Further, cost elasticity calculations indicate that including offsets would be better than simply lowering the cap.[37]

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[35] This omission of both transportation and industry was included in legislation proposed by Senators Kerry and Lieberman.

[36] Note that the NEMS–RFF model shows that domestic energy-related CO_2 reductions actually increase about 4 percent with the transportation sector excluded. With the GHG cap identical in the two cases, this implies that more of the burden of meeting the cap falls to CO_2 and less to other GHGs.

[37] Elasticity is calculated as the percentage change in PDV cost per percentage change in CO_2 emissions reductions relative to the Central C&T case. These calculations help address the problem of comparing cost-effectiveness estimates among policies with very different effectiveness levels. Larger elasticities are good for policies with smaller reductions in CO_2, and smaller elasticities are good for policies with larger reductions in CO_2 relative to the Central case. Of the two policies with smaller reductions in CO_2 than the Central C&T case, the More Offsets case performs better than the Less Stringent Cap case.

These C&T results provide a useful benchmark against which to compare the energy sector–specific policies we analyze below. The Central C&T policy reduces CO_2 emissions at approximately $12/ton; the following sections show how less comprehensive options fare when compared to this economywide pricing approach.

6.2 Energy Efficiency (EE) Policies

One of the fundamental ways to reduce emissions is to reduce overall energy use, as 86 percent of CO_2 emissions are related to energy production and consumption (including transportation). Reductions in residential, commercial, and industrial energy use primarily come about in two ways: through reductions in the consumption of energy services, or energy conservation (e.g., turning the lights off and the heat down), and through improvements in how efficiently appliances and other durable goods use energy.

The first public policies designed to promote energy efficiency were put in place in the 1970s, when concern over high energy prices led to a focus on reducing energy consumption. Today policymakers are showing renewed interest in EE measures, which various analyses have suggested can reduce energy use in a cost-effective manner (NRC 2009b). Some of these studies have even claimed that EE measures can reduce energy consumption (and associated CO_2 emissions) at negative cost—that is, at a net savings to consumers (Creyts et al. 2007). Economists have generally been skeptical of these claims, however, as data show that consumers are reluctant to purchase such technologies, arguing that the technologies themselves may have hidden costs (Joskow and Marron 1993).

6.2.1 Policy Background

EE policies and programs in the United States can be grouped into four categories, as described below.

Technical Standards

Auffhammer and Sanstad (forthcoming) describe technical standards as "regulations that prescribe either the degree of energy efficiency of a specific item (e.g., appliances) or require a certain technology or material to be used (e.g., insulation to buildings)." Common technical standards include appliance standards and building codes.

Federal appliance standards were initially put in place in 1987, with the passage of the National Alliance Energy Conservation Act, and were updated in 1988 and 1992. A key recent example of an improved technical standard can be found in EISA 2007, which mandated that light bulbs achieve roughly 25 percent greater efficiency by 2014. This phased-in standard effectively bans the sale of most current incandescent light bulbs starting in 2012.

Building codes are more commonly applied on a state level, in part to account for regional differences in climate. States often base their legislation on one of several broad codes developed by the Council of American Building Officials. Not all states have building codes applied to energy efficiency, however, and there have been several proposals for a national standard.

Financial Incentive Programs

Tax credits and demand-side management (DSM) programs are two primary types of financial incentive programs designed to encourage the adoption of energy efficient technologies. The first federal income tax credit for energy efficiency was introduced in 1978 to encourage improvements in buildings. About 30 million claims were made for the credit, but this led to a loss of $5 billion in tax revenue during the credit's seven-year lifetime. The 2005 Energy Policy Act (EPAct) also included tax incentives for home improvements in energy efficiency and extended credits to manufacturers of energy-efficient appliances. Six states currently have state-specific tax credits or deductions for energy efficiency measures, down from a peak of nine states in the early 1980s.

DSM programs are operated by public utilities to encourage residential, commercial, and industrial consumers of electricity to purchase and/or use more energy-efficient equipment. Examples of DSM programs include combined loan and information programs; rebate programs that reduce the cost of purchasing energy-efficient appliances or other devices; or energy audit services, provided by either utilities or local or state governments to help energy consumers identify areas for energy savings.

A recent example of a financial incentive program can be found in the Obama administration's 2009 ARRA, which set aside $5 billion for the government's Weatherization Assistance Program. This program offers up to $6,500 in home energy efficiency upgrades for households earning up to 200 percent of the federal poverty level, and is designed to both reduce energy costs for low-income families and create new jobs (U.S. DOE 2009b).

Information and Voluntary Programs

Federal and state governments have created a variety of informational programs (some of which are tied to financial incentives) to encourage commercial and residential consumers to voluntarily purchase more efficient equipment or otherwise use energy more efficiently. One example is the Energy Star labeling program, through which EPA rates more than 35 different types of appliances and other products based on their energy use and offers the Energy Star label to those meeting defined standards. The federal government also has several informational programs specifically targeting home builders, encouraging the use of materials that lead to the construction and/or retrofitting of more energy-efficient homes and offices.

Technology Research and Development

Beginning in the 1970s, the federal government has allocated funding specifically for end-use efficiency research and development (R&D), although this and other energy-related topics remain a small fraction of the government's overall R&D spending. DOE's efficiency R&D program includes research on buildings, industry, and transportation; building programs received about 32 percent of the $2 billion in efficiency funding spent between 1978 and 2000. As Auffhammer and Sanstad (forthcoming) note, "Federal support for efficiency research has contributed to or resulted in a number of key efficient technologies for buildings including high-efficiency refrigerators, compact fluorescent and electronic ballast lighting technologies, and low-emissivity windows." More recently, in June 2009 the Obama administration announced $150 million in new funding for advanced building systems and solid state lighting R&D (U.S. DOE 2009a).

The Effects of EE Policies and Programs

Based on data compiled by Gillingham et al. (2006) and Nadel (2004), Auffhammer and Sanstad estimate that, as of the early 2000s, federal EE policies and programs had led to a cumulative 4 percent savings in national energy consumption compared to what consumption would have been without the policies. California's EE policies and programs—often considered the most aggressive—have led to a cumulative statewide 7.5 percent savings in electricity consumption, with utilities estimating savings ranging between 6 percent and 25 percent for individual programs and sectors (Marshall and Gorin 2007).

Estimates of the cost-effectiveness of energy efficiency programs in reducing energy use and CO_2 emissions vary widely. In their extensive survey of the energy efficiency literature, Gillingham et al. (2006) estimate that efficiency investments have reduced electricity use at an average cost of about 2.8¢/kWh of electricity saved (2002$). However, other studies have characterized this as a very optimistic estimate. Using improved statistical methods, Arimura et al. (2009) estimate an average cost of 6.2¢/kWh (2007$) saved. Using an average emissions intensity of electricity generation in the United States of 0.000523 tons CO_2/kWh of generation, these estimates translate to CO_2 cost-effectiveness estimates of $54 and $119/ton of CO_2 reduced. These estimates serve as a useful benchmark for our analysis below.

6.2.2 Policies Modeled

In addition to the energy efficiency initiatives included in EISA 2007 and ARRA, energy efficiency plays a prominent role in more recent legislation. For example, H.R. 2454 features provisions for national building energy codes, building retrofit policies, and some relatively minor lighting and appliance standards; if adopted, these provisions would represent another significant step forward in national energy efficiency legislation. For that reason, we chose to look at several of the policies in WM as examples of extensive new energy efficiency policies.

The WM building codes provision calls for a 30 percent reduction in energy use by new buildings upon enactment of the law, a 50 percent reduction by residential buildings by 2014 and by commercial buildings by 2015, and a 5 percent reduction at three-year intervals thereafter up until 2029 (residential) and 2030 (commercial). The retrofit provision requires EPA to develop building retrofit policies to achieve the utmost cost-effective energy efficiency improvements; the programs are administered through the states, which receive CO_2 emissions allowances under the C&T program in H.R. 2454 to help in financing the programs. The lighting provisions create new standards for outdoor lighting, portable light fixtures, and incandescent reflector lamps. The appliance feature amends the Energy Policy and Conservation Act by requiring testing procedures for water dispensers, portable electric spas, and hot food–holding cabinets and sets standards for these appliances as of 2012; commercial furnaces also face standards under the bill, beginning in 2011. We chose to analyze how these policies, which would represent significant new progress in national energy efficiency legislation, compare in cost and cost-effectiveness to other proposed measures for reducing GHG emissions.

We therefore use the NEMS–RFF model to evaluate two energy efficiency policies based on the H.R. 2454 provisions: (a) the *Building Code Provisions* alone and (b) the *Full WM EE Provisions*.[38] As a sensitivity analysis, we also analyze policy option (b) under EIA's *AEO2009* alternative *High-Tech Assumptions*. The High-Tech Assumptions are very optimistic: they assume accelerated technological progress (beyond that already found in the Reference case) across the board, which manifests itself in higher efficiencies for all energy-using equipment in the model. One could consider the High-Tech scenario to be one in which government investments in energy R&D lead to the diffusion of highly efficient equipment and appliances at relatively low cost.

6.2.3 Key Metrics: Effectiveness of Alternative Policies

We focus our attention on the CO_2 reductions from the policies because building energy codes, and energy efficiency policies more generally, mainly affect electricity and natural gas consumption and have only a very small impact on petroleum (leading to a reduction of less than 70,000 barrels per day, according to NEMS–RFF output). We first discuss the reductions in CO_2 emissions from the 2020 and 2030 Reference case levels for the three policy scenarios (Table 6.3) and later discuss cumulative reductions over the project period. The percentages in Table 6.3 indicate the CO_2 emissions reductions spurred by each policy in a given year, compared to the Reference case in the same year.

In 2020, the Building Codes reduce CO_2 emissions by 3 mmtons, whereas the Full WM EE Provisions—building codes, building retrofits, and the lighting and appliance standards described above—reduce emissions by 10 mmtons. By 2030, however, the Building Codes achieve a reduction in emissions almost as great as that of the Full WM EE Provisions (which include the Building Codes): 40 mmtons over the Reference case, compared with 44 mmtons for the Full WM EE case. In the later years of the projection period, the Building Codes have more "bite"—as new buildings gradually replace old ones and the codes increase in stringency—and therefore comprise a greater portion of the reductions achieved by the Full WM EE Provisions.

These reductions bring about only a small percentage reduction in total CO_2 emissions—well below 1 percent even for the Full WM EE Provisions in 2030. There are several reasons for these small impacts in our two forecast years, even though the Building Codes policy could be considered aggressive. First and foremost, as explained above, building codes apply to new buildings only and rely on stock turnover to have an impact. Unlike vehicles and appliances, new buildings replace old ones quite slowly.

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[38] This representation followed the approach used by EIA in its analysis of the WM bill.

Table 6.3: CO_2 Emissions Reductions with EE Provisions: Changes from the Reference Case

	2020		2030		Total CO_2 emissions reductions, 2010–2030 (mmtons)	
	mmtons	%	mmtons	%		
					Residential sector only	Total
Building Codes	3	0.05	40	0.65	179	208
Full WM EE Provisions	10	0.17	44	0.71	249	300
Full WM EE Provisions + High-Tech NEMS Assumptions	53	0.90	117	1.89	847	1,332

Note: The Full EE cases include the building codes, retrofits, lighting, and appliances provisions of H.R. 2454.

Second, efficiency improvements occur even in the Reference case as a result of natural technological progress, which improves efficiencies and lowers costs, as well as policies embodied in recent federal legislation. The NEMS–RFF model projects that a new building shell in 2030 in the Reference case (i.e., in the absence of any new policy) will be 29 percent more efficient than in 2005. In the Building Codes policy case, a new shell in 2030 would be 66 percent more efficient than in 2005. Thus, the policy leads to new shells that are only 37 percent more efficient than in the baseline.[39]

Third, the Building Codes policy spurs little change in equipment inside of buildings, instead leading mostly to changes in building shells. The efficiency of heating and cooling systems, in particular, is an important aspect of overall building energy use and emissions. Although the model predicts some changes in these systems relative to the baseline, they are quite small.

Fourth, 64 percent of the reductions in energy use from the Building Codes policy are reductions in natural gas consumption due to reduced demand for heating. Reducing natural gas consumption generally does less for carbon emissions than reducing electricity consumption; thus, the emissions benefit from the Building Codes may be less than that from a policy that more directly targets electricity.

Finally, a change to the efficiency of a building is the "gift that keeps on giving," i.e., emissions reductions from these policies continue for many years beyond our 2030 end date. For purposes of evaluation and comparisons across policies, it was necessary to choose a consistent policy horizon for our study, and the NEMS–RFF model does not forecast beyond 2030. Unfortunately, this works against policies such as building codes that take a number of years to affect emissions but tend to have long-lasting impacts once in place. Therefore, although we report cumulative

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[39] This is the improvement for new homes; the building shell improvement in 2030 over 2005 for an average home (i.e., a mix of new and old) is 9 percent in the Reference case and 14 percent in the Building Codes policy case.

emissions reductions over a 2010–2030 time period, we use a longer time horizon (2010–2050) to calculate our cost-effectiveness estimates in the next section.

The last row of Table 6.3 shows the Full WM EE Provisions under the alternative High-Tech Assumptions. These assumptions lead to significantly greater emissions reductions—more than 5 times greater in 2020 and 2.7 times greater in 2030. By 2030, residential CO_2 emissions are 5.3 percent below the Reference case level, and total CO_2 emissions are 1.9 percent below those of the Reference case. The implications of this policy scenario are clear: further technological developments beyond what can be expected in a business-as-usual setting can do a lot to bring down emissions. If investments in R&D are to be successful and yield significant improvements in energy technology, policies such as building codes and retrofits would be much more effective at reducing emissions.

Notably, the reductions in this third scenario embody both the effects of the High-Tech Assumptions and the EE policies, and Auffhammer and Sanstad (forthcoming) find that most of the reductions come from the High-Tech Assumptions. In fact, as shown in previous versions of their analysis, 84 percent of the total reductions achieved with the Full WM EE Provisions + High-Tech Assumptions are obtained with the High-Tech Assumptions alone. The two aspects of the policy scenario do have some differential effects on energy use and emissions, however. The High-Tech Assumptions tend to have their impact mainly on electricity consumption, whereas the policies themselves (the building codes, retrofits, and other policies in the WM bill) have a larger impact on natural gas consumption.

6.2.4 Cost and Cost-Effectiveness of Alternative Policies

For the EE policies modeled here, welfare costs are computed as the sum of the additional investment costs required to meet the new standards, less the PDV of the energy savings from the investments. The investment costs are the sum of all of the additional equipment costs over and above the less efficient equipment alternative. These costs vary significantly by region, building type, and other factors, but by 2030 an average house in the Building Codes policy case costs $2,000 more (in 2007$) than it otherwise would. About three-quarters of this extra cost is from changes to the building shell and the remainder from changes to heating and cooling systems.

Unfortunately, the NEMS–RFF model does not provide cost estimates for much of the equipment used in the commercial sector. Some is missing in the residential sector as well, but Auffhammer and Sanstad are able to construct a fairly reasonable estimate of costs for that sector. Although they also report costs for the commercial sector, they strongly caution that those costs are incomplete. For that reason, we focus here only on the results for the efficiency policies as applied to the residential sector.

The welfare cost estimates are highly sensitive to two factors: the lifetime over which the energy savings are enjoyed and the discount rate used to translate that stream of savings into a PDV. Auffhammer and Sanstad show that the Building Codes policy can have costs per ton of emissions reduced that range from –$15 when a 5 percent discount rate and 2050 time horizon are used up to $260 when a 25 percent discount rate and 2030 time horizon are used.

From our perspective, it is clear that some energy savings beyond 2030 should be counted for purposes of calculating the full cost of a building constructed before that date. We accept Auffhammer and Sanstad's suggestion of a 2050 end date, as this allows for 20 years of energy savings on the buildings constructed at the end of the policy horizon.[40] In calculating cost-effectiveness, we also calculate the CO_2 reductions to 2050 to be consistent with this end date. Although the model does not forecast beyond 2030, we use building survival rates from the

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[40] Because energy prices are not available from the model beyond 2030, the authors use the energy savings in 2030 along with building survival rates from NEMS to calculate energy savings for the 2031–2050 period.

Table 6.4: Welfare Costs and Cost per Ton (Cost-Effectiveness) of Residential Sector EE Policies in Reducing CO_2 Emissions, Partial Market Failure Case

	Total welfare costs in residential sector (billion $)	Cost-effectiveness ($/ton)	Total residential sector CO_2 emissions reductions, 2010–2030 (mmtons)	Total residential sector CO_2 emissions reductions, 2010–2050 (mmtons)
Building Codes	15.7	25	179	617
Full WM EE Provisions	26.6	34	249	786
Full WM EE Provisions + High-Tech Assumptions	–42.2	–17	847	2,485

Note: The Partial Market Failure case uses a discount rate of 10 percent for discounting energy savings over the 2010–2050 time period.

model and the emissions reductions in 2030 to estimate these reductions out to 2050.

The appropriate discount rate for discounting future energy savings is less clear. The NEMS–RFF model uses discount rates in the range of 15 to 50 percent for most residential sector investments—with 20 percent the rate used most often—based on observed consumer behavior. We chose a 10 percent discount rate for our central, or Partial Market Failure, case as in the other chapters of this study; this implicitly assumes that there are some market failures in the market for energy efficiency but also some hidden costs that consumers incorporate when making their investment decisions. Those hidden costs, which could relate to unobserved quality differences in products and other factors, lead to an implicit discount rate that is above the social rate of 5 percent. In addition to the central case, we look at a Complete Market Failure case, in which the 5 percent rate is used, and a No Market Failure case (or "full hidden costs" case) with a discount rate of 20 percent.[41]

Cost and cost-effectiveness results for the Partial Market Failure case are shown in Table 6.4. The Building Codes lead to a cumulative reduction in CO_2 emissions in the residential sector over the 2010–2050 period of 617 mmtons, at an average cost per ton of emissions reduced of $25. The combined Full WM EE Provisions policy—building codes, building retrofits, and lighting and appliance standards—yields total emissions reductions of 786 mmtons in the residential sector over the 2010–2050 period, at a higher average cost of $34/ton. Thus, the combination policy achieves greater emissions reductions than the Building Codes alone, but it does so at a slightly higher cost per ton of emissions reduced.

The last row of Table 6.4 shows the costs and cumulative emissions reductions with the Full WM EE Provisions under the more optimistic High-Tech

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[41] The net costs of equipment and energy savings for any year's cohort of new investments are discounted to 2010 at the social rate of 5 percent; the energy savings out to 2050 are discounted at 5, 10, or 20 percent depending on the market failure case.

Table 6.5: Welfare Costs and Cost per Ton (Cost-Effectiveness) of Residential Sector EE Policies in Reducing CO_2 Emissions, Alternative Discount Rates

	Total welfare costs in residential sector (billion $)		Cost-effectiveness ($/ton)	
	No Market Failure discount rate (20%)	Complete Market Failure discount rate (5%)	No Market Failure discount rate (20%)	Complete Market Failure discount rate (5%)
Building Codes	31.7	–9.2	51	–15
Full WM EE Provisions	46.9	–5.2	60	–7
Full WM EE Provisions with High-Tech Assumptions	45.0	–178.4	18	–72

Note: The Full WM EE cases include the building codes, retrofits, lighting, and appliances provisions of H.R. 2454.

Assumptions. Residential sector emissions reductions in the High-Tech scenario are more than three times greater than those obtained in the standard EE policy (2,485 mmtons over the 2010–2050 period compared with 786 mmtons). At –$17/ton, these reductions are achieved at a net gain to society—in other words, the energy savings over the 40-year period, discounted at a 10 percent rate, more than outweigh the higher investment costs. We hasten to add, however, that costs associated with any R&D or other investments necessary to achieve the High-Tech outcomes are not included here. These results highlight the benefits of achieving the High-Tech outcomes; more research is needed to better understand the costs.[42]

Table 6.5 shows the cost estimates for the two alternative discount rates. At the Complete Market Failure rate, the average welfare costs for the three policy scenarios fall to –$15, –$7, and –$72 per ton of CO_2 reduced. At the No Market Failure rate of 20 percent, the average costs are $51, $60, and $18. These numbers highlight the critical importance of the discount rate, an issue we return to below. For the High-Tech scenario, the rate is especially significant: the average cost changes by a full $90/ton, from –$72 at a Complete Market Failure rate up to $18 at a No Market Failure rate.

It is interesting to compare these cost estimates with others in the literature. As reported above, Gillingham et al. (2006) look across studies at a range of EE programs and estimate an average cost of $54/ton of CO_2 emissions reduced. A more recent updated estimate from Arimura et al. (2009), based on utility DSM programs, is $119/ton, far more costly than our estimates. Jacobsen and Kotchen (2010) focus on residential building codes using a unique dataset from one county in Florida; their findings are probably most directly

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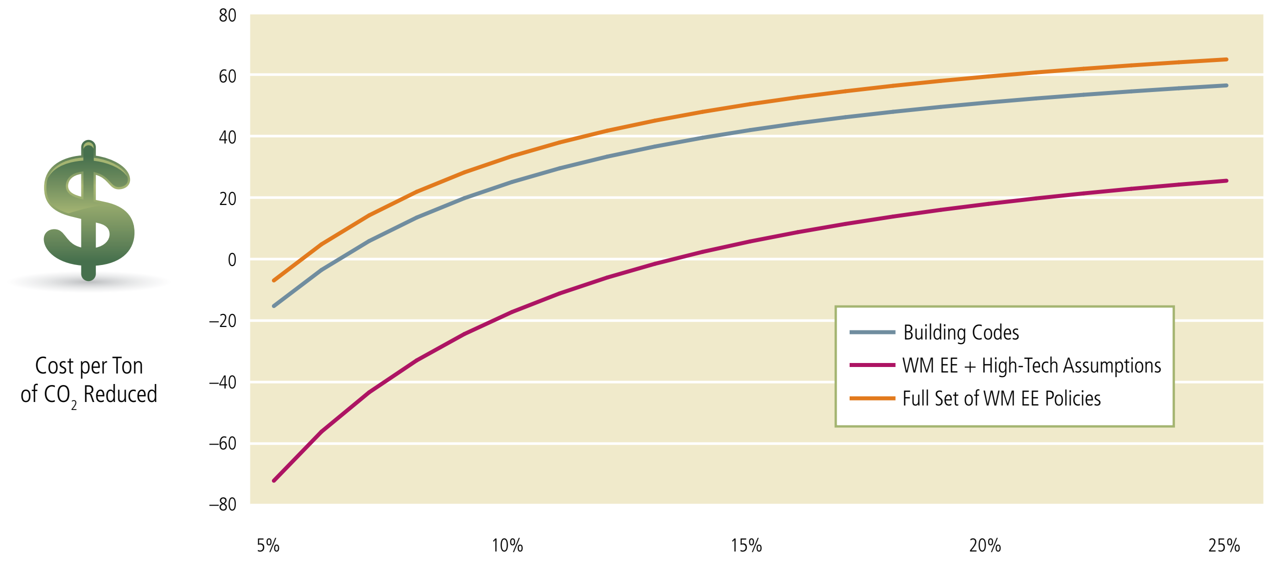
[42] Moreover, the scaling that Auffhammer and Sanstad are required to do because of missing costs from NEMS (as explained above) is less reasonable for the High-Tech scenario because more costs are missing. This means that the cost-effectiveness estimate is a less precise measure of the true costs.

Figure 6.8: Cost-Effectiveness of EE Policies at Various Discount Rates



comparable to the results here. Although they do not calculate total costs and cost-effectiveness in reducing CO_2 emissions, they do report average construction costs and energy savings for a typical house built to meet the codes. Using their numbers, with discount rates of 10 percent and 20 percent over a 30-year lifetime for the investments, we calculate that the discounted net present value of costs would range from –$252 to $838 per residence.[43] By comparison, our central estimate of total costs, $15.7 billion (Table 6.4), translates to approximately $402 per residence (using NEMS forecasts of new housing starts). It thus appears that our numbers are in the same ballpark as those of Jacobsen and Kotchen.

We conclude by emphasizing again the importance of the discount factor and time horizon in assessing the costs of the Building Codes and other EE policies. Figure 6.8 shows how the residential cost-effectiveness estimates for the Building Codes policy and the Full WM EE policy under High-Tech Assumptions vary with discount rates ranging from 5 to 25 percent. The graph makes clear that the costs are higher with the higher discount rate. The differences can be quite dramatic, particularly under the High-Tech Assumptions, where the costs are negative until the discount rate reaches about 14 percent; the Building Codes policy's costs are negative only until the discount rate reaches about 6.5 percent. Further research into the appropriate discount rate and time horizon for policies that target long-lived investments such as buildings is an important topic for future research.

6.2.5 Case Study in Energy Efficiency: Geothermal Heat Pumps

Building codes make some progress in reducing energy use in the residential sector, but they do not directly address the myriad ways in which energy is used in buildings—including space heating and cooling, water heating, dozens of appliances, computers, televisions, and more. Space

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[43] Jacobsen and Kotchen (2010) estimate that construction costs range between $675 and $1,012 per residence and yield energy savings of $29 to $89 per year.

heating, cooling, and water heating are particularly important, as together they account for approximately 68 percent of an average home's delivered energy use.[44] The NEMS–RFF model projects some improvements in heating and cooling system efficiencies in response to the Building Codes policy, but changes in building shell efficiencies accounted for most of the policy response. Additional incentives may be needed to bring about further changes in heating and cooling energy use.

One of the most promising technologies, GHPs act as central heating and cooling systems by using an electric heat pump to circulate fluid through a series of coils that are buried underground. Because subsurface temperatures remain fairly constant throughout the year—warmer than outdoor air in winter and cooler than outdoor air in summer—GHPs work much more efficiently than the more common electric air source heat pumps and natural gas furnaces, which rely on outside air. Essentially, GHPs use energy only to move air (rather than directly to heat or cool it); thus, they require considerably less energy expenditure than traditional heating and cooling systems and can produce up to four times the energy they expend.

Although they have been in existence in the United States since the 1940s, only about 600,000 GHPs are in use (Lund et al. 2004). About one-third of these are in homes, with the remainder in commercial buildings.[45] A study conducted by Oak Ridge National Laboratory (ORNL; Hughes 2008) concluded from a survey of U.S. GHP industry experts that high initial installation costs to consumers, a lack of familiarity with GHPs and their benefits, limited design and installation infrastructures for GHP systems, and a lack of new technologies and techniques are the most significant barriers to the wide application of GHPs. Bony (2010) also emphasizes the initial-cost barrier, noting that, although other issues are present—notably, many consumers' lack of familiarity with the systems—the purchase and installation costs of GHPs pose a serious obstacle.

The up-front costs of GHPs are indeed high in comparison with alternatives. CEC (n.d.) estimates that the equipment for a GHP system for a typical-sized home costs almost twice what a traditional system costs—approximately $7,500 compared with $4,000. Navigant Consulting (2007), in providing information to EIA for the NEMS model, shows similar figures. The GHP infrastructure located outside the home—the underground pipes and the heat exchanger—accounts for roughly half of the total up-front costs (Hughes 2008).The drilling necessary for the underground pipes adds an additional expense, which can vary widely by location and terrain. In the NEMS–RFF model, full purchase and installation costs for GHP systems, including drilling costs, are on the order of $10,000.

The advantage of GHPs comes from their high efficiency and thus greatly reduced energy costs. Calculations show that energy costs can be 30 to 45 percent lower than those with conventional electric or natural gas systems (Hughes 2008; Liu 2010). In addition, maintenance and other costs are lower, as the systems tend to be durable and long lasting. According to the U.S. DOE (n.d. a), the underground system can last more than 50 years and the inside components 25 years.

GHP Policies: Direct Consumer Subsidy and Zero-Interest Consumer Loan

As with the EE policies described above, our analysis of GHP policies focuses on the residential sector. We model two policies to increase residential GHP penetration: a $4,000 *Direct Consumer Subsidy* for the purchase and installation of a GHP system, and a $4,000 *Zero-Interest Loan* for the purchase and installation of a GHP, paid back over a seven-year period. (In other words, the Loan policy reduces the purchase price or installed capital cost by $4,000, just like the Subsidy, but raises operating costs for seven years to pay back the loan.)

Although heating and cooling system costs vary by the type of unit, the $4,000 Subsidy should bring initial GHP purchase and installation costs

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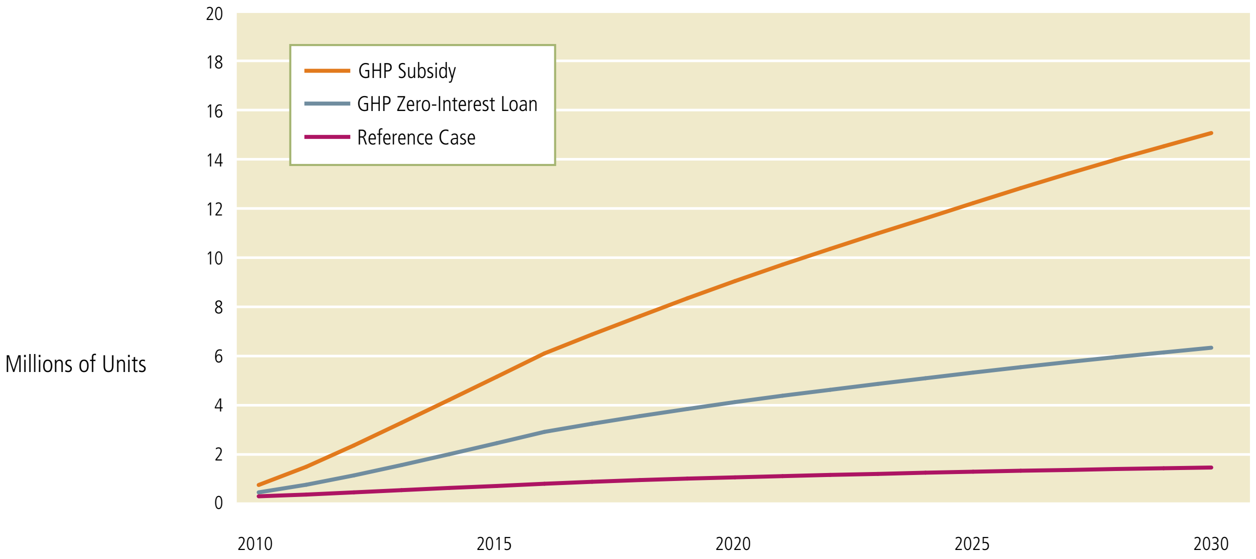
[44] This estimate is based on information for 2007 in the NEMS–RFF model and includes all housing types; Liu (2010) cites U.S. DOE estimates that space heating and cooling and water heating account for 73 percent of delivered energy in single-family homes.

[45] This breakdown is based on NEMS–RFF baseline information.

Figure 6.9: Residential GHPs in Stock: Reference Case and Alternative Policy Scenarios



roughly in line with costs of alternative systems. The advantage of the Loan option is that it may work to overcome the high initial cost of the system, which appears to be a barrier to penetration into the marketplace, while reducing the cost of the policy—both the cost to the government and the welfare cost.[46] We chose a seven-year payback period as this is the average home ownership tenure in the United States. The Zero-Interest Loan policy is quite similar to new policies adopted in a handful of California cities and counties to promote solar energy. Those programs provide financing to consumers for the purchase of solar panels and allow repayment through property taxes over 10- to 20-year periods (though not at zero interest as in our case). Bony (2010) reports that some pilot *loop tariff* programs for GHPs have operated in selected locations. These programs allow the utility to cover the cost of the underground system and recoup that cost from consumers through monthly utility bills.

A 30 percent income tax credit currently exists for residential GHPs, as well as for solar panels, wind turbines, and fuel cells. The tax credit was established for some of these options in the EPAct of 2005 and extended to GHPs in the Energy Improvement and Extension Act of 2008. The credit is scheduled to expire in 2016; thus, the Reference case results include the tax credit through 2016 (and the Loan and Subsidy policies modeled build on this existing credit). Our two policies begin in 2010 and are in place through 2030.

Results: Penetration of GHPs into the Marketplace, Energy Savings, and CO_2 Reductions

The GHP Subsidy has a significant impact on GHP purchases. Figure 6.9 shows the stock of GHPs in

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[46] We also make two adjustments to the NEMS–RFF model. We reduce the switching cost in the model for GHPs and we alter switching shares. Observed behavior in the residential marketplace suggests that when consumers purchase a new heating system to replace an old one, they tend to purchase the same technology. In other words, households using natural gas tend to stay with natural gas, and so forth. The model captures this limited switching in two ways: it imposes an upper limit on the amount of switching that can occur overall in a given year and it sets additional costs for particular technologies. We make relatively minor modifications in the switching shares to allow for more flexibility in the model (making sure to keep our baseline results very close to the Reference case) and we lower the switching cost for GHPs from $8,000 to $4,000.

Table 6.6: Reductions in Residential Sector CO_2 Emissions from GHP Subsidy and Zero-Interest Loan Policies

	2020		2030		Total residential sector CO_2 emissions reductions, 2010–2030 (mmtons)
	mmtons	%	mmtons	%	
GHP Subsidy	11	0.9	22	1.7	245
GHP Zero-Interest Loan	6	0.5	12	0.9	138

Note: Percentages shown are percentage reductions from 2020 and 2030 Reference case levels in residential sector emissions, not in total emissions.

the residential sector over our 2010–2030 projection period in the Reference case and in the two policy cases. By 2020, 7.9 times as many GHPs are in place as in the Reference case; by 2030, 9.7 times as many. The Zero-Interest Loan policy also has a strong impact but one that is quite a bit smaller than that of the Subsidy. By 2020, 3.6 times as many GHPs are in place as in the Reference case; by 2030, 4.1 times as many.

By 2030, 10.8 percent of all heating units in the residential sector are GHPs in the Subsidy case and 4.6 percent are GHPs in the Zero-Interest Loan case. These numbers compare with only 1.1 percent in the Reference case. Much of the expansion in GHPs comes at the expense of natural gas: by 2030, more than 9 million fewer natural gas furnaces are in place with the GHP subsidy, 12 percent below the Reference case level for that year. This is a larger drop than for electric heating systems. The number of central air-conditioning systems drops by 9.7 million, or 13 percent.

In the early years of the policies, most of the GHPs purchased are for new houses rather than to replace equipment in old houses. However, by 2030, the number of GHPs sold as replacements is almost as great as the number for new homes. With the Subsidy, approximately 548,000 GHPs are purchased for new homes in 2030 and 455,000 to retrofit existing homes. With the Loan policy, 209,000 are purchased for new homes in 2030 and 195,000 for existing homes.

Table 6.6 shows the change in residential CO_2 emissions from the two policies in 2020 and 2030. Reductions are relatively small in percentage terms, as even with the ramp-up of purchases brought about by the subsidy, only 10 percent of heating units in place by 2030 are GHPs. Moreover, the declines in residential energy use almost all come in the form of natural gas and heating oil. Even though GHPs replace many electricity-powered central air-conditioning units, the electricity use associated with heating can increase because of the substitution of GHPs, which rely on a small amount of electricity for the heat pump component, for natural gas furnaces. On net, forecast electricity use stays roughly the same in the policy cases as in the Reference case. This limits the CO_2 emissions reductions to some extent.

With such a small percentage reduction in residential sector CO_2 emissions, the economywide percentage reduction is negligible. This small reduction compared with overall CO_2 emissions in the economy is to be expected as the policy targets only a very limited source of total emissions. The entire residential sector accounts for 21 percent of total CO_2 emissions. Even *eliminating* space-heating and -cooling emissions—clearly an unrealistic outcome—would cut total emissions by less than 10 percent. (See Box 6.3 on the bounds for GHP penetration.)

Box 6.3: Exploring the Bounds of GHP Penetration

A recent ORNL study (Liu 2010) assesses the technical potential of GHPs for reducing energy use and CO_2 emissions. The study assumes that GHPs replace existing heating and cooling equipment in all single-family homes in the United States. Taking account of regional differences in equipment stock in existing homes and in climate, Liu estimates that such retrofits could save 4.1 quadrillion Btus of primary energy, which is 44.4 percent of existing energy consumption for space heating, space cooling, and water heating in U.S. single-family homes. This corresponds to a reduction in CO_2 emissions of 264 mmtons.

Liu finds significant differences in the energy and CO_2 savings across regions. Emissions in the South are reduced twice as much as those in the Midwest and nearly five times as much as in the West. Reductions in electricity use for space cooling are a key factor in this result.

Although 100 percent use of GHPs in single-family homes is unrealistic for the foreseeable future, and the Liu study does not address the question of policies to bring about change, the results do illustrate the upper bound on the potential for such systems in the residential sector.

Results: Policy Costs and Cost-Effectiveness

The welfare costs of the GHP Subsidy policy are calculated as the deadweight losses associated with the additional GHPs purchased in each year less the discounted value of the energy savings from those GHPs. The $4,000-per-unit subsidy is the key component of deadweight loss for the Subsidy policy; for the Loan policy, we use the forgone interest costs on the $4,000 payment (over the seven-year loan period). We compute those costs at the social discount rate of 5 percent, but the estimated costs are not highly sensitive to this rate. Because of the long-lived nature of GHPs, in calculating cost-effectiveness, we calculate energy savings out to 2050, along with the CO_2 emissions reductions to 2050.[47] This approach is consistent with our analysis for the Building Codes and Full WM EE Provisions scenarios.

Also consistent with that analysis, we use a 10 percent discount rate for discounting the stream of energy savings as our Partial Market Failure rate. We also show the calculations for a 5 percent rate, which assumes complete market failure in the market for EE investments, and a 20 percent rate, which assumes that observed behavior is due to hidden costs or other factors and not to market failures.[48]

Table 6.7 shows the welfare costs and cost-effectiveness of the two policies at the Partial Market Failure rate. Both policies have negative costs; in other words, the discounted savings in energy costs over the 2010–2050 time period more than compensate for the deadweight losses from the higher equipment purchase costs. The Subsidy policy comes in at –$9/ton of CO_2 reduced, and the Loan policy is particularly low-cost, reducing emissions at an average cost of –$36/ton.

At the Complete Market Failure rate, both policies are extremely cost-effective (Table 6.8). The Loan policy, for example, generates energy savings that offset the deadweight losses from the equipment costs by so much that society enjoys a $117 benefit on each ton of CO_2 reduced (in addition to the environmental benefits, which are

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[47] We do not have information from the model beyond 2030, so we extrapolate the emissions reductions and energy cost savings in 2030 out to 2050, assuming that the GHP systems last until that date and using building survival rates from the NEMS model. We use building survival rates because of the long life of GHP systems, particularly the underground components, which are expected to last more than 50 years.

[48] We always use the social discount rate of 5 percent for discounting equipment costs to 2010.

Table 6.7: Welfare Costs and Cost per Ton (Cost-Effectiveness) of Residential Sector GHP Policies, Partial Market Failure Rate

	Total welfare costs (billion $)	Cost-effectiveness ($/ton)	Total CO_2 emissions reductions, 2010–2030 (mmtons)	Total CO_2 emissions reductions, 2010–2050 (mmtons)
GHP Subsidy	–5.1	–9	245	559
GHP Zero-Interest Loan	–11.7	–36	138	329

Table 6.8: Welfare Costs and Cost-Effectiveness of Residential Sector GHP Policies, Alternative Cases

	Cost-effectiveness ($/ton)	
	Complete Market Failure	No Market Failure
GHP Subsidy	–92	36
GHP Zero-Interest Loan	–117	9

outside of our analysis here). At the 20 percent rate, the costs of both policies are positive and the GHP Subsidy now looks like a relatively high-cost option. Interestingly, however, the Loan policy still looks relatively cost-effective, reducing CO_2 emissions at just $9/ton (less than the costs of the Central C&T policy). In fact, the Loan policy has negative costs up to a discount rate of 17 percent, and even at 23 percent, the average cost per ton is only $15. These results highlight the advantages of using consumer loans rather than subsidies to spur energy efficiency.

Conclusions

Energy-efficient technologies with which many consumers are unfamiliar or that have relatively high up-front costs may be good targets for government policies. We find that a Direct Consumer Subsidy for GHPs can greatly increase the use of such systems. We also find that a Zero-Interest Loan to consumers for GHP purchase, while less effective than the Subsidy, is highly cost-effective at reducing CO_2 emissions. Neither option can make a big dent in overall emissions, as they target only a relatively small sector of the economy, but they can make strides in reducing energy use and emissions related to residential space heating and cooling. The cost-effectiveness of the Loan policy suggests that this is an interesting policy option that might prove useful for other energy efficiency investments beyond GHPs.

6.3 Incentives for Specific Generation Technologies

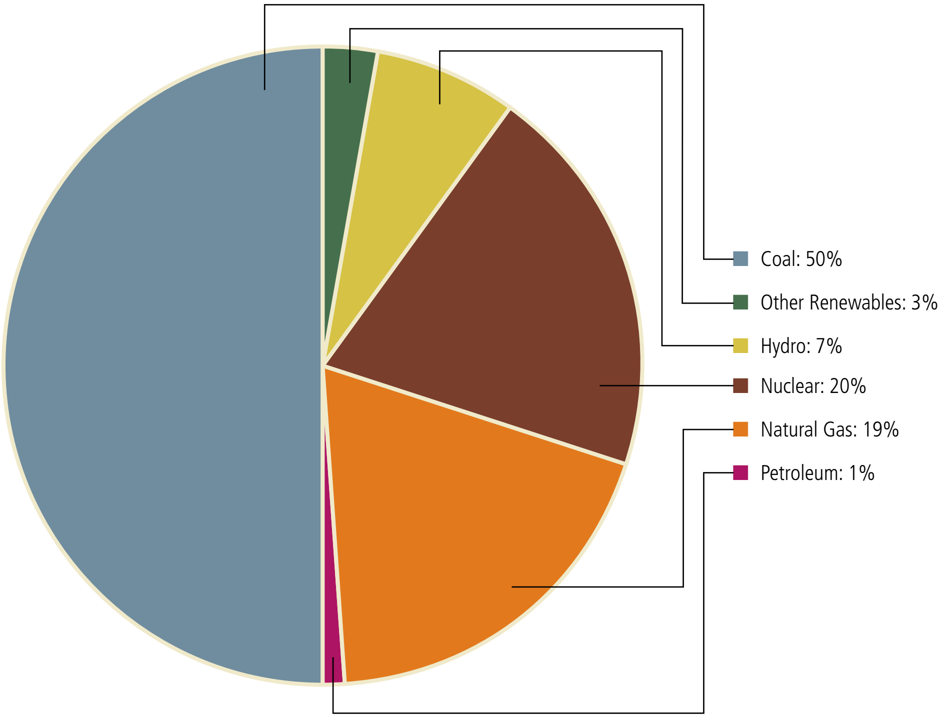
6.3.1 Background on Electricity Generation in the United States

Nearly half of the electricity consumed in this country is produced using coal, the most CO_2-intensive of the fossil fuels. (Figure 6.10 shows the distribution of electricity generation across fuel types.) Currently, renewable sources such as hydroelectric power, geothermal, wind, solar, and biomass—all of which emit no CO_2 (with the exception of biomass under certain conditions)—account for 10 percent of total generation. The largest contributor is hydro, however; the remaining non-hydro renewables account for only 3 percent of total generation. Nuclear power, another zero-carbon source, makes up 20 percent—a percentage similar to that generated by natural gas.

Coal's current dominance as a generation fuel follows from its low cost relative to other sources of energy, its dispatchability and flexibility, and the fact that certain environmental externalities—the damage from global warming related to CO_2 (and other GHG) emissions being one of them—are not fully taken into account in private decisions about electricity supply. In addition, other market failures—such as the inability of private investors to capture the social benefits of R&D and technological learning—may be contributing to the difficulties that renewable sources have in competing with coal. Nuclear power faces barriers because of worries over risks from accidents, terrorism, and waste disposal. These concerns, in combination with its very high initial investment costs, often put nuclear power at a disadvantage in the competition. Finally, natural gas has had trouble competing with coal because of its price volatility and the overall higher price of natural gas relative to coal, limitations in pipeline capacity and the high cost of building pipelines, and the expense and small size of more advanced gas-burning technology.

Overcoming these problems and reducing the cost differential between coal and cleaner sources of power can go a long way to reducing CO_2 emissions. Emitting 102 metric tons of CO_2 emissions per billion Btus, anthracite coal is the

Figure 6.10: Distribution of Electricity Generation across Fuel Types, 2008



Box 6.4: Representation of the Power Sector in NEMS–RFF

NEMS represents U.S. electricity generation, transmission, and pricing within its electricity market module (EMM). Capacity planning, fuel dispatching, finance and pricing, and load and demand are each represented in a submodule. Electricity generation is divided into 15 supply regions, and fuel consumption is accounted for in the nine census divisions. Outputs from the EMM include electricity prices, fuel demands, CO_2 emissions, capacity additions, capital requirements, and avoided costs.

Generation technologies represented in the power sector include coal steam, combined cycle, combustion turbine, fuel cells, nuclear, hydropower, geothermal, solar thermal and photovoltaic (PV), wind, wood, and MSW. The EMM also represents generation with carbon sequestration and distributed generation technologies and can model load shifting. Technology choice is determined by the timing of demand growth, the extent to which new capacity will be used, operating efficiencies, and construction and operating costs.

Because the EMM submodules solve simultaneously, the solution for each individual submodule depends on the solution to all of the other submodules. The capacity-planning submodule predicts the construction of new generation facilities and the retirement of fossil steam and nuclear plants. The fuel dispatch submodule projects fuel mix and allows surplus capacity to be traded to other regions. The finance and pricing submodule computes total revenue needed, and calculates regulated and competitive electricity prices.

dirtiest fuel; bituminous coal comes next at 92 tons. Although oil emits 76 tons per billion Btus, it is rarely used as a source of electricity generation. Natural gas is next at only 53 tons per billion Btus. Unless one takes a life cycle perspective, none of the renewables we consider directly emits CO_2 (burning biomass would emit CO_2, but the original process of biomass growth would also take up CO_2).

In the remainder of this chapter, we assess a variety of technology-specific policies that attempt to alter the electricity generation mix using NEMS–RFF (see Box 6.4 for an explanation of how the electricity sector is modeled). We begin with renewable fuels and analyze several policy options currently on the table, with particular attention to generation technology mandates such as a federal renewable portfolio standard (RPS). Our assessment of the portfolio standard leads us to broaden this option to include more "clean" energy portfolio standards, including nuclear power and natural gas in the portfolio. We then turn to nuclear power, where we focus on the important role that policy can play in reducing risks and encouraging investment in a technology with uncertain—but invariably high—initial costs.

6.3.2 Renewable Energy in the Power Sector

Policy Background

Non-hydro renewable sources of electricity accounted for only 3 percent of total power generation in 2008; Figure 6.11 shows the breakdown of these renewable sources among wind, biomass, geothermal, and solar. Wind accounted for 42 percent of non-hydro renewables generation, the largest share in 2008, and biomass from wood and derived fuels was second at 31 percent. Geothermal made up 12 percent, and solar accounted for only 1 percent.[49]

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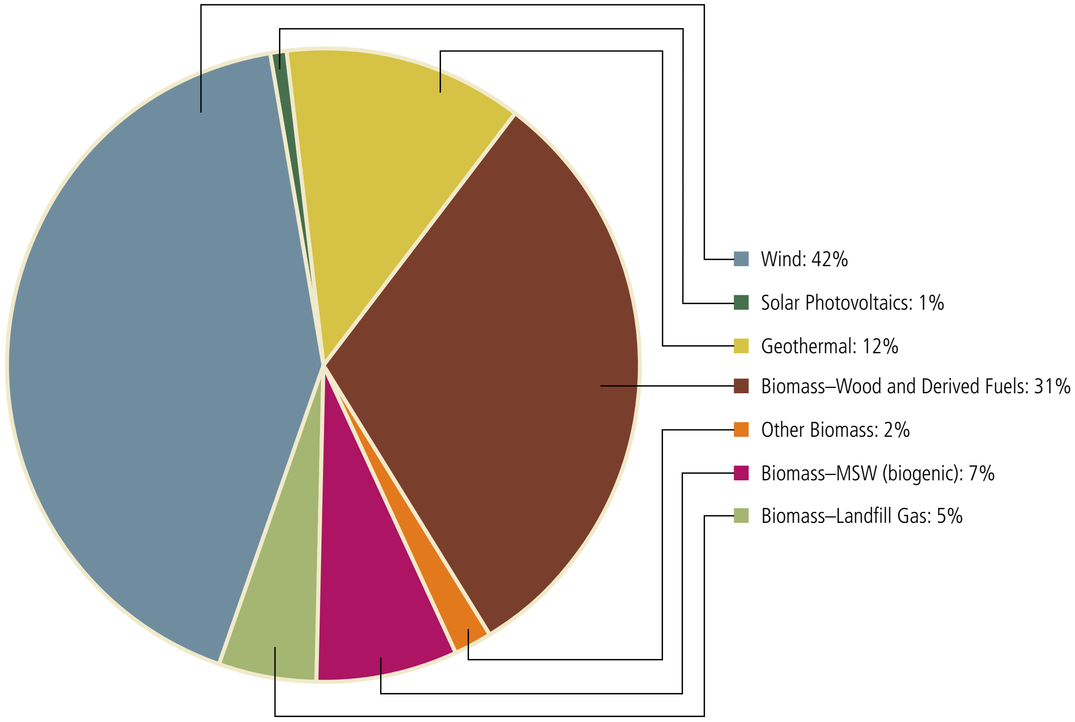
[49] This includes solar photvoltaic (PV) and concentrating solar power, though the latter accounts for only a very small amount of generation at the present time.

Figure 6.11: Electricity Net Generation from Renewables, 2008



Although renewables account for a small percentage of total generation, their use has increased in recent years. Most analysts attribute this rise to a ramp-up of policies encouraging renewables, primarily state RPSs (which mandate that renewables be a certain percentage of the generation mix) and federal tax incentives. Most of the increase has come in the form of wind energy; between 2004 and 2008, for example, electricity generation from wind rose four-fold.

Each of these renewable energy options faces hurdles related to costs, dispatchability, and reliability (see NRC 2010a for more detail). Box 6.5 presents a brief description of each energy source and its characteristics, highlighting some of the issues that currently limit renewables' penetration in the marketplace.

Policies Modeled

This study examines five policies designed to increase the penetration of renewables and other forms of clean energy: a federal *RPS* similar to those appearing in proposals in Congress; a *CEPS* that broadens the RPS to include new generation from other clean generation types such as nuclear; a variation on the CEPS that includes generation from new natural gas (*CEPS–NG*); a "two-bucket" policy that combines an RPS with a separate standard for new generation from natural gas (referred to as *RINGPS*); and a broad CEPS (*CEPS–All*) that gives clean energy credits to all fuel types—including existing generation—that are cleaner (in terms of carbon emissions) than coal. Each of these is described in more detail below. In addition, we recognize that at least some of these policies might be paired with carbon pricing policies and also model the effects of that pairing.

As oil use is very small in the electricity sector, we focus our attention on the effectiveness and cost-effectiveness of all of the policies for achieving reductions in CO_2 emissions. We look at CO_2 rather than all GHGs because for these policies, virtually all reductions come in the form of CO_2. To aid in understanding the dynamics of these policies, we present results for both 2020 and 2030, as well as for aggregate costs and CO_2 reductions over the project period.

Renewable Portfolio Standards (RPS)

Twenty-nine states currently have RPSs (see below for more information on some of these programs), which require that utilities use renewable sources to generate a specific minimum amount of the power they produce and sell. The standards vary substantially across the states in terms of their timetables and targets and the list of eligible renewables included, but most states allow renewable energy credit (REC) trading as a way to meet the standard cost-effectively. In these states, the RPS generally works by creating a REC for every kWh of eligible renewable electricity generated. Renewables owners and operators then sell these RECs to utilities, which are required to purchase some predefined number of RECs for every megawatt-hour of power they sell.

There have been numerous proposals for a federal RPS, including the incorporation of an RPS of 15 percent in the WM bill. For this study, Palmer et al. (2010) model a slightly more stringent RPS, one that was originally proposed by Senator Jeff Bingaman in an earlier standalone RPS proposal. This scenario calls for 25 percent minimum generation by non-hydro renewables nationwide by 2025, with interim targets leading up to this ultimate goal. RECs are used as

Box 6.5: Overview of Renewable Sources of Electricity

Wind. Wind power uses turbines to harness kinetic energy from wind and convert it into electricity. The availability and intensity of wind resources vary considerably across the country, with the Midwest offering some of the best wind power sites. Wind is also not dispatchable (that is, power is available when nature provides it, not necessarily when it is needed) and often the periods of most intense wind availability (nighttime in many regions) do not correspond to the periods of peak electricity demand.

Biopower. Biopower is the use of biomass to generate electricity through technologies such as direct-firing, cofiring at a coal plant, or gasification. Biopower is attractive because it is a potential renewable substitute for coal and, because it is renewable, it has low or even zero net carbon emissions. However, biomass feedstocks, which include agricultural or wood residues, municipal waste, and dedicated energy crops, are often limited or costly.

Geothermal. Geothermal energy captures heat from the earth to power generators and produce electricity. Geothermal resources include underground reservoirs of steam, hot water, and hot dry rocks, but only limited forms of the first two are currently economic. Unfortunately, reservoirs are currently available in only a few locations. Hot dry rocks are more widespread but require drilling of deep wells and the use of a technology that is still in its infancy.

Solar. Solar PV uses semiconductor materials to convert both direct and diffuse sunlight directly into electricity. Because PV can convert energy from indirect sunlight, it is ideally suited for smaller, distributed generation. However, despite dramatic declines in cost over the past few decades, PV is still a relatively inefficient means of energy conversion and is dependent on sunny climates. Solar thermal, or concentrating solar power, uses mirrors to concentrate the sun’s energy onto collectors that in turn heat up water to make steam to turn a steam turbine. Many systems have the capability to store energy for up to 12 hours, but the systems are costly and take up a lot of space. They are most feasible in desert locations, but new transmission capacity would be needed to move the electricity to market.

a way to achieve these targets. This relatively aggressive policy probably represents the outer limits of a federal minimum standard for renewables generation that might be passed by the U.S. Congress,[50] as it increases the percentage of generation that comes from renewables from its current level of 3 percent to 25 percent in approximately 15 years.

Results from the NEMS–RFF model show that such an RPS leads to just over 1,000 billion kWh of power generated by non-hydro renewables in 2030, more than twice the 2030 level in the Reference case. By 2020, 14.2 percent of total generation is from renewables and, by 2030, 20.5 percent.[51] Most of the increase comes from biomass—in the Reference case, biomass generates 123 billion kWh of power in 2030; with the RPS policy, it generates 535 billion kWh. Wind increases 51 percent and solar only 30 percent.

Other Considerations: State Policies Affecting the Growth of Renewable Energy

Examining the potential growth of renewables across the United States requires looking beyond federal policy to the vast patchwork of state policies that also affect the uptake of renewables. Allison and Williams (2010) describe current laws, regulations, and regulatory actions influencing the penetration of renewable electric energy sources in 17 of the 18 most populous states in the United States (the study states).[52] Within each state, the production and consumption of electricity generated by renewable sources is greatly affected by the structure of electric transmission and energy markets that has resulted from the interaction of federal and state regulations.

For more than 30 years, the Federal Energy Regulatory Commission (FERC) has sought to provide electric energy suppliers and consumers with greater competitive market-based opportunities through initiatives designed to create large, multistate, open-access, and nondiscriminatory wholesale transmission markets, as well as workably competitive wholesale electric energy markets. FERC's transmission initiatives have led to the formation of four large regional transmission organizations and three large independent system operators, each of which operates exclusively within one of the nation's largest three states and serves all (New York) or most (California and Texas) of the consumers in the state.

In addition, 14 states (8 of which are study states) have restructured their electric power markets to provide consumers with access to competitive interstate electric energy markets. Although useful in improving competition, these market-based initiatives and state restructuring have produced outcomes that may limit the ability of states to promote the production and consumption of renewable electric energy. Allison and Williams (2010) argue that it is difficult to envision how state laws and regulations can overcome the effects of FERC competitive initiatives and restructured retail electric energy markets on limiting the penetration of renewables; only federal legislation can level the mandate playing field.

Of the study states, 15 have RPSs mandating that a certain minimum percentage of electricity generation come from renewable sources, and 16 have *net metering service* (NMS) policies that encourage the development of renewable distributed generation. The key elements of state RPS and NMS programs display considerable diversity.

In general, all RPS programs include electricity generated by biomass, hydropower, solar thermal, solar PV, and wind (although hydropower is treated very differently from state to state). In addition, some states (largely those on the coasts) have included tidal, wave, and other ocean-based

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[50] The proposed policy includes a 5¢ REC price cap to limit the economic costs of reaching these targets; Palmer et al. (2010) include this cap as part of their modeled policy.

[51] This percentage is less than the 25 percent RPS standard because the basis to which the 25 percent is applied is less than total generation. Under the RPS policy as modeled, generation by existing MSW incinerators, existing hydroelectric facilities, and distributed generators that produce power for their own use are all excluded from the base. These exclusions are similar to those typically found in federal RPS proposals.

[52] California, Texas, New York, Florida, Illinois, Pennsylvania, Ohio, Michigan, Georgia, North Carolina, New Jersey, Virginia, Washington, Arizona, Massachusetts, Indiana, and Missouri.

sources of energy. Illinois, Pennsylvania, and Ohio—all of which produce substantial amounts of coal—have also included provisions for "clean coal." Energy efficiency is considered to count toward RPS goals in several of the studied states, but with a wide range of caveats. RPS programs also vary in the entities to which they apply; in California, for example, RPS requirements apply to all retail sellers of electricity, whereas in Washington, the RPS applies to any qualifying utility serving more than 25,000 customers.

State RPS specifications differ depending on climate, energy source availability, and a host of other factors. Some states use RPS programs to drive the development of certain industries within their borders; North Carolina, for example, specifies that its solar contracts be "of sufficient length to stimulate the development of solar energy" (UCS 2008, 6). This approach has caused many states to grant RECs only to renewable energy projects located within their borders and to recognize only purchases of power from renewable energy sources located within their borders as meeting their RPS mandate. As a consequence, the most efficient sources of renewable electric energy may be unavailable to electric energy providers and users.

Five states—Illinois, Indiana, Massachusetts, New York, and Pennsylvania—have set statewide "green power" purchasing requirements for state and local governments. Other states have similar goals on the local level. Of the 17 subject states, 5 raise funds for renewable energy or EE measures by levying a fee on customers' utility bills. Finally, a few states require that utilities offer customers the voluntary option of purchasing green power produced from a variety of renewable energy sources.

Although the various state policies indicate progress, perhaps the biggest threat to the development of renewable electric power generators is the power of state and local governments to veto proposed transmission line construction projects. Many sources of energy for renewable power generation exist at sites far from the areas where most electric energy is consumed. In many states, those who wish to construct transmission lines must obtain siting permission from, and satisfy the zoning and environmental regulations of, several levels of government. If developing renewable sources of electric power is truly a national priority, then federal legislation may be needed to preempt state siting, zoning, and environmental laws and regulations that make it difficult to construct transmission lines that would connect renewable electric energy generators with interstate electric energy markets.

Overall, states have stepped in to fill a vacuum in renewable energy policy. In doing so, they have produced a patchwork of policies that have helped move forward the development of renewable energy but, according to Allison and Williams (2010), they have done so in ways that are inefficient and not likely to produce the level of renewable energy development that some observers think the nation needs to meet its long-term energy and environmental challenges. In the absence of federal policy, the development of uniform state renewable energy policies based on best practices identified by their effects on renewable energy development is a path to explore further.

Clean Energy Portfolio Standard (CEPS)

The RPS encourages the use of a particular type of energy source (renewables), but it does not penalize or reward the use of other fuels based on their carbon content. In recognition of this drawback of the policy, we model a CEPS, broadening the portfolio standard to include other "clean" fuels besides renewables, including incremental generation from nuclear power plants and generation from natural gas and coal plants that have carbon capture and storage (CCS) technology. Under the CEPS policy, generation from new nuclear power plants receives one credit per megawatt-hour generated, integrated gasification combined cycle coal with CCS receives 0.90 credit per megawatt-hour, and natural gas combined cycle plants with CCS receive 0.95 credit per megawatt-hour. These fractions reflect the difference in emissions rate relative to a new pulverized coal boiler. The CEPS policy features the same minimum requirement for this collection of eligible generators as required for renewables under the RPS policy—that is, 25 percent by 2025. However, we emphasize that only *new* nuclear and coal and gas with CCS capacity are covered under the standard, not all existing plants.

Notably, the CEPS policy has some clear similarities to legislation proposed (although not introduced, as of April 2010) by Senator Lindsey Graham of South Carolina. In particular, the Graham bill—titled the Clean Energy Act of 2009—features a phased-in CEPS, rising from 13 percent in 2012 to 50 percent in 2050. The minimum standard for clean energy generation for the period from 2025 to 2029 is 25 percent, the same as the CEPS modeled here. Technologies included in the Graham CEPS include the suite of renewables discussed here, as well as new nuclear and coal with CCS (as long as at least 65 percent of CO_2 emissions are captured).

Clean Energy Portfolio Standard with Natural Gas (CEPS–NG)

Some observers have argued that natural gas should be a *bridge fuel*, a relatively clean fossil fuel for electricity generation in the short run as the economy gradually moves to less carbon-intensive fuels, such as renewables, in the long run. To facilitate this outcome, we model an expanded CEPS (referred to as CEPS–NG) that also includes new natural gas capacity (without CCS) in the portfolio. This policy allows generation from new natural gas capacity to receive a fraction of a clean energy credit—dependent on the technology—for each megawatt-hour of electricity generated by a natural gas–fired generator. Four types of natural gas generators are included, each with the following fraction of a credit (natural gas with CCS still receives 0.95 credit per megawatt-hour): 0.59 credit for advanced natural gas combined cycle; 0.56 credit for conventional natural gas combined cycle; 0.37 credit for advanced natural gas turbine; and 0.33 credit for conventional natural gas turbine. The CEPS–NG policy features the same 25 percent target by 2025 as in the RPS and CEPS policies.

Renewables and Incremental Natural Gas Portfolio Standard (RINGPS)

To further test the role of natural gas as a bridge fuel, we model another portfolio standard variation that more directly provides incentives for the use of this relatively low-carbon fossil fuel alongside zero-carbon sources. The policy combines a 25 percent RPS with a 20 percent Incremental Natural Gas Portfolio Standard, meaning that 25 percent of total electricity generation (excluding generation from hydro and MSW plants) must come from renewables and 20 percent must come from new natural gas plants[53] (this is above and beyond existing natural gas generation already in place). This RINGPS policy increases the overall percentage of electricity generation that comes from fuels that are cleaner than coal from 54 percent in 2030 in the Reference case, to 67 percent in the RINGPS case.

Clean Energy Portfolio Standard–All (CEPS–All)

Our most aggressive CEPS policy, referred to as CEPS–All, seeks to replicate the share of generation produced by technologies other than coal (with the exception of coal with CCS) obtained under the Central C&T policy. The scope of CEPS–All is larger than that of CEPS and includes generation from new and existing non-coal generators. Unlike the two other CEPS scenarios, the base for calculating the "clean energy" requirements includes all utility electricity sales and generation by all renewables (including hydroelectric and MSW incineration). Clean energy credits are assigned based on the relative emissions rate of each "clean" technology compared to a pulverized coal boiler. In contrast to the CEPS and CEPS–NG policies, the CEPS–All policy does not include a cap on the price of clean energy credits.

Finally, we briefly examine the cost and effectiveness of an extension of existing production and investment tax credits for renewables; see Box 6.6 for details.

Policy Combinations

We model two variations to test the effect of combining an RPS and a carbon pricing policy, as

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[53] Because of the intricacies of the model, this run produced 21 percent generation from renewables and 24 percent generation from new natural gas plants, rather than the original 25/20 split envisioned.

Box. 6.6: An Alternative Renewables Policy: Production and Investment Tax Credits

Palmer et al. (2010) also model an extension of the current production and investment tax credits for renewables. For new generators brought online in 2009, the Production Tax Credit (PTC) provides a 2.1¢/kWh tax credit for wind, geothermal, and closed-loop biomass and a 1.1¢/kWh tax credit for landfill gas, other forms of biomass, and hydrokinetic and wave energy. The PTC policy provides a 30 percent tax credit for the initial cost of investment in new solar power facilities. As Palmer et. al (2010, 14) notes, "The American Recovery and Reinvestment Act of 2009 extends the deadlines on the production tax credit but also allows investors with limited expected tax liability to substitute a grant for the tax credit and generators to elect a 30 percent investment tax credit rather than the production tax credit."

The PTC applies to all generation for the first 10 years of operation. However, this credit is due to expire beginning in 2012; thus Palmer et al. (2010) assess the cost and effectiveness of extending it indefinitely. Model results show that this extension of the PTC has very little impact on emissions and is quite costly: at approximately $34/ton, this policy is over two times more costly than the RPS.

has been proposed in recent federal legislation. The first combines an RPS with the Central C&T program. Because the cap inhibits the ability of the RPS to lower overall GHG emissions, however, we also model the RPS with the Carbon Tax in place of C&T.[54] Because a carbon tax is paid on all emissions, combining an RPS with a tax should spur additional carbon emissions reductions beyond what the tax itself would provide.

Effectiveness of Alternative Policies

We start the analysis with a focus on the RPS by itself and in concert with carbon pricing policies. Table 6.9 shows these reductions for the RPS and RPS combination policies in 2020 and 2030, including pairing an RPS with either the Central C&T case or an equivalent Carbon Tax. The last row of the table shows results for the Central C&T case alone for comparison purposes.

The RPS by itself does not have a large impact on CO_2 emissions: by 2030, emissions are 377 mmtons, or 6.1 percent, below what they would be without this policy. In other words, despite the fact that generation from renewables rises from 10 percent without an RPS to 20 percent with it (an additional 500 billion kWh) in 2030, CO_2 emissions fall by only about 6 percent. This reduction remains small because renewables do not replace the average carbon emitter; they replace the highest-cost emitters and, although this group includes coal, it disproportionately includes the relatively low-carbon natural gas. These results highlight the limitations of the RPS: first, it incentivizes the use of a particular category of fuels, renewables, rather than penalizing or rewarding *all* fuels based on their carbon content and, second, it primarily shifts the fuel mix without doing much to reduce energy use (except indirectly, by raising energy prices because the mix of generation spurred by this policy is more expensive than without the policy).

Combining an RPS with the Central C&T policy will not reduce emissions beyond the cap except insofar as it leads to changes in the banking and borrowing of allowances. Its main effect is on the allowance price. As shown in Table 6.9, the combination reduces CO_2 emissions by an additional 31 mmtons in 2030 compared to the Central C&T policy alone. The allowance price is about $3/ton lower in 2030 with the RPS than without it—a reduction that occurs because the RPS takes pressure off of other carbon emitters to reduce

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[54] The level of the tax is equivalent to the allowance price that would result in the Central C&T scenario.

Table 6.9: CO$_2$ Emissions Reductions with an RPS: Changes from Reference Case Levels

	2020		2030		Total CO$_2$ emissions reductions, 2010–2030
	mmtons	%	mmtons	%	mmtons
RPS	177	3.0	377	6.1	3,489
RPS, C&T	493	8.4	1,409	22.8	12,697
RPS, Carbon Tax	505	8.6	1,469	23.7	13,103
C&T alone	497	8.5	1,378	22.3	12,366

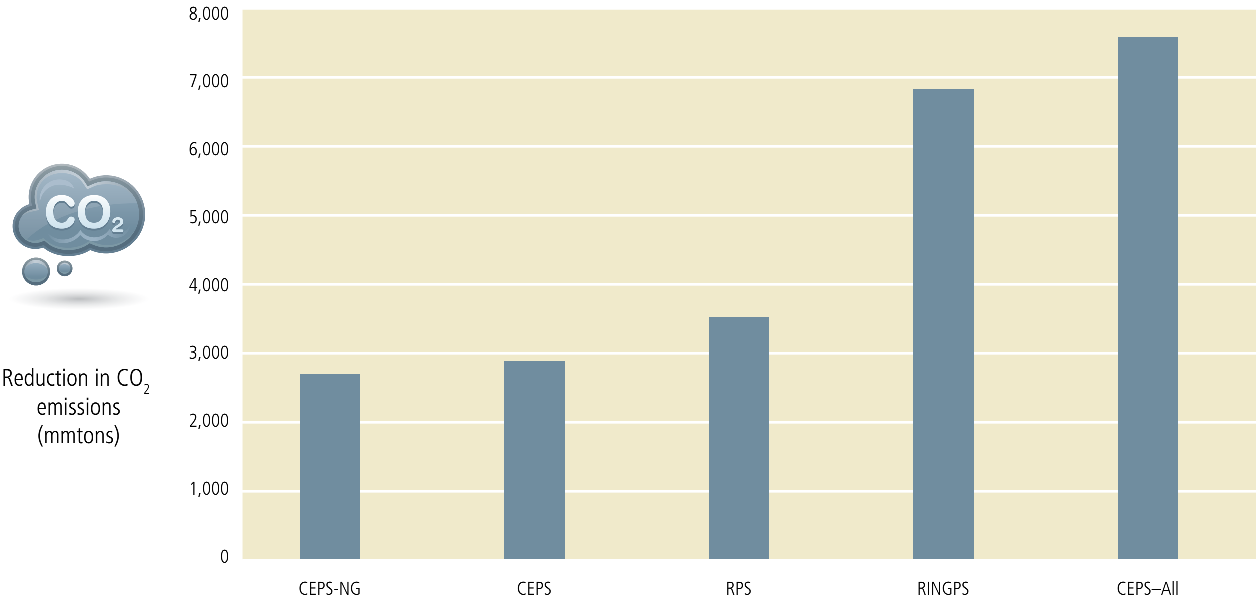
Table 6.10: CO$_2$ Emissions Reductions with CEPS Variations: Changes from Reference Case Levels

	2020		2030		Total CO$_2$ emissions reductions, 2010–2030
	mmtons	%	mmtons	%	mmtons
CEPS	124	2.1	292	4.7	2,850
CEPS–NG	148	2.5	230	3.7	2,652
RINGPS	386	6.6	530	8.6	6,860
CEPS–All	271	4.6	1,041	16.8	7,632

their emissions. This benefit in lower allowance prices comes at the expense of higher overall welfare costs per ton of carbon reduced, however (as described below). The RPS–Carbon Tax combination does achieve greater reductions in CO$_2$ emissions than the RPS–C&T combination, but this additional reduction is minimal (only 2 percent of 2030 carbon emissions).

Looking at the broader portfolio standards, Table 6.10 shows the CO$_2$ emissions reductions for the CEPS and RINGPS policies in 2020 and 2030 relative to the Reference case. The CEPS–NG does better than the CEPS by 2020, whereas the CEPS achieves greater emissions reductions in 2030—but neither reduces emissions as much as the RPS. The CEPS and CEPS–NG perform poorly because they give credits to nuclear generation that the NEMS–RFF model predicts would have

Figure 6.12: Aggregate CO_2 Reductions of Renewables Policies, 2010–2030



happened anyway, effectively reducing the standard significantly below the 25 percent target. As a consequence, coal generation is greater than in the RPS case.

The RINGPS policy achieves the greatest CO_2 reductions in the short term (2020), at 6.6 percent. The CEPS–All performs best in the long run, however, surpassing the RINGPS considerably by 2030 with almost double the emissions reductions. Both of these policies achieve considerably greater reductions than the RPS or other CEPS policies, as they are designed to cover considerably larger swaths of the electricity generation sector.

Although these annual emissions reductions are informative, even more illustrative is how these policies compare in terms of aggregate reductions over the entire project period, as shown in Figure 6.12. Of the single policies, the CEPS–All achieves the greatest aggregate reductions at 7,632 mmtons, or approximately 62 percent of the reductions achieved under the Central C&T case. Given that the CEPS–All was designed to mimic the generation breakdown under C&T, why does it achieve only 62 percent of the emissions reductions? This is largely because the CEPS–All only covers electricity generation, whereas C&T reaches farther, and because the CEPS–All does not encourage any additional savings through EE measures.

Notably, in looking at aggregate consumption, scale is an important issue: the RPS, CEPS, and CEPS–NG are designed to cover only 25 percent of electricity generation, whereas the RINGPS and CEPS–All cover larger percentages.

Of course, combining any of the above policies with carbon pricing will result in larger reductions in CO_2, but the reductions will be almost entirely attributable to the pricing policy—as in the case when the RPS is combined with the Carbon Tax and Central C&T.

Cost and Cost-Effectiveness of Renewables Policies

The costs of renewables policies have several components, including the economic losses from changes in producer and consumer surplus[55] in the electricity market due to an individual policy.

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[55] Producer surplus can be thought of as profits and is formally the excess of the price—the amount producers get on the market for their product (here, electricity) at the margin—over what they have to pay to deliver the product (their costs). Consumer surplus is the excess of what consumers are willing to pay for the product over what they have to pay (the price).

Table 6.11: Welfare Costs and Cost per Ton (Cost-Effectiveness) of Renewables Policies in Reducing CO_2 Emissions

	Total welfare costs (billion $)	Cost-effectiveness ($/ton)	Total CO_2 emissions reductions, 2010–2030 (mmtons)
RPS	47.5	14	3,489
CEPS	40.2	14	2,851
CEPS–NG	29.8	11	2,652
CEPS–All	116.2	15	7,632
RINGPS	162.1	24	6,860
C&T + RPS	151.0	12	12,697
Carbon Tax + RPS	170.0	13	13,103
Central C&T	142.3	12	12,366

Cost calculations also include the costs associated with preexisting market distortions created by existing tax credits or, in the cases that combine with a C&T policy, changes in the distortion resulting from C&T. Table 6.11 shows the welfare costs and cost-effectiveness of the renewables policies; as these policies have minimal effect on energy efficiency, we do not present multiple rates of market failure.

By itself, the RPS has an average cost of approximately $14/ton of CO_2 emissions reduced, but results in relatively few emissions reductions (28 percent of the reductions found under the Central C&T policy). This issue of scale is a critical factor when comparing the RPS and other policies that work on broader sectors of the economy. If, for example, an RPS and C&T were scaled to achieve similar levels of CO_2 reductions, the RPS would be hugely more costly (if it were even possible to reduce carbon emissions to that level with an RPS). Palmer et al. (2010) acknowledge the scaling issue and further test it by estimating the costs of a scaled-down C&T option—that is, a C&T policy that would achieve the lower emissions reductions that the RPS achieves[56]—finding that costs are about one-third lower than those of the RPS.

The average cost of reducing a ton of CO_2 emissions with the CEPS is nearly equivalent to that of the RPS, whereas the average cost of the CEPS–All policy is slightly higher. The average cost of the CEPS–NG policy is lower than that of these other policies, however ($11/ton), and the policy

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[56] If the marginal abatement cost of CO_2 reductions is linear, one can use the CO_2 allowance prices and associated CO_2 emissions reductions under the Central C&T policy in each year to construct a marginal abatement cost curve for that year. The curve can then be used to find the marginal and total costs of using C&T to obtain the annual emissions reductions found under each of the other policies. The assumption of linear marginal costs is probably overly conservative at low levels of emissions reductions, however, implying that the costs for C&T are probably overstated.

achieves 76 percent of the emissions reductions that the RPS achieves at only 63 percent of the total costs. This lower cost occurs because these policies admit more types of technologies under the portfolio standard "umbrella," which presents more low-cost generation options for meeting electricity demand. Further, the cost of getting additional carbon reductions rises as more and more reductions are achieved. Thus, by getting only 76 percent of the emissions reductions that the RPS gets, the CEPS–NG avoids the most expensive options.

At $24/ton, the RINGPS policy bears a high welfare cost because relatively expensive technologies (natural gas and renewables) are mandated to compose nearly half of the energy mix for electricity. The RINGPS policy leads to decreased nuclear generation compared to the Reference case and does not take advantage of low-cost CO_2 emissions reductions associated with lower electricity consumption. So although the RINGPS policy is almost as effective as the CEPS–All in reducing CO_2 emissions, its costs are more than 50 percent higher. In addition, although the RINGPS policy yields lower electricity prices than the baseline scenario in some interim years, by 2030 the national average electricity price is at roughly the same level as in the Reference case, and overall the policy has only a very small effect on electricity sales.

Combining an RPS with either the Central C&T or Carbon Tax is far more effective, reducing emissions by substantially more than the RPS alone. Do such combinations make sense from a policy perspective? Combining an RPS with C&T would not lead to additional reductions in total GHGs (as the cap remains fixed and the RPS would not push beyond it). The combination does lead to some shifting toward additional reductions in energy-related CO_2, but these are minimal. Similarly, the additional emissions reductions are small when an RPS is added to the Carbon Tax, while the costs of adding the RPS are $28 billion.

An RPS could be worthwhile if it has some ancillary benefits. Advocates for a federal RPS often argue that the reliable and steady demand for renewables would help to get nascent markets up and running and provide investors with some certainty about future demand. In addition, a reliable demand might also help to get new technologies, such as hot rocks geothermal and offshore wind energy, off the ground (though only if the cost of those options is low enough relative to other renewables). It also might provide incentives for much-needed investment in transmission capacity. Currently, limited transmission capacity is hindering the development of wind and solar in some locations, but investments in new transmission lines in these locales are only viable if wind and solar generation are available. Overall, the cost and emissions estimates provide some useful benchmarking—are these ancillary benefits real and are they worth incurring the extra costs that an RPS imposes?

6.3.3 Policies Not Modeled

Although we discuss above a wide variety of policies and policy combinations, these are not exhaustive of the renewables policies that can be used to spur reductions in CO_2 emissions. We describe several policies that we omitted—and the reasons for their omission—below.

Investment in Renewables R&D

Government funding for R&D on renewables technology increased significantly under the ARRA. If successful, such subsidies for R&D can make up some or all of the difference between the value that cannot be realized by the innovator (because they have incomplete property rights) and the value that they can receive—and if innovations make renewable energy significantly cheaper or more efficient, they can reduce the amount of government assistance necessary to achieve a given target in the future. However, although R&D has the potential to reduce program costs in the future, the benefits are highly uncertain (Palmer 2010), presenting a significant challenge to attempts to model the effects of R&D. A more detailed discussion of R&D funding is included in Chapter 8.

Feed-In Tariffs

Under a feed-in tariff (FIT), electric utilities are required to purchase electricity generated by a host of different renewable energy technologies. Long-term (15- to 25-year) contracts are often put in place, which helps reduce risk and guarantee producers of renewable energy a steady price. On the other hand, putting in place these long-term contracts can lead to needless expense if conditions change mid-contract—for example, if electricity prices fall after contracts are put in place. Because the model does not readily capture the effects of FITs, and because such effects could be similar to the effects of a tax credit (albeit at a much higher level than modeled here), we do not model FITs as part of this study.

Transmission Expansion

Many promising sites for renewable energy remain distant and disconnected from the grid. Subsidizing expansion of the grid into these areas could help bring the most promising technologies to a more prominent place in the market. At the same time, an expanded grid may impact both renewable and nonrenewable sources alike. This makes modeling challenging, as it is not straightforward to link policies encouraging new transmission capacity with the resulting effects on renewables capacity and generation.

6.3.4 Nuclear Power

Policy Background

The United States currently has 103 nuclear energy plants, which together generate about 20 percent of total U.S. electricity with zero CO_2 emissions (although emissions are generated upstream of the nuclear power stage in the nuclear energy life cycle). Growth in nuclear power has been hindered by significant political and public concerns, however, including high construction costs, the potential for nuclear accidents and terrorism, disposal of nuclear wastes, and nuclear material proliferation. These concerns have stalled the industry such that the last plant was placed into service in 1996, with construction on that plant started a full 23 years earlier.

More recently, several factors have combined to stir new interest in nuclear energy, including growing concern over climate change, advances in nuclear power technology, and changes in federal policy. As of January 2010, 18 construction and operating license applications were before the Nuclear Regulatory Commission, 13 of which are currently under review (U.S. DOE 2010).

The federal government has not been a passive observer in this nuclear revitalization. The EPAct of 1992 assured utilities of recovering their stranded assets under deregulation and helped consolidate the industry; lower costs; and increase safety, output, and profits. The EPAct of 2005 subsequently offered production tax credits, standby support, and a loan guarantee program for nuclear plants. The EPAct of 2007 funded the last and most important of these programs for getting new plants built: an $18.5 billion loan guarantee program, which in early 2010 was bolstered with a pledge of an additional $36 billion in loan guarantees by the Obama administration as part of its 2011 budget. The first of the loan guarantees (totaling $8 billion) was offered in February 2010 for two new nuclear plants in Georgia.

In addition, in 1989 the Nuclear Regulatory Commission streamlined its licensing process by preapproving several plant designs, preapproving sites for generic reactors (with four approved so far), and permitting construction and operating licenses to be approved as a package. The earliest submission has a planned operational start date of 2017.

Nuclear Power's Potential for Growth

Opinion varies widely on nuclear power's potential for growth over the next 20 years. NEMS–RFF forecasts 10 gigawatts of new nuclear plants (including one Tennessee Valley Authority unit with construction restarting) by 2020 in the Reference case, with no more net additions through 2030.

Nuclear power is more advantaged under a carbon pricing system. A polling of experts (Rothwell 2010) finds projected new capacity in the 25- to 28-gigawatt range by 2030 under a C&T program similar to that passed by the House of Representatives, assuming that only current applications are approved. In contrast, NEMS–RFF predicts 48 gigawatts of new capacity under the Central C&T policy by 2030 (but without this constraint of current applications), resulting in

Table 6.12: CO$_2$ Reductions from Reference Case Levels with Lower ROE on Nuclear Investment

	2020		2030		Total CO$_2$ emissions reductions, 2010–2030
	mmtons	%	mmtons	%	mmtons
14% Nuclear ROE	33	<1	185	3	958
11% Nuclear ROE	57	1	491	8	2,643

an increase in nuclear power's share of electricity generation to 27 percent.

Rothwell (2010) examines whether these projections are reasonable and what more the federal government should do, if anything, to help this sector. Rothwell concludes that the total overnight construction costs[57] of about $3,300/ kilowatt assumed in NEMS–RFF is reasonable, and that the Reference case estimate of 10 new gigawatts of capacity by 2020 is also reasonable. He believes, however, that the finding in the Reference case that no new gigawatts of capacity would be built from 2020 to 2030 is unreasonable, given the current state of reviews and the number of applications from utilities operating under state utility rate-of-return regulations. Rothwell also suggests that even the estimate of 48 gigawatts of new capacity by 2030 for the Central C&T policy is too low.

Policies Modeled

The growth of nuclear power can be hindered by uncertainties in capital markets, as encompassed in the high ROE that potential investors in nuclear power will demand (currently set at 17 percent in NEMS–RFF). Possibilities to overcome these burdens include an enhanced federal loan guarantee program—beyond that already undertaken by the Obama administration—or other actions that subsidize loans or give investors greater assurance about the viability and profitability of nuclear power.

To simulate the effects of these policies, Rothwell assumes a lower ROE demanded by investors in nuclear power. Specifically, he lowers the ROE in NEMS–RFF from 17 percent to 14 percent and 11 percent levels. At a *14 Percent Nuclear ROE*, 6.5 gigawatts of new nuclear capacity is added by 2020; at an *11 Percent Nuclear ROE*, 17.3 gigawatts of new capacity is added by 2020.[58] By 2030, under the 14 Percent Nuclear ROE, nuclear capacity grows to around 50 gigawatts, matching what is predicted under a C&T regime. Under the 11 Percent Nuclear ROE, the growth is far more rapid, reaching 132 gigawatts by 2030.

These findings indicate that reducing the ROE is one key to nuclear power's success, as new construction is so sensitive to it. Because the linkage between loan guarantees and the rate of return demanded by investors on nuclear investments is unknown, it is difficult to suggest the appropriate size of new loan guarantees.

Effectiveness of Alternative Policies

Like other clean technology policies, an expansion in nuclear power is predicted to lower CO$_2$ emissions, as coal and other carbon-intensive fuels are

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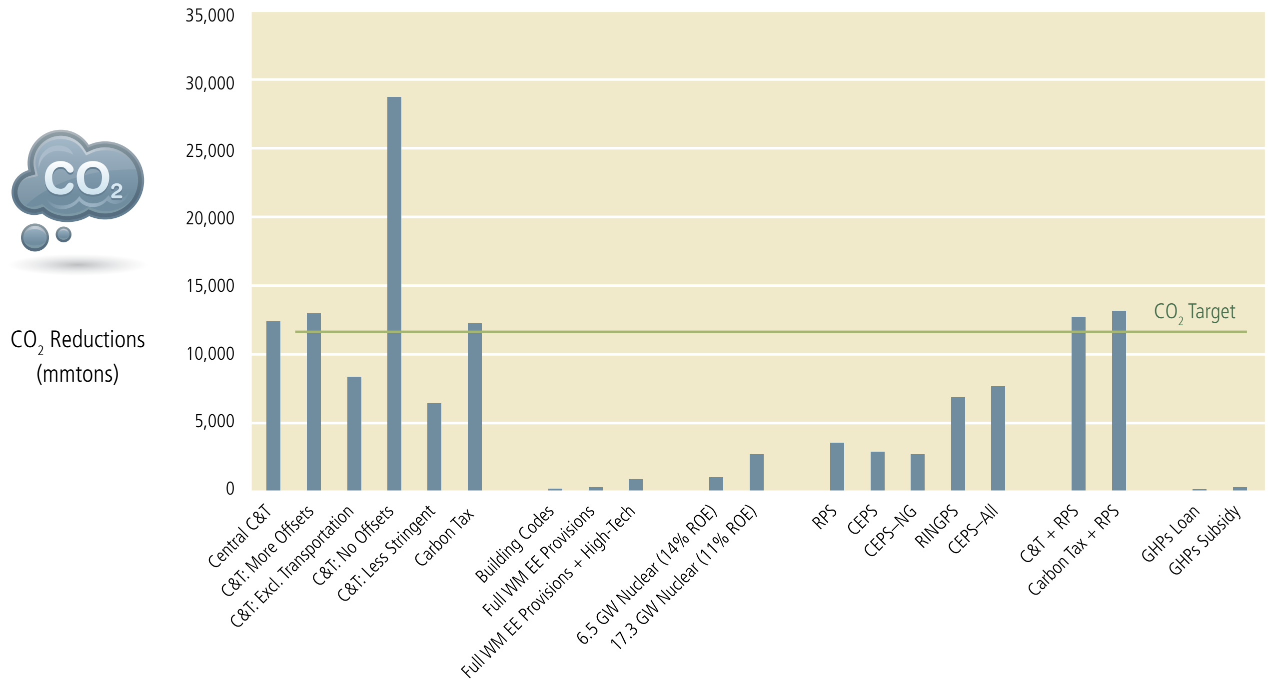
[57] The overnight cost is the cost of a construction project in which no interest is incurred during construction.

[58] Rothwell felt that he did not have enough information to estimate welfare costs of additional nuclear capacity built after 2020.

Figure 6.13: Cumulative Reductions in CO_2 Emissions Relative to the Reference Case, 2010–2030



Note: Again, the three EE policies include residential sector emissions only.

replaced in electricity generation. Even with this significant growth in nuclear power with lower ROEs, however, effects on CO_2 emissions are limited, as shown in Table 6.12.

As with energy efficiency investments, new nuclear plants will reap energy savings beyond the 2010–2030 project period. Accordingly, we also report effectiveness data over the assumed 50-year lifetime of new capacity. Over this extended lifetime of the 14 Percent Nuclear ROE case (with 6.5 gigawatts of new capacity), an estimated 0.03 mmbd, or 548 million barrels over 50 years, of oil consumption and 1,630 mmtons of CO_2 would be reduced. In the 11 Percent Nuclear ROE case (with 17.3 gigawatts of new capacity by 2020), oil consumption would fall by 0.04 mmbd, or 730 million barrels over 50 years, and CO_2 emissions would fall by 2,830 mmtons. We use these figures in calculating the cost-effectiveness of nuclear policies.

Cost of Nuclear Policies

The cost of loan guarantees is the difference between the market rate and the rate the government would charge on the loans. Would this cost to taxpayers (which Rothwell [2010] identifies as a welfare cost) of an expanded loan guarantee program be a good investment in terms of oil and CO_2 emissions reduced? Rothwell estimates the costs to taxpayers of the loan guarantee necessary to support 6.5 additional gigawatts of nuclear capacity by 2020 to be $710 million, and he estimates the costs of 17.3 gigawatts of new capacity by 2020 to be $4.5 billion.[59]

In cost-effectiveness terms, at an ROE of 14 percent, oil would be reduced at a cost of $1.28/barrel, and CO_2 emissions would be reduced at a cost of less than $1/ton—both extremely low costs. By trying to stimulate considerably more nuclear power (17.3 gigawatts) with an 11 percent ROE, costs go up significantly but are still

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[59] Note that these cost estimates do not add any values for the expected default risks.

low, rising to $6.16/barrel of oil and $1.59/ton of CO_2. Notably, these cost-effectiveness estimates are based on an assumption that the generation plants being replaced by new nuclear reflect the average cost in the system.[60]

6.4 Summary of Key Metrics of Policies to Reduce GHG Emissions

Figure 6.13 shows cumulative CO_2 reductions from covered sectors relative to the Reference case over the 2010–2030 study period for all the policies covered in this chapter. The horizontal line marks the target reduction in domestic CO_2 emissions. As noted above, the Central C&T case leads to a reduction in energy-related CO_2 emissions of about 10 percent compared to the Reference case. Other C&T policies and the Carbon Tax policy deliver as little as 5 percent or as much as 23 percent CO_2 reductions compared to the Reference case—the latter when all reductions must come from covered sectors and the former when two billion tons can come from offsets.

The nonpricing policies have smaller CO_2 reductions; the largest reduction from this group is 7,632 mmtons from the CEPS–All policy. Notably, some nonpricing policies have small reductions simply because of their focus on a narrow set of technologies. For instance, the Zero-Interest Loan and Subsidy policies examined in this chapter apply only to GHPs. In principle, however, they could apply to any energy-efficient investment, which would dramatically improve the CO_2 reductions associated with this class of policies (while also dramatically raising costs). The level of reductions spurred by nuclear loan guarantees depends on how large a commitment the federal government would make to these guarantees and, more broadly, on how much they would stimulate lenders to subsequently fund new nuclear plants.

Figures 6.14 (a) and (b) show the effectiveness of the above policies at reducing oil use below Reference case levels in 2020 and 2030 (the horizontal lines indicate the study target for oil reductions). Although the C&T policies make some progress toward the study's oil reduction target, others have almost no effect because their impacts are confined to the electric power sector where oil use is very small. The reductions in oil consumption are far larger (up to 7 percent of total oil consumption) by 2030 compared to 2020 because the policies have a longer opportunity to result in changes in the oil-using capital stock.

Figure 6.15 shows the total PDV of policy costs, added up over the study period and discounted to 2010. As in Chapter 5, we calculate costs at three different discount rates where appropriate (that is, where energy-efficient investments are directly at issue). Any value of fuel savings beyond 2030 from investments made in the 2010–2030 period is included in these costs. Costs vary from over $500 billion under a C&T with No Offsets to very small values (or even negative values, under certain assumptions) for other policies. Depending on design features of the C&T and RPS/CEPS policies, costs can vary widely.

Each of the five policies that affect energy efficiency (Building Codes, Full WM EE Provisions, Full WM EE Provisions with High-Tech Assumptions, and the two GHP policies) shows marked changes in cost based on different assumed rates of market failure. In particular, each drops from a relatively small positive cost to a (sometimes substantial) negative cost when moving from the No Market Failure rate to the Complete Market Failure rate.

Figures 6.16 (a) and (b) summarize all the cost-effectiveness results in this chapter, in terms of barrels of oil reduced (a) and domestic energy-related CO_2 emissions reduced (b). Note that a given policy reduces *both* of these metrics, so examining cost-effectiveness for these metrics separately is somewhat misleading. As this class of policies is primarily designed to reduce CO_2, one could consider average costs per ton of CO_2 reduced as the primary cost-effectiveness measure, with

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[60] However, Rothwell shows that costs would be improved if coal were the only type of generation plant being replaced, although emissions reduced would be greater with the coal plants being backed out.

Figure 6.14(a): Reductions in Oil Use Relative to Reference Case, 2020

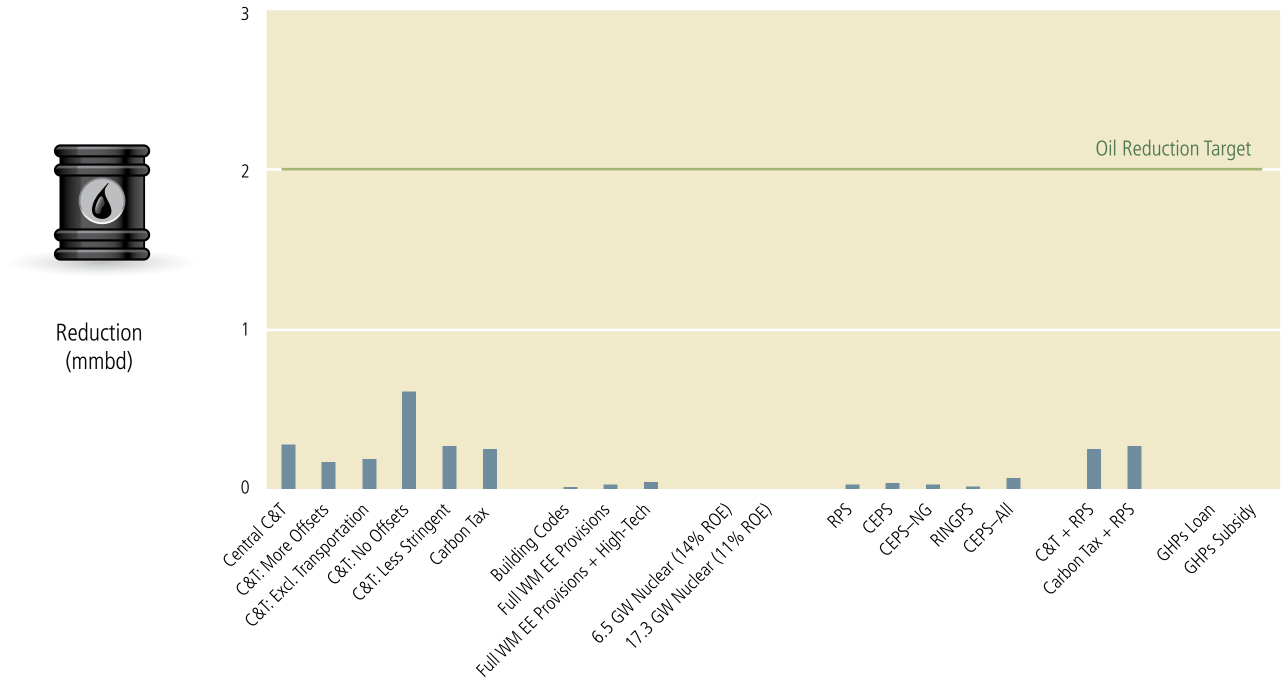


Figure 6.14(b): Reductions in Oil Use Relative to Reference Case, 2030

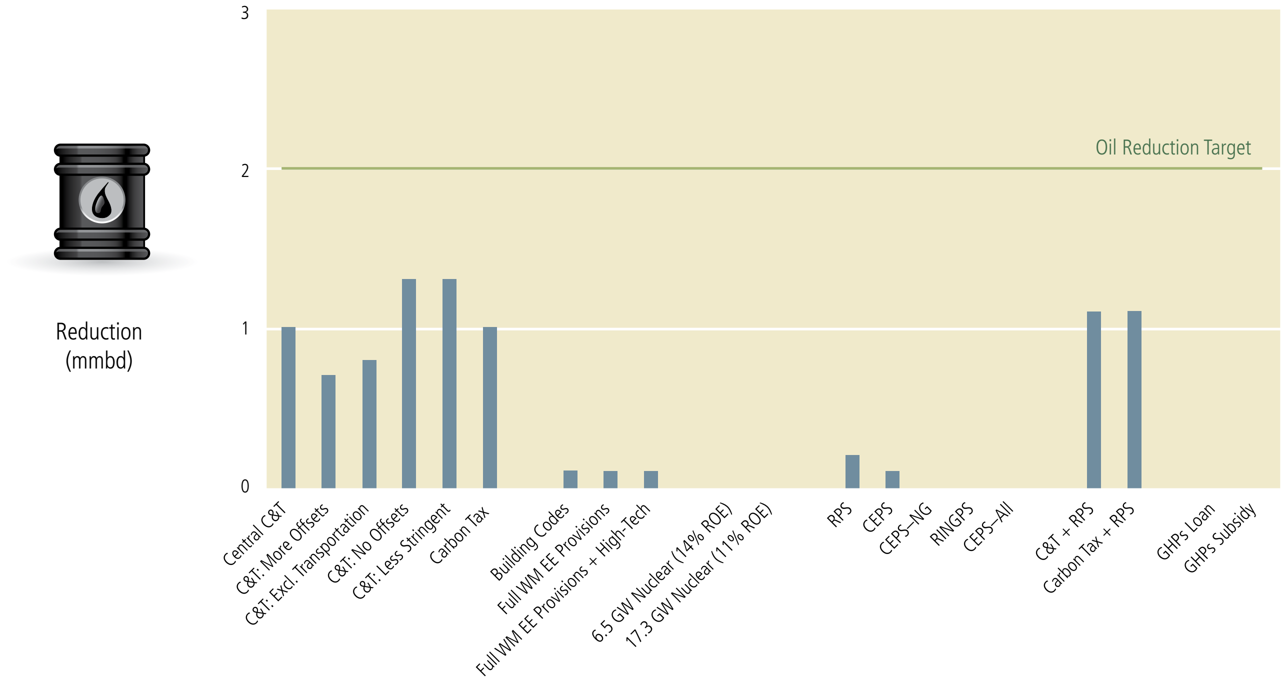
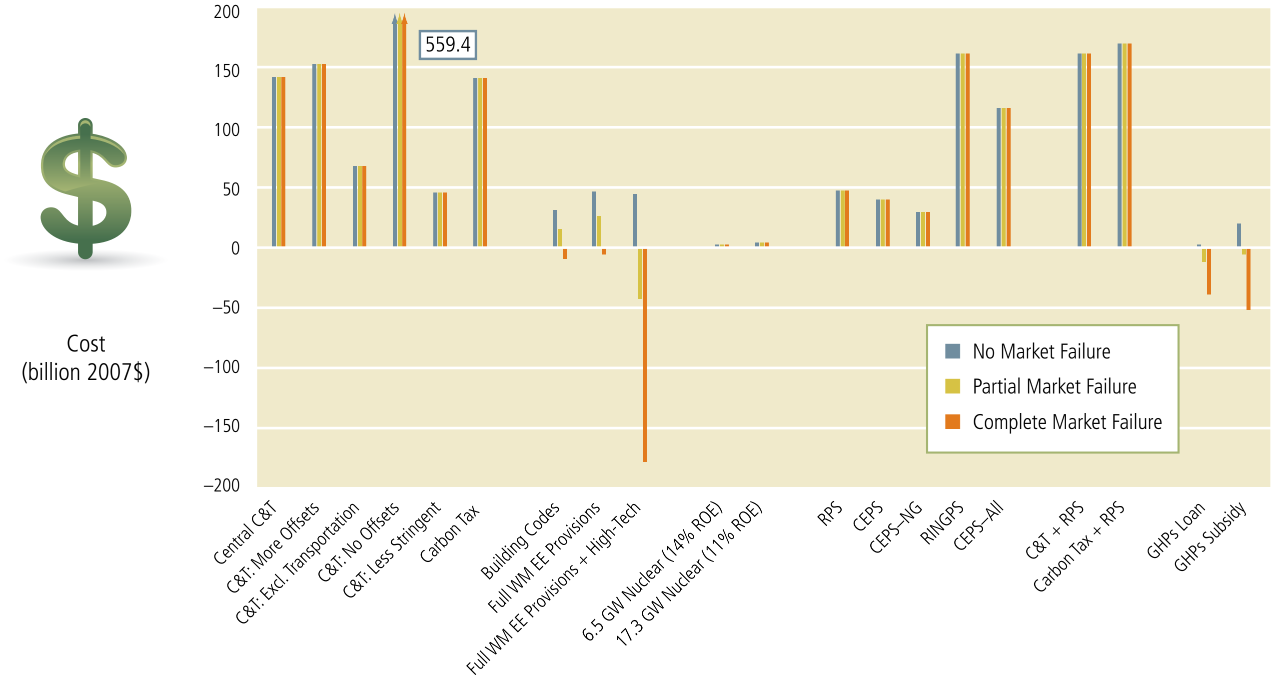


Figure 6.15: Present Discounted Value of Policy Costs, 2010–2030



reductions in oil consumption an ancillary benefit. Indeed, as shown in Figure 6.16(a), dividing total welfare costs by relatively small amounts of oil reductions results in extremely high average costs for some policies; nonetheless, where these policies do make progress toward reducing oil consumption at a relatively low cost per barrel (e.g., the Central C&T policy), these reductions should not be discounted.

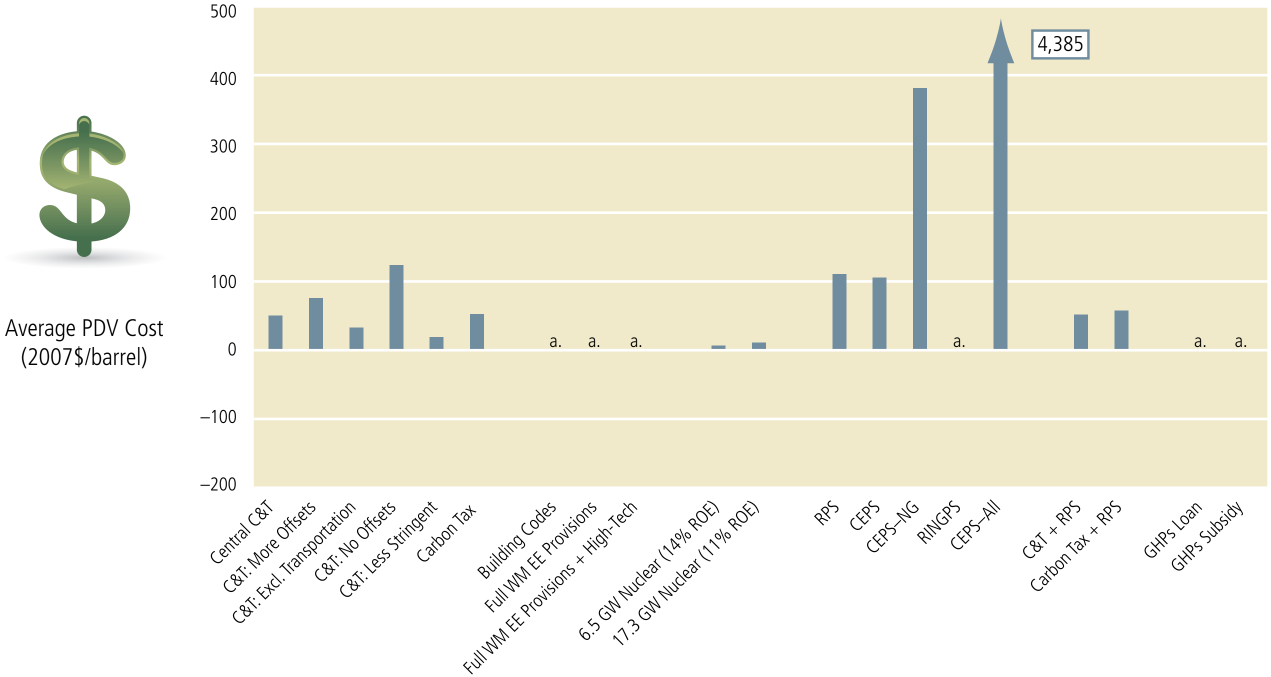
Figure 6.16(b) summarizes our finding that a number of policies have similar and relatively low average cost per ton reduced—in particular, the C&T policies and some of the variants of the portfolio standards. (Note, however, that the latter type of policy results in far fewer emissions reductions.) Building Codes and broader energy efficiency mandates and incentives have higher average cost, although using EIA's High-Tech assumptions can result in negative costs even under the Partial Market Failure rate. Similarly, the two GHP policies examined also show a switch from a positive to negative cost per ton, depending on assumption on rate of market failure. The most cost-effective policies that have positive costs—those involving new incentives for nuclear power—unfortunately result in few reductions in CO_2 emissions.

6.5 Summary

The main findings of this chapter can be summarized as follows:

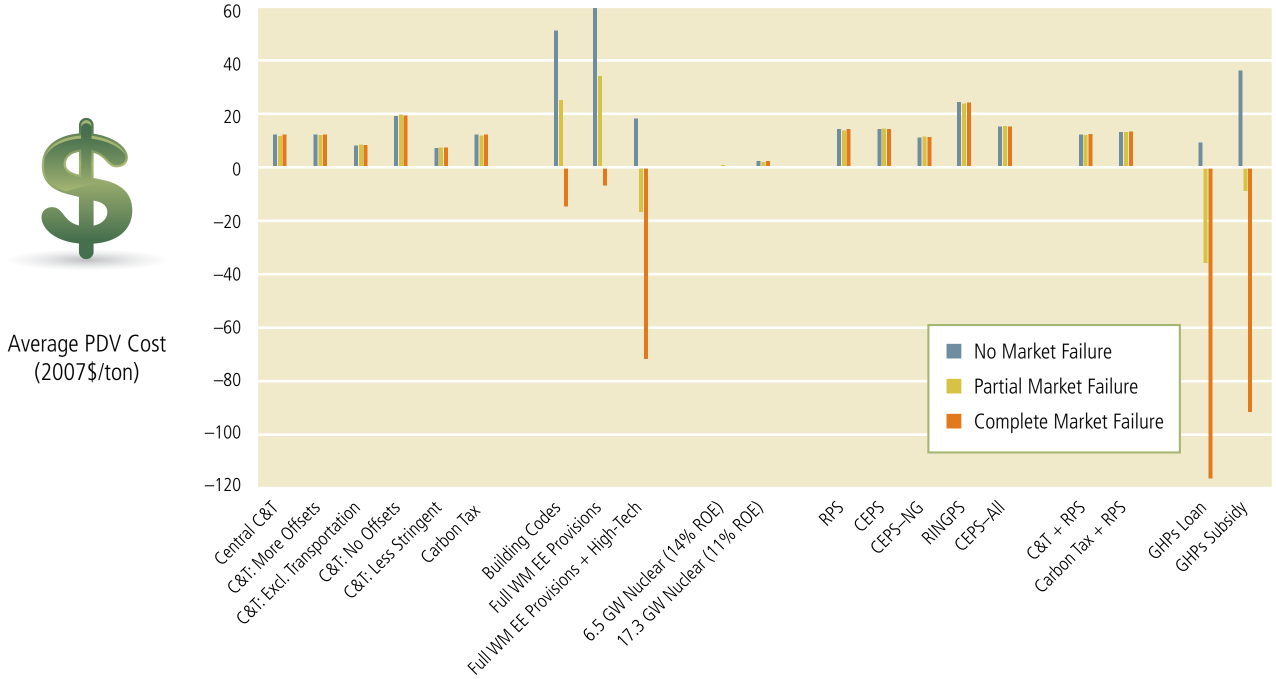
- C&T or Carbon Tax policies are likely to be less costly in reducing energy-related CO_2 emissions than other policies scaled to the same degree of effectiveness.
- As individual policies, only C&T policies or Carbon Taxes meet this study's CO_2 emissions reduction target.

Figure 6.16(a): Cost per Barrel (Cost-Effectiveness) for Reducing Oil Use, 2010–2030



Note: (a.) Cost per barrel for policies in this category is not calculated, as cumulative reductions in oil use are very small or even negative (i.e., an increase in oil use).

Figure 6.16(b): Cost per Ton (Cost-Effectiveness) for Reducing CO_2 Emissions, 2010–2030



- Obtaining significantly greater reductions in energy-related CO_2 emissions generally entails incurring higher costs, irrespective of the policy type.

- Carbon pricing policies can deliver significant (1 mmbd) reductions in oil use by 2030 when the policy is applied economywide.

- Permitting offsets in a C&T system substantially lowers costs to domestic emitters.

- Policies that reduce energy demand and stimulate clean investment are significantly more effective than policies that only encourage investment, such as the RPS, or policies that only target increasing energy efficiency.

- Although not as effective as carbon pricing policies, the CEPS–All is more effective at reducing CO_2 emissions than other types of portfolio standards—and it achieves these reductions at a relatively low cost.

- Stimulating investment in GHPs and, presumably, in other types of energy efficiency investments by financing their investment costs in utility bills and providing zero interest loans can be quite cost-effective in reducing energy demand relative to directly subsidizing such investments.

- Nuclear power loan guarantees could be a very cost-effective approach to stimulating the building of several new plants, especially if the successful and timely building and operation of these plants lead to a reduction in the rate of return investors will demand on future new nuclear power plants.

No single policy, no silver bullet, will simultaneously and significantly reduce oil consumption and CO_2 emissions. We assess an array of policies in cross-cutting combinations, examining their effectiveness in reducing both oil and CO_2 emissions.

7. Crosscutting Policy Combinations

7.1 Why Crosscutting Policy Combinations?

This study illustrates that no single policy, no silver bullet, will simultaneously and significantly reduce oil consumption and CO_2 emissions. We also need to avoid a buckshot approach, in which decisionmakers implement several uncoordinated policies that may cancel out any intended benefits or even make things worse. Thus, as the feature perhaps of greatest use to policymakers, and one that distinguishes this study from most other similar studies, we assess an array of policies in crosscutting combinations, examining their effectiveness in reducing both oil and CO_2 emissions. We also discuss interactions among policies that make up each of the combinations. We use the term *crosscutting* here to distinguish these policy combinations from those examined in Chapters 5 and 6 combining several policies that primarily are meant to address either oil reductions or CO_2 reductions.

We model four combinations, each designed to make progress on oil and emissions targets using varying policy instruments. These include (as shown in Table 7.1):

1. **Pure Pricing:** This combination examines how individual high-performing oil and carbon pricing policies work in conjunction with each other.

2. **Pricing + EE Measures:** This combination builds on the pricing options above, but combines them with residential building efficiency and automobile fuel economy policies to more directly target possible market failures associated with investments in energy efficiency.

3. **Regulatory Alternatives to Pricing:** It is typically difficult to obtain enough political support to enact pricing policies, whereas regulatory alternatives tend to be popular with legislators, so we examine a suite of alternatives to pricing.

Table 7.1: Crosscutting Combination Policies

Combination Policies	Components
Pure Pricing	Combines the Phased Oil Tax with the Carbon Tax
Pure Pricing + EE Measures	Combines the Phased Oil Tax and Carbon Tax with the Building Codes and Pavley CAFE
Regulatory Alternatives	Combines the LNG Trucks policy, Building Codes, Pavley CAFE, and CEPS–All
Blended Portfolio	Combines the Phased Oil Tax, High Feebate, Hybrid Subsidy, Building Codes provisions, GHP Subsidy, and CEPS–All with a modified LNG Trucks policy at half the original penetration rate (5 percent per year rather than 10 percent)

4. **Blended Portfolio:** This combination incorporates both pricing and regulatory options, including some of the best performing individual policies, particularly on the oil side.

Table 7.1 shows the individual policies that compose each combination.

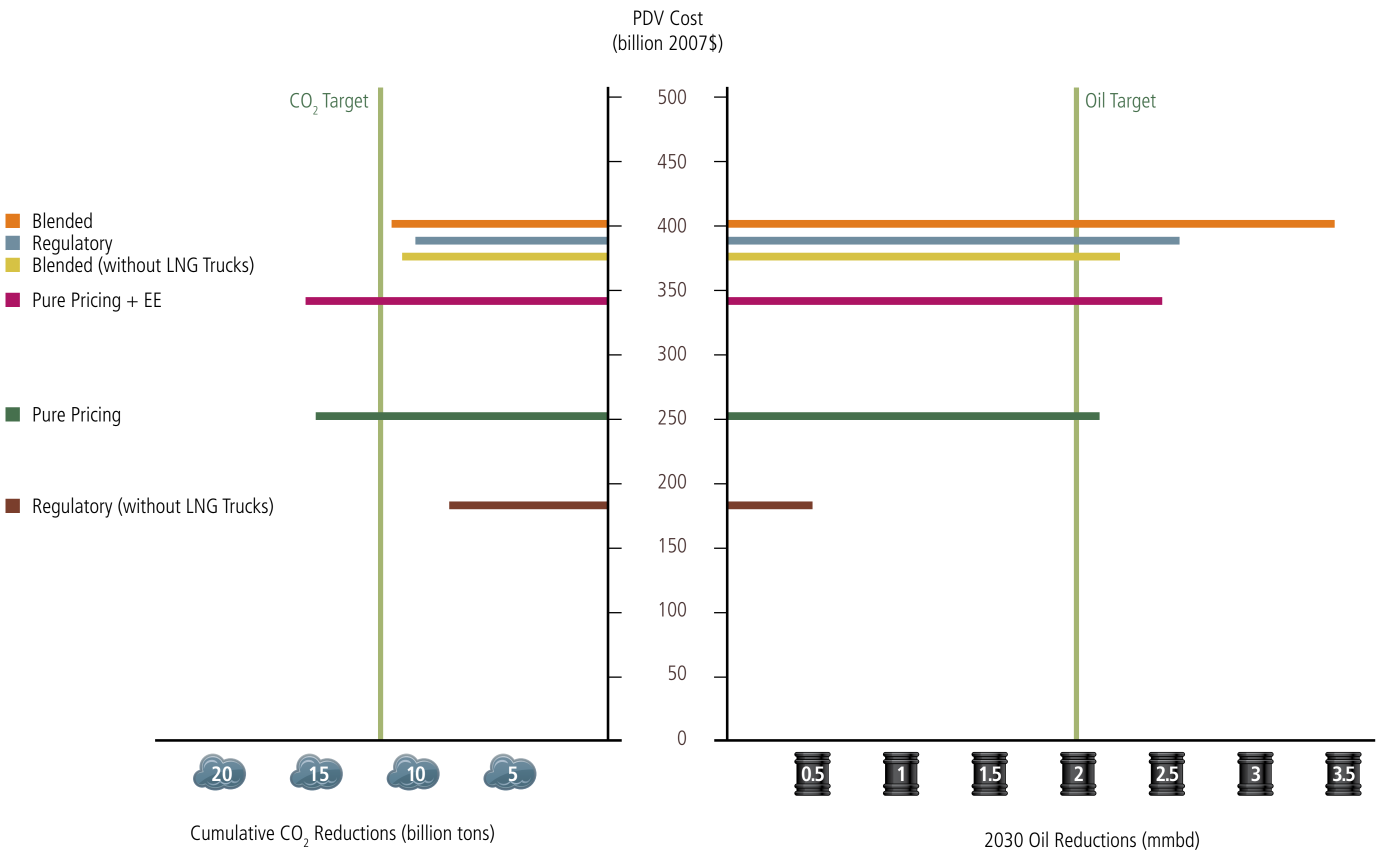
As the potential number of such combinations is so large, we developed several rubrics to help us settle on these policy combinations. Specifically, we wanted to include policies that (a) are effective by themselves, (b) cover both the pricing and regulatory policy types, and (c) give some attention to possible market failures in energy efficiency.

We also created variants for two of the options that exclude the LNG Trucks policy. This policy is separable from all of the others, in that NEMS–RFF (like the original NEMS model) does not permit any policy or economic changes to spur demand for LNG trucks. Therefore, none of the crosscutting policies covers LNG truck penetration unless we explicitly force the model to do so, which we do for the regulatory and blended options but not the pricing options. Thus, for an “apples-to-apples” comparison among all four crosscutting policies, we illustrate how the Regulatory Alternatives and Blended Portfolio perform without the LNG Trucks policy included.

7.2 Effectiveness and Cost of Crosscutting Combinations

Figure 7.1 summarizes how well each crosscutting combination fares in terms of the study’s

Figure 7.1: Effectiveness and PDV Costs of Crosscutting Policy Combinations (Partial Market Failure)



key effectiveness metrics (along the horizontal axis) and the PDV welfare cost metric (along the vertical axis) for the Partial Market Failure case. Because the combined policies are intended to reduce both oil use and CO_2 emissions, with neither measure dominating, we can no longer use cost-effectiveness measures as we did when examining individual policies. As a result, we focus on the PDV welfare cost as our cost metric.

Broadly speaking, each of the main crosscutting combinations—with the exception of Regulatory Alternatives without LNG Trucks—achieves oil reductions in excess of 2 mmbd in 2030 compared to the Reference case (or 4 mmbd compared to 2007). Only the Pure Pricing and Pure Pricing + EE policies meet and exceed the cumulative CO_2 reduction target, although the Blended Portfolio (with or without LNG Trucks) comes close. Pure Pricing and Regulatory Alternatives without LNG Trucks are the least expensive, at $253 billion and $183 billion, respectively, over the projection period (although the latter does poorly on effectiveness).

The addition of the EE policies to the pricing instruments (Pure Pricing + EE) yields additional reductions in emissions and oil use, but total cost rises by proportionately more than the increase in reductions. Oil reductions in 2030 in this crosscutting combination are 19 percent greater, and cumulative CO_2 emissions reductions are 3 percent greater than in the Pure Pricing option, but costs are approximately 35 percent higher at all rates of market failure. Both of the EE policies included in this combination—Building Codes and Pavley CAFE—have long-lasting benefits that continue well beyond 2030; one should keep this in mind when interpreting these results. Nonetheless, the findings emphasize the additional costs incurred by adding these efficiency policies on top of pricing policies (although using the Complete Market Failure case would make these costs negative).

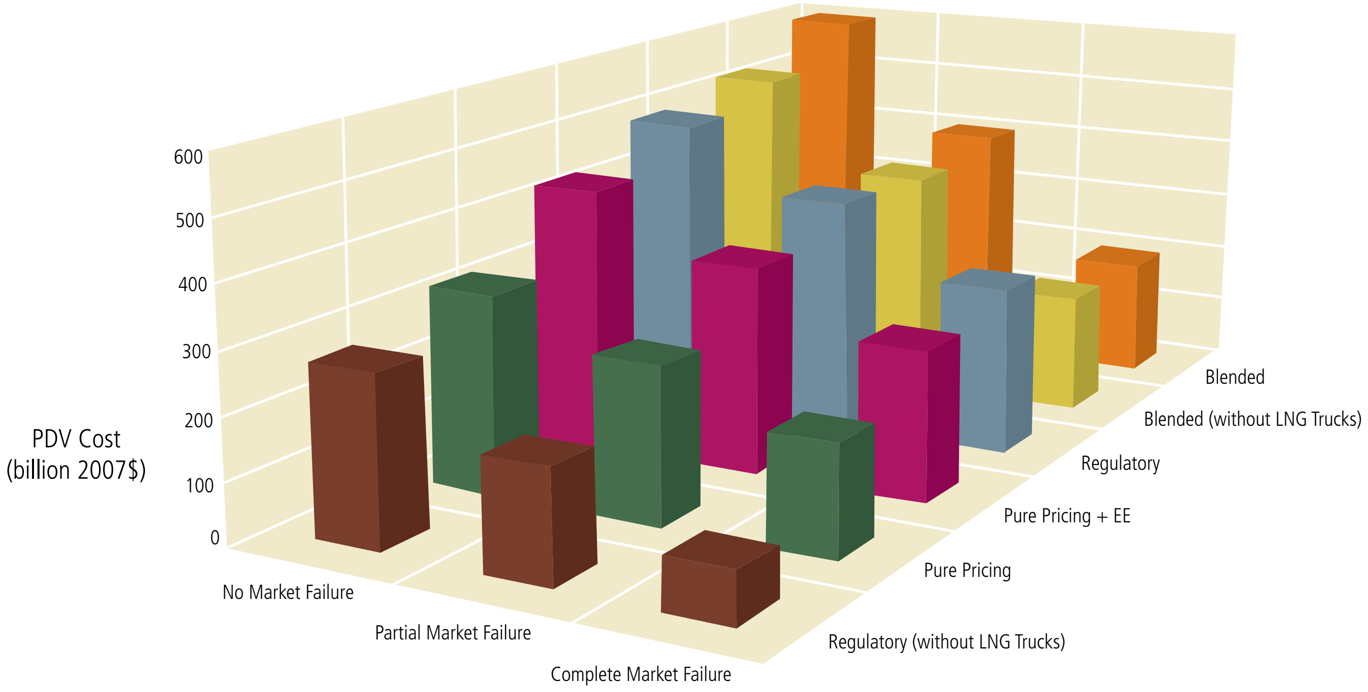
The Regulatory Alternative combination performs poorly compared to the Pure Pricing and Pure Pricing + EE combinations, with higher costs and far lower CO_2 reductions. This is primarily because of the lack of energy conservation incentives; putting a price on carbon, because it raises energy prices, spurs households and businesses to reduce their overall energy use. This incentive is lacking in our Regulatory Alternative. Oil reductions exceed those of the pricing options; but when we remove the LNG Trucks policy, oil reductions are minimal, although costs drop considerably as well.

Our fourth policy combination, the Blended Portfolio, blends both pricing and regulatory policy options and results in significant reductions in both CO_2 emissions and oil consumption. In fact, this combination leads to the greatest reduction in oil use of any policy or policy combination tested in this study, largely because it combines our Phased Oil Tax with a modified LNG Trucks mandate. Even with the LNG truck penetration rate at half the level initially analyzed, this combination results in a reduction of 3.4 mmbd beyond Reference case levels in 2030 (5.4 mmbd measured from 2007 levels). This reduction is 62 percent greater than that of the Pure Pricing combination. Without the LNG Trucks option, the Blended Portfolio loses 35 percent of its effectiveness in reducing oil, but still reaches the established target.

The Blended Portfolio nearly reaches the CO_2 emissions reduction target (98 percent)—a noteworthy achievement, given that it does not contain a Carbon Tax or C&T program. These significant reductions are largely a product of the CEPS–All, which leads to 62 percent of the CO_2 reductions achieved by the Central C&T case, and the cumulative reduction in oil use (and accompanying reduction in CO_2 emissions) spurred by the various transportation policies.

Figure 7.2 summarizes each crosscutting combination's PDV welfare costs for the No Market Failure, Partial Market Failure, and Complete Market Failure cases, and illustrates that changes in assumptions about rates of market failure can have significant impacts on cost. As expected, the costs of every combination are higher with the assumption of No Market Failure compared to the Partial Market Failure case, and the costs of the Complete Market Failure case are lower than those of the other two cases. Importantly, though

Figure 7.2: PDV Costs of Crosscutting Policy Combinations



perhaps less obviously, the cost spread (or range) over the six policies is considerably larger for the No Market Failure case ($320 billion) than that of the other two cases ($218 and $194 billion for the Partial and Complete Market Failure cases, respectively). This reflects the relatively small effect of these assumptions on the Regulatory policy combination. Although the spread is not much different for the Complete and Partial Market Failure cases, the combination policies are much more tightly clustered around the mean for the former than for the latter (determined by comparing the standard deviations in Table 7.2, and illustrated in Figure 7.2).

Finally, we examine the ranking of the policies based on their costs, depending on these market failure assumptions. Compared to the Partial Market Failure rankings, the cheapest two combination policies are unchanged. The only reordering for the No Market Failure case is a switching of the Regulatory and Blended (without LNG Trucks) policies (the former is cheaper in the No Market Failure case). Reorderings are much greater for the Complete Market Failure case. Most notably, the Blended policy, which incorporates the most complete list of EE policies, becomes the third-cheapest policy, whereas for the other market failure cases it is the most expensive. These reorderings indicate an asymmetry: the market failure assumptions matter greatly in ranking policies when moving from Partial to Complete Market Failure, but they matter little when moving from Partial to No Market Failure.

7.3 Other Metrics of Interest

In addition to our key metrics, other effects of these crosscutting policies are of interest. In particular, we include and discuss results for electricity prices, generation mix, gasoline prices, VMT, and fuel economy for the four original policy combinations. Figure 7.3 shows that Pure Pricing and Pure Pricing + EE measures lead

Table 7.2: Ranking of PDV Welfare Costs for Crosscutting Policy Combinations by No Market, Partial Market, and Complete Market Failure Cases

Combination Policy	No Market Failure (2007$, billions)	Partial Market Failure (2007$, billions)	Complete Market Failure (2007$, billions)
Regulatory (without LNG Trucks)	273.9 (1)	183 (1)	83.9 (1)
Pure Pricing	324.4 (2)	253.4 (2)	183.4 (2)
Pure Pricing + EE Measures	433.0 (3)	341.0 (3)	248.0 (5)
Regulatory Alternatives	492.8 (4)	388.6 (5)	277.6 (6)
Blended (without LNG Trucks)	526.7 (5)	376.3 (4)	196.6 (4)
Blended Portfolio	594.3 (6)	401.4 (6)	195.4 (3)
Spread	320.4	218.4	193.7
Mean (Average)	440.9	324.0	197.5
Standard Deviation	120.8	89.1	60.7

to a very similar increase in electricity prices above Reference case levels. The Regulatory and Blended policies track Reference case electricity prices very closely until the later years of the projection period, when prices rise (although not to levels seen in the Pricing combinations). These differences occur primarily because greater CO_2 reductions occur with Pricing than with the other policies, which in turn drives up generation costs. As shown in Figure 7.4, the change in generation mix also partly explains these price differences. All policies reduce generation from coal; however, with Pricing, the generation mix features less coal, less natural gas, and more relatively costly renewables.

In the transportation sector, the Pricing policies again lead to the greatest increases in gasoline price relative to the Reference case (Figure 7.5). The Blended Portfolio also has a strong effect on price, given that it contains an oil tax. The Regulatory combination tracks Reference case gasoline prices fairly closely until 2020, when prices rise slightly—but in general, the Regulatory option is considerably less effective at raising gasoline price and therefore reducing consumption.

Figure 7.6 shows the effect of the four combinations on VMT. A comparison with Figure 7.5 shows that a higher fuel price has the expected correlation with a drop in VMT; to that effect, the combination policies are found in reverse order in the two figures. Notably, the Regulatory combination actually increases VMT over the Reference case, due to the Pavley CAFE rebound effect and the absence of a substantial increase in gasoline price.

When considering the effects on new car and truck fuel economy (Figure 7.7), the crosscutting combinations featuring Pavley CAFE or Feebates (all but the Pure Pricing approach) push up fuel economy in a relatively similar fashion. Pure

Figure 7.3: Combination Policy Electricity Prices, 2010–2030

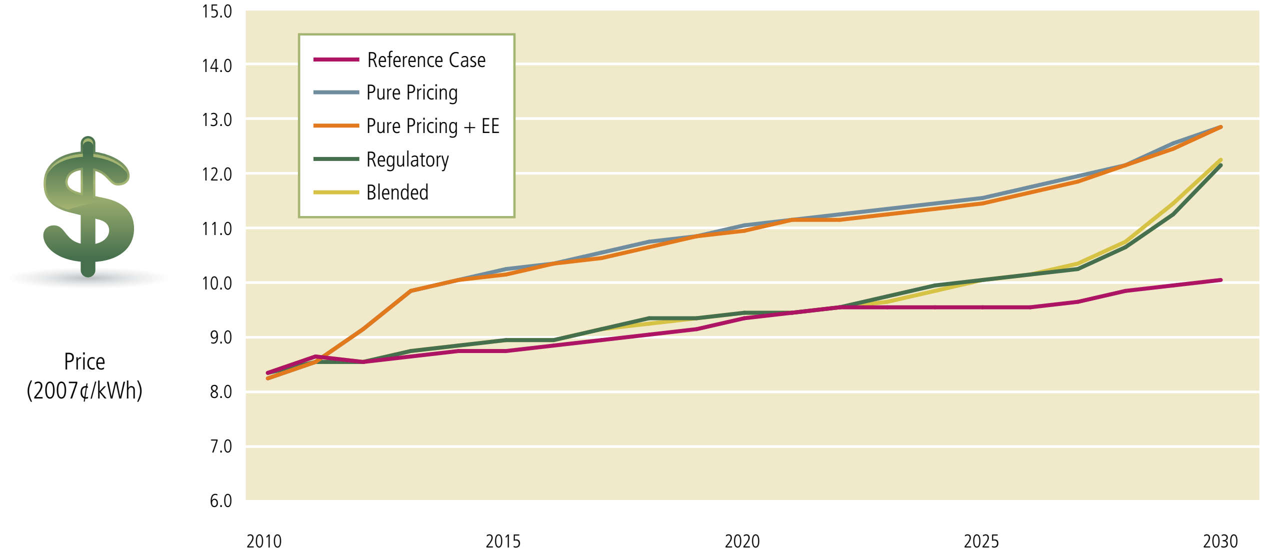
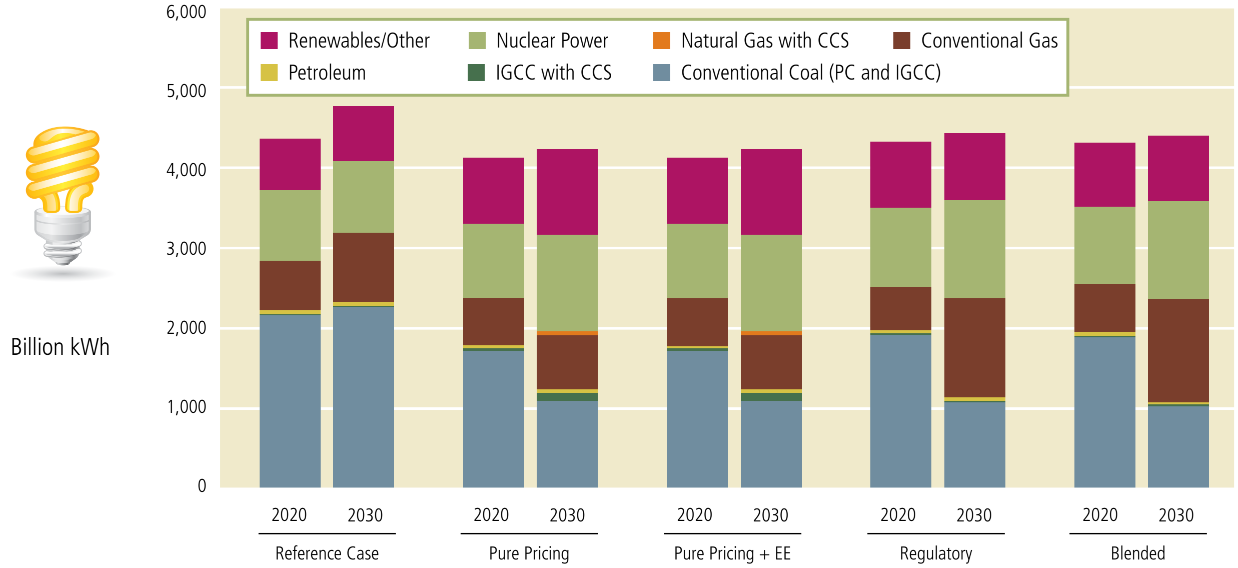


Figure 7.4: Combination Policy Net Electricity Generation, 2020 and 2030



Notes: IGCC, integrated gasification combined cycle; PC, pulverized coal.

Figure 7.5: Combination Policy Gasoline Prices, 2010–2030

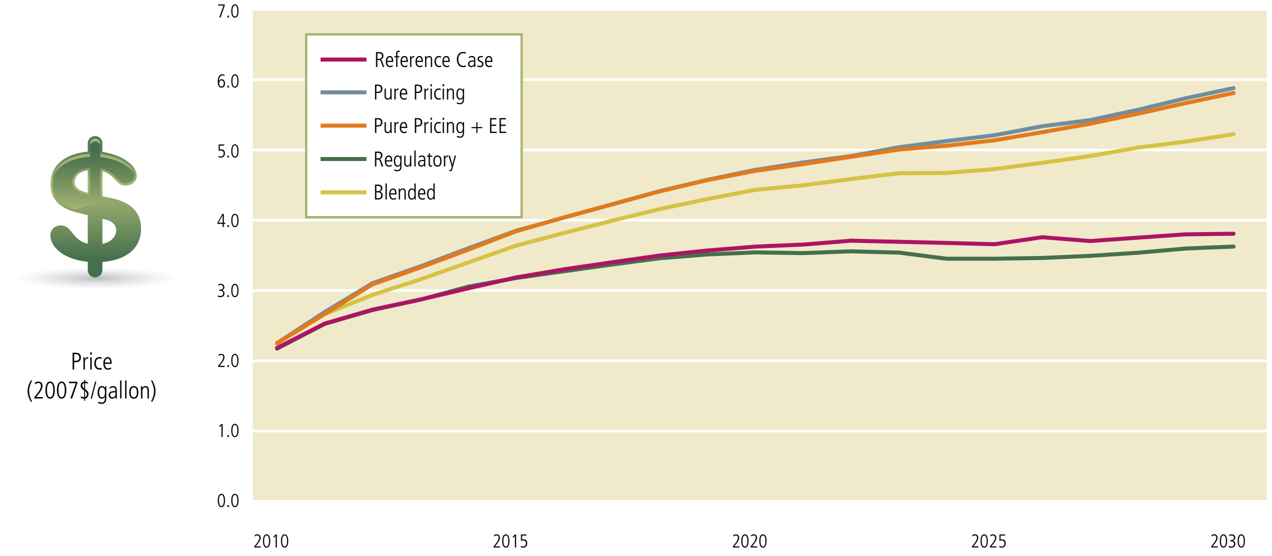


Figure 7.6: Combination Policy VMT, 2010–2030

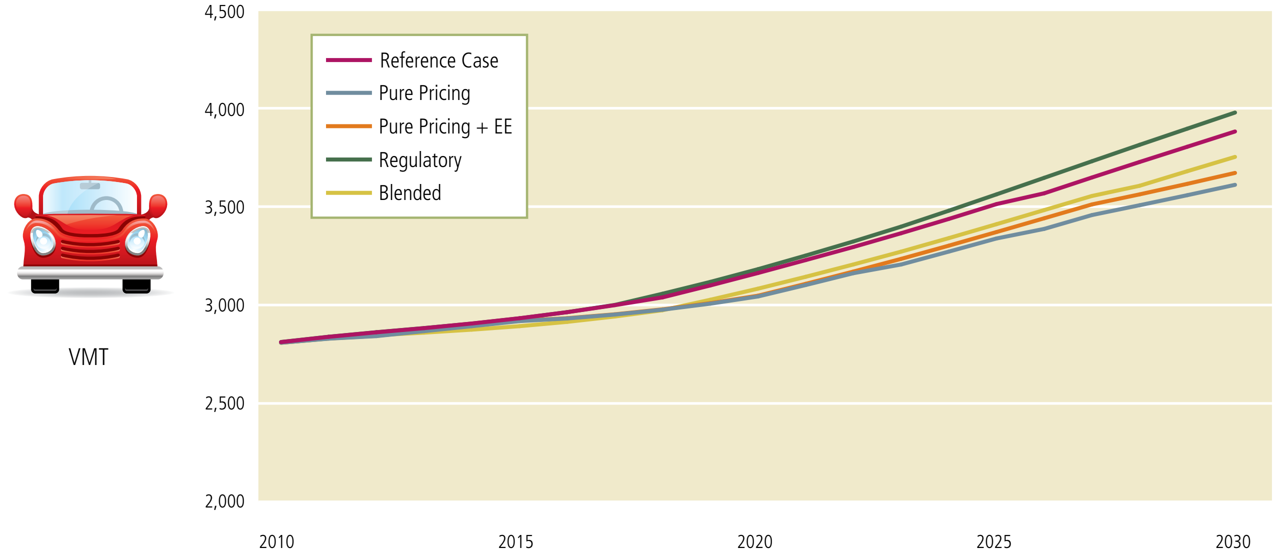


Figure 7.7: Combination Policy Fuel Economy of New Cars, 2010–2030

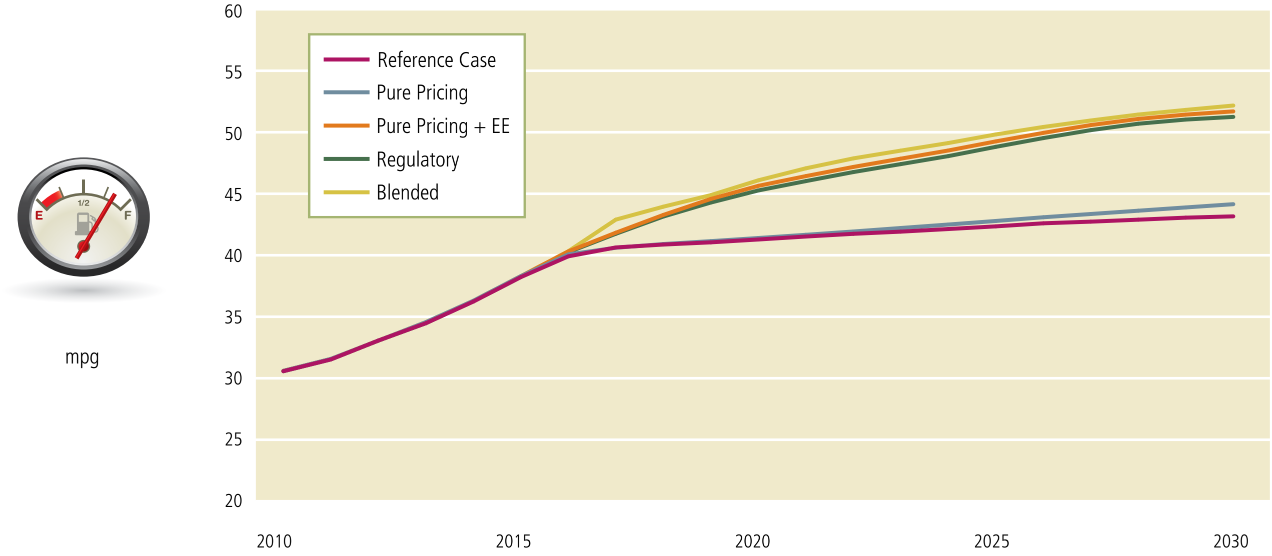
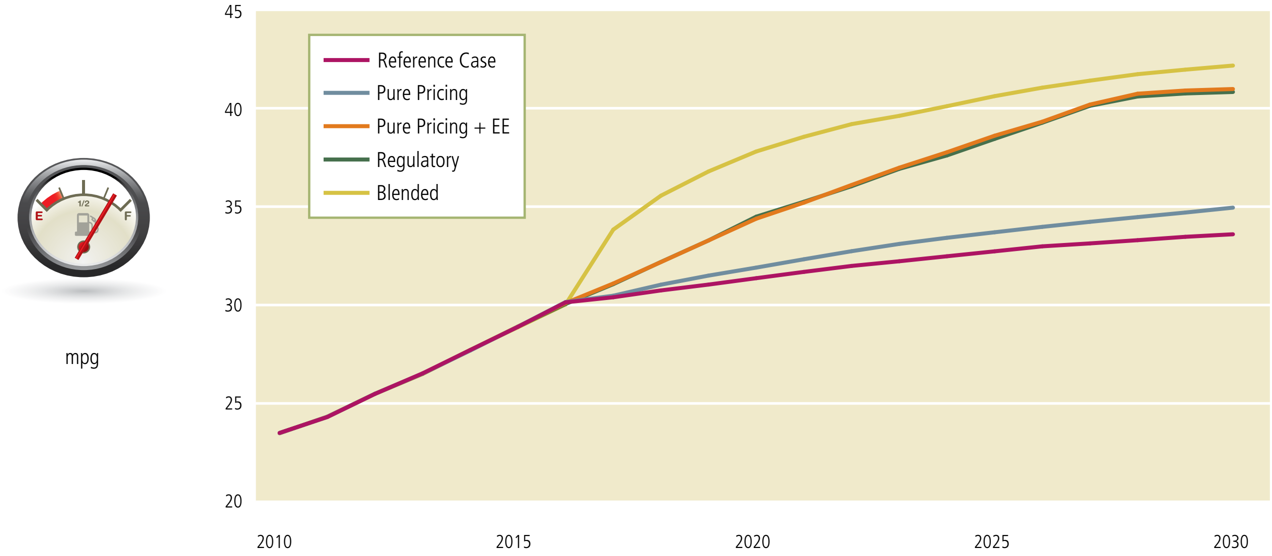


Figure 7.8: Combination Policy Fuel Economy of New Light Trucks, 2010–2030



Pricing leads to relatively small increases in fuel economy compared to the Reference case, due to the assumed lack of price responsiveness of new-car purchasing decisions to fuel price increases. For new trucks (Figure 7.8), the Blended policy results in the greatest improvements in fuel economy, whereas Pure Pricing results in the least.

7.4 Cautions and Opportunities in Mixing Policies

Policymakers obviously may want to consider policy combinations other than the ones we investigate. We urge caution, however, in using the results of our individual policy analyses to simply sum the oil and CO_2 reductions and the costs to obtain an estimate for a combination. One problem with this approach may be called the *starting point* issue. With the performance of two policies measured from the same starting point—the baseline Reference case in our study—the estimated costs when they are measured individually may be quite different from those when they are measured in combination. In the latter case, one policy "starts where the other leaves off." If the marginal costs of obtaining carbon or oil reductions are rising (i.e., it becomes increasingly costly to get additional reductions), then the true costs of the combination of policies are greater than the sum of the individual policy costs. Because the costs are higher, it is also possible that overall reductions in oil and CO_2 will be lower than would be suggested by adding reductions from the individual policy analyses.

In addition to the starting point issue, there are also complications related to prices. Some policies have impacts on prices that affect the cost of other options in the combination. For example, when combined with Oil Tax policies, the net costs of LNG Truck mandates are lower because higher prices for diesel imply a greater value from replacing diesel use with LNG. On the other hand, increased pressure on natural gas prices due to the LNG mandate increases the costs of policies, like the CEPS–All, that involve switching from coal to natural gas in power generation.

The NEMS-RFF model accounts for these market interactions when assessing the impacts of the policy combinations, and we also account for them in our welfare cost calculations. In general, we find that the effectiveness of the combination policies is lower than the sum of the effectiveness of their component policies (as indicated by negative numbers in the first four numerical columns of Table 7.3), but the difference is generally modest. For oil reductions, the greatest difference is between the Pure Pricing + EE combination and its component policies evaluated separately: 2.2 billion barrels fewer reductions for the combination over the projection period. The greatest difference in CO_2 emissions is also for this policy combination versus its components, at 366 mmtons over the projection period.

In contrast, as expected, costs of the policy combinations generally exceed those summed over their individual policies (as indicated by positive numbers in the last three numerical columns of Table 7.3), irrespective of policy type and treatment of market failure; one exception occurs with the Pure Pricing combination under the Complete Market Failure case. For our "main" case of Partial Market Failure, the greatest excess of costs from the combination policies over their components is $127.8 billion, for the Blended Portfolio without LNG Trucks. These differences vary greatly depending on the policy and the market failure assumption made, emphasizing the need for caution in using the individual policy cost results to draw strong conclusions about the costs of combination strategies.

Table 7.3: Crosscutting Policy Combinations Minus the Sum of Individual Policies, by Metric

	Progress on oil target		Aggregate reductions	Aggregate reductions	PDV welfare cost, No Market Failure	PDV welfare cost, Partial Market Failure	PDV welfare cost, Complete Market Failure
Crosscutting policy combinations	Reduction from 2007 (mmbd)		Oil consumption (billion barrels)	CO_2 emissions (mmtons CO_2)	(2007$, billions)	(2007$, billions)	(2007$, billions)
	in 2020	in 2030	to 2030	to 2030	to 2030	to 2030	to 2030
Pure Pricing	–0.1	–0.4	–1.1	61.0	70.8	23.8	–23.2
Pure Pricing + EE Measures	–0.1	–0.8	–2.2	–366.0	26.8	51.1	86.9
Regulatory Alternatives	–0.1	–0.2	–0.7	–277.0	14.6	25.7	41.5
Blended Portfolio of Policies	–0.3	0.1	–1.1	–329.5	83.8	59.7	49.6
Regulatory Alternatives (without LNG Trucks)	–0.1	–0.2	–0.6	–277.0	5.1	6.5	16.6
Blended Portfolio of Policies (without LNG Trucks)	–0.4	0.1	–1.0	–329.0	120.9	127.8	135.2

Just how much or how fast the government should push energy-related technology development is difficult to gauge, given uncertainty about the likelihood that research will lead to viable technologies and the potential for crowding out (nonenergy) R&D in other sectors of the economy.

8. Research and Development and Biofuels Policies

8.1 Research and Development

Of the several areas for additional research, none is more important than examining policies for stimulating energy research and development (R&D). Most analysts agree that to meet aggressive goals for reducing GHGs and oil, the United States will need to improve the cost and effectiveness of currently available technologies and adopt these improved technologies on a large scale. Examples where such improvements are needed include vehicle batteries, nuclear power generation, and carbon capture and storage.

There is less agreement about how to make these changes happen. Many of the major reports on energy policy, such as those referenced in Chapter 1, seem to indicate that such changes will come about primarily through increased federal spending on R&D. In fact, history has shown that the vast majority of U.S. R&D spending comes from the private sector: in 2006, for example, industry funded 66 percent of U.S. R&D, about $340 billion (Newell 2008), whereas government financed only 28 percent, with the rest coming from universities, colleges, and other nonprofits. This private sector spending is critical for driving the country's energy R&D, as the private sector responds to market signals about the profit that can be made from technologies that reduce GHG emissions and oil consumption. Further, most federal R&D funding is spent on national defense and health care rather than energy, a situation unlikely to significantly change.

Additional reasons to rely on the private sector include its flexibility and breadth of interests relative to the government. Each day, tens of thousands of companies look for new ideas to develop and market in every corner of society, including energy. In contrast, government officials and legislators have a legacy of appropriating big funds for single projects and, whether explicitly or implicitly, "picking winners," often with poor results.

Conceptually, encouraging innovation in the private sector is fairly straightforward. Beyond issues like patent protection, the surest way is through policies that make innovation profitable—for example, by taxing oil and pricing carbon, which raise the prices of carbon-intensive or oil-intensive fuels or fuel-using activities and create a greater demand for products and fuels that save on these outputs. This section, however, is about how governments can more directly stimulate energy R&D.

8.1.1 The Government's Role in R&D Funding

Although the private sector's role is critical, important roles remain for government. The first place in which the federal government plays an important role is in funding basic research; in general, the more generic or basic the research, the less the benefits of breakthroughs can be appropriated by industry and the less profit can be made. In these cases, the private sector will take on too little of this vital basic research, so there is a clear need for government to step in. Numerous studies, in fact, suggest that the socially appropriate level of R&D is several times the level actually performed by industry (e.g., Griliches 1992; Mansfield 1985; Levin et al. 1988; Jones and Williams 1998). Another government role is to fund the education and training of future innovators; companies often underinvest in such training, given the potential for highly trained employees to take their new skills to other companies.

8.1.2 The Government's Role in Technology Deployment

In principle, additional policy intervention might be warranted when significant learning by doing is associated with a new, immature technology. In these cases, companies that are early adopters create knowledge for later adopters that the early adopters cannot appropriate, leading to too little early adoption. For other technologies, the scale of deployment (such as a new fuel distribution infrastructure) may be so large and the benefits so pervasive that only government has the resources and incentive, as the provider of social good, to take on those technological developments. A final case is one in which consumers systematically undervalue a given innovation, and only government intervention can lead to its more widespread deployment. Possible evidence for this is the tendency of consumers to require very short payback periods for energy-efficient homes or lighting.

8.1.3 Stimulating R&D

Strengthening patent protection is one avenue to spur R&D, as this helps ensure that innovators reap the financial benefits of their discoveries. Alternative approaches to stimulating additional private sector R&D include contracts and grants, tax credits, and prizes. Prizes are gaining in popularity, both on a federal and a private level (the privately funded Progressive Automotive X-Prize, for example, offered $10 million for a vehicle with at least 100 mpg and very low GHG emissions). Prizes have the advantage of rewarding outputs rather than inputs, but may have limited reach because of the huge sums that need to be at stake to create serious technological breakthroughs.

Just how much or how fast the government should push energy-related technology development is difficult to gauge, given uncertainty about the likelihood that research will lead to viable technologies and the potential for crowding out other (nonenergy) R&D in other sectors of the economy (Nordhaus 2002; Goulder and Schneider 1999). Some studies (NRC 2001) suggest that past federal spending on energy R&D to mitigate pollution and improve knowledge has often yielded considerable net benefits, but considerably more study and guidance are needed to determine the appropriate amount of government investment in energy R&D.

This project did not attempt to model and score R&D policies using NEMS, given a lack of clarity on how much social value is created per dollar of R&D and on how R&D productivity varies by the source and the recipient of the funds, the purpose of the funding (whether for basic or applied research or for deployment), and the instrument used to distribute the funds. These are all important areas for future research.

8.2 Biofuels

Biofuels, which are derived from plants, can be used both as liquid fuels in transportation and to fuel electricity generation. Key transportation biofuels include ethanol derived from corn, cellulosic ethanol derived from plants, and biodiesel derived from soybeans. Sources of important biofuels for electricity generation include forest residues, wood waste, agricultural residues, and dedicated biomass crops.

Biofuels are attractive as a substitute for oil-derived transportation fuels in the United States for several reasons. First, to a large extent they can be produced domestically; an *America's Energy Future* report (NRC 2009a) suggests that 24.9 billion gallons of biofuels could be produced in the United States annually with technologies already in use, and an additional 25 percent could be produced with technologies expected to be available by 2020 (a total of 32.6 billion gallons). Also, the use of some biofuels can lead to lower CO_2 emissions compared to the consumption of oil products.[61]

For these reasons, biofuels have been the target of a wide variety of policies that aim to increase

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[61] Carbon content varies widely among biofuels, however, and life cycle studies indicate that the production and consumption of some biofuels actually lead to an increase in carbon emissions (NRC 2009a).

Table 8.1: Mandates versus Projection in *AEO2009* in 2022 (billions of gallons)

	Cellulosic Ethanol	Biodiesel	Other Advanced	Total Advanced	Corn Ethanol	Total
Mandate	16	1	5	21	15	36
Projection in NEMS in *AEO2009*	4.7	1.2	0.7	6.8	15	21.8

their penetration. The oldest policy—the ethanol tax credit—was introduced in 1978 to encourage the blending of ethanol with gasoline to address air pollution problems. It gave producers a 40¢/gallon credit on ethanol (currently 45¢). In addition, foreign ethanol producers became subject to a 54¢/gallon tax, protecting the domestic ethanol industry.[62]

This tax credit policy has helped ethanol become the largest source of nonpetroleum-based transportation fuel.[63] By 2008, 2.6 percent of the 189 billion gasoline equivalent gallons of vehicle fuel consumed in the United States came from alternative and replacement fuels, with ethanol accounting for 77 percent of this and biodiesel accounting for another 5.4 percent (EIA 2009a).

One of the newest policies, and arguably the most important, to spur the use of biofuels is the Renewable Fuels Standard, first introduced as part of the Energy Policy Act of 2005 and later tightened as part of the 2007 EISA. This legislation sets specific mandates for ethanol production through 2022. For example, in 2009, 9 billion gallons of corn ethanol (and other ethanol) are to be produced. By 2022, total corn ethanol requirements are to peak at 15 billion gallons and required cellulosic ethanol production is 16 billion gallons. Counting other advanced biofuels, a total of 36 billion gallons of biofuels is to be produced in 2022. If this goal is met, biofuels would make up about 12 percent of total liquid fuels, according to the estimate in *AEO2009* of total liquid fuel production in 2022.

As is evident in the projection above, Congress can mandate that these fuels are to be used, but that does not mean they will be. Corn ethanol production has kept pace with the mandates in 2007 and 2008 and is estimated to have kept pace in 2009 (*AEO2010*), in spite of the recession. Even before the recession was fully realized, however, EIA did not expect advanced ethanol targets to be met by 2022 (see Table 8.1; although *AEO2009* does assume that corn ethanol and biodiesel targets will be met in 2022). Indeed, rather than making up 12 percent of all liquid fuels, in *AEO2009* biofuels make up only 8 percent of total liquid fuels.

Because these projections show that even existing biofuels mandates will not be met, we opted not to examine *new* policies designed to further spur the penetration of biofuels. It would be useful, however, to examine how technology policies can speed the development of technologies to make cellulosic ethanol. NRC (2009a) estimates, for example, that "incremental" technology improve-

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[62] Cellulosic ethanol is currently enjoying a credit of $1.01/gallon.

[63] Other policies are relevant as well, as detailed in Blonz et al. (2008). The Biomass Crop Assistance Program provides subsidies to farmers of up to 75 percent of the costs of converting land into biofuels production. It also subsidizes the first two years of costs associated with harvesting, storing, and transporting raw biomass to a refinery. This program, however, has not yet been funded by Congress.

ments can reduce process costs by 25 percent by 2025 and 40 percent by 2035.

Other key economic issues for further research include the effect of expanding biomass production on land and crop prices—and the accompanying impact on both food and biofuels prices—and the net life cycle effect of biofuels use on carbon emissions.

Hill et al. (2006, 11206) nicely sum up the land use issue in the United States: "neither biofuel [ethanol nor biodiesel] can replace much petroleum without impacting food supplies. Even dedicating all U.S. corn and soybean production to biofuels would meet only 12 percent of gasoline demand and 6 percent of diesel demand." The authors also note, however, that because of the fossil energy required to produce ethanol and biodiesel, such a transition to biofuels would provide a net energy gain equivalent to just 2.4 percent and 2.9 percent of U.S. gasoline and diesel consumption, respectively. The possibilities for economic losses are also large under certain conditions. For instance, McDonald et al. (2004) show that a substantial use of switchgrass for creating biofuels would reduce the crude oil price only slightly but would increase the world price of cereals by shifting land from grain to switchgrass production, leading to an overall decline in economic welfare.

These issues are similarly prevalent in developing countries, particularly in Brazil and Southeast Asia. Fargione et al. (2008) estimate that the conversion of rainforests, peatlands, savannas, or grasslands to produce food crops in these countries releases 17 to 420 times more CO_2 than the annual GHG reductions to be gained by replacing fossil fuels with biofuels grown on those converted lands. On the other hand, biofuels grown on degraded or abandoned agricultural lands do not face a similar *carbon debt*, and can instead offer advantages in terms of GHG reductions. This illustrates the importance of knowing where biofuels are grown in judging their efficacy at reducing GHG emissions.

Policymakers need to understand what is being given up when policies are designed for their political acceptability and recognize the potential for large trade-offs with costs.

9. Broader Considerations

The strength of the NEMS–RFF model rests in its ability to project, in a consistent way, the effects of a diverse range of energy and climate policies. However, the model is not well suited to analyzing some other considerations that are important to a broader policy evaluation. This section discusses some of these considerations, including:

- the cost and distributional trade-offs in the use of energy tax revenues;
- price volatility; and
- ancillary benefits of policies.

9.1 Revenue Recycling Issues

Alternative uses of the revenues raised from taxes on oil, fuel, or CO_2, or from allowance auctions in a C&T system, have important implications both for overall policy costs and for determining who bears the burden of the policy. As we shall see, there may be trade-offs between using the revenues in the most efficient way and creating the political will to use pricing mechanisms to address oil use and carbon emissions—and the latter may well trump the former. Yet it is still important to understand the trade-offs.

9.1.1 Cost Implications

To be fully comprehensive, any measure of policy cost should address how the policy affects the costs of other distortions already in the economy created by the broader fiscal system. In particular, income and payroll taxes distort economic activity because, by reducing the after-tax rewards of working, they discourage some people from participating in the labor force (for example, a partner of a working spouse may choose to stay home rather than work) and lead others to put in less effort on the job or to spend less time accumulating skills to raise their productivity. Similarly, the level of investment and saving is lower than it would otherwise be because the income earned on investment and saving is penalized through taxation. The tax system also creates a bias toward spending that receives favorable tax treatment (for example, employer medical insurance and home ownership) at the expense of ordinary (nontax-favored) spending.

Although the NEMS model (in its version from 2009) does provide options for the distribution of revenues, this model is not set up to capture these types of distortions—that is, the model does not capture the effect of the broader tax system on altering incentives for labor supply, capital accumulation, tax avoidance, and so on. However, based on other models that take such distortions into account, we can provide some sense, albeit rough, of how costs would be affected if linkages between new policies and preexisting taxes in the economy were taken into account.

New energy or climate policies interact with these broader distortions in two main ways: first, by lowering policy costs if the distortions are reduced and, second, by raising costs.[64]

First, to the extent that new policies lead to additional revenues for the government, and these revenues are used to reduce marginal income tax rates and other taxes that distort the economy, important economic efficiency benefits will accrue. A substantial empirical literature attempts to estimate the impact of tax changes on labor

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[64] See, for example, Goulder (1995, 2002) and Parry and Oates (2000).

supply, capital accumulation, spending on tax-favored goods, and so on (e.g., Saez et al. 2009). This type of evidence has been used to measure the economic welfare effects of changes to the broader tax system. A typical assumption is that a general reduction in marginal personal income tax rates will yield an economic welfare benefit of around 30¢ (or more) per dollar of revenue recycled in this way, compared with returning revenues in lump-sum cash transfers to households.[65] Returning revenue in lump-sum transfers does not provide the same incentives for households to alter their behavior in ways that enhance economic efficiency. That is, cash transfers do not increase the returns from being in the labor force as opposed to staying at home, or the return on savings relative to consumption, nor do they alleviate incentives for exploiting tax deductions, exemptions, and other loopholes.

To get some idea of the effects of alternative recycling approaches on costs, consider the Phased Oil Tax policy discussed in Chapter 5. The PDV of revenue raised under this policy amounts to $2,366 billion over the 2010 to 2030 period.[66] Multiplying by 0.3 suggests that potentially large gains in economic efficiency, on the order of $700 billion over the study period, may result from using this revenue to reduce marginal income tax rates. This gain could easily swamp the PDV of the cost of the policy reported in Chapter 5 ($64 to $112 billion).

For another example, under the Central C&T policy, with 100 percent allowance auctions, the PDV of revenue that would be collected on allowance purchases to cover domestic CO_2 emissions over the 2010 to 2030 period is $2,089 billion. Again, multiplying by 0.3 gives an economic efficiency gain ($627 billion) that greatly exceeds the PDV cost estimate in Chapter 6 ($142.3 billion).

Do these estimates imply that the overall costs of oil taxes and C&T policies can be negative if the potential for using revenue to cut other distortionary taxes is exploited? Not necessarily, because there is a second, counteracting effect. New policies, like oil taxes and carbon emissions pricing, that increase the costs of energy, transportation, and the production of goods tend to cause a reduction in the overall level of economic activity, employment, investment, and so on. Although this effect appears to be very slight at the economywide level (most studies of these pricing policies show that GDP falls by less than 1 percent), most studies suggest that, for energy taxes and carbon pricing policies, the resulting welfare cost is nonetheless large enough to offset, and perhaps more than offset, the entire potential gains in economic efficiency from recycling revenues to reduce marginal income tax rates (e.g., Goulder 2002). Accurately estimating the size of this counteracting effect (and whether it exceeds or falls short of the revenue recycling benefit) is complicated, as it depends on how energy and climate policies affect energy prices and manufacturing costs throughout the economy and how these higher costs affect production, employment, capital accumulation, and so on.

However, the more striking implication for policy is the difference in overall costs between energy tax and emissions pricing policies that do, and do not, exploit large economic welfare gains from the recycling of revenues. Oil taxes with revenues returned in lump-sum transfers to households effectively impose an extra cost—on the order of $700 billion over our study period for the Phased Oil Tax—relative to oil taxes whose revenues substitute for distortionary taxes or are otherwise used to generate comparable gains in economic efficiency.[67] Similarly, using auction revenues to fund lump-sum transfers, or not raising revenues at all by giving away allowances for free, might raise the overall costs of our Central CO_2 C&T policy on the order of $600 billion relative to a policy that auctions the allowances and uses the revenues to cut other distortionary taxes.

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[65] Values around this number have long been used in government guidelines (e.g., OMB 1992). For a more recent discussion, see Parry and Williams (2010).

[66] This figure takes into account the revenue consequences of the erosion in the base of prevailing taxes on highway fuels.

[67] For example, using some of the revenues to fund socially desirable highway projects, or desirable technology development programs, might produce similar economic welfare benefits to those from cutting distortionary taxes. Using the revenues to reduce the federal budget deficit might also produce large economic benefits by lowering the future tax burden.

Of course, as discussed below, alternative uses for new revenue sources may also have critically important implications for distributional outcomes and feasibility. The basic lesson is that, from the perspective of keeping down overall welfare costs (broadly defined), the (potential) revenue from new energy or climate policies should be used, as much as possible, in ways that increase the efficiency of the economy, subject to meeting distributional and feasibility constraints.

Finally, preexisting tax distortions have less dramatic implications for the overall welfare costs of regulatory approaches to energy and climate policy, such as fuel economy and EE regulations, RPS policies, and CEPS policies. These policies do not provide any potential revenue recycling benefit. However, they also have a much weaker effect on energy prices and production costs in general than (comparatively scaled) pricing policies; therefore, they have a much less adverse effect on economywide employment, investment, and so on from higher energy costs. The reason is that these policies do not create large new tax burdens or large amounts of allowance value that tend to be passed forward into higher energy prices under tax and C&T approaches.

In fact, when broader impacts of policies on preexisting tax distortions are taken into account, the costs of regulatory approaches might actually be lower overall than those of a pricing policy that does not make efficient use of the revenues for the same overall effectiveness (e.g., Goulder et al. 1999; Parry and Williams 1999). However, this requires regulatory policies that are well designed in terms of both mimicking many of the behavioral responses that would occur under pricing policies and providing flexibility. A CEPS–All policy in which credits for reducing carbon can be traded across technologies and generators would be an example of a well-designed policy.

9.1.2. Distributional Incidence

New energy taxes or fully auctioned C&T systems, with revenues automatically offset by reductions in marginal income tax rates or other distortionary taxes, result in two large, interrelated problems: fairness and feasibility.

Lower-income households typically spend a significantly greater share of their budgets on electricity-using and other energy-intensive durable goods (see, for example, Dinan and Rogers 2002; Burtraw et al. 2009). This means that lower-income households suffer disproportionately—that is, they bear a bigger burden relative to their income—as a result of new taxes or emissions pricing policies that increase energy prices. Recycling energy tax or climate policy revenues in broad income tax reductions provides some compensation for all taxpayers, but this compensation relative to income is greater for higher-income groups, given that they pay a larger share of their income in tax. Partly in response to this concern, proposals to return all of the revenues from new energy taxes or carbon pricing policies in lump-sum cash rebates, or dividends, to households have been gaining ground (such as in the legislation proposed by Senators Cantwell and Collins, which provides for *cap-and-dividend*). Under this approach, all individuals receive equal compensation from revenue recycling.

With such a policy, according to Burtraw et al. (2009), the bottom 40 percent of households, ranked by income, actually would become better off overall under a cap-and-dividend policy to control domestic CO_2 emissions—that is, the cash transfers they receive would more than offset their increased expenditures on energy-related goods.

As noted in the previous section, whatever one may think of this effect on the income distribution, this approach comes at a high cost in terms of forgoing potential economic welfare gains from using revenues to reduce distortionary taxes. A possible compromise might be to provide enough lump-sum transfers to keep the overall burden of the policy, relative to income, approximately the same for all income classes and to use the remaining revenues for a general reduction in distortionary taxes. More generally, if higher energy prices are the key stumbling block to implementing climate and oil security policies, this underscores a potential attractiveness of regulatory and other approaches that attempt to mimic, insofar as possible, the effects of pricing policies without a large transfer of revenue to the government. For example, combining a CEPS with regulations governing the energy efficiency of buildings and appliances could exploit many of the CO_2 reductions from the power sector that would occur under C&T but with a much smaller effect on electricity prices.

Another argument for automatically rebating revenues in lump-sum transfers is that it might reduce political opposition to new energy and climate pricing policies, as it demonstrates to households that they will immediately receive some compensation for the burden of the new policy. Making judgments about what policies are and are not politically feasible, however, is very difficult. Only a few short years ago the conventional wisdom was that all of the allowances in a C&T program would need to be given away for free to industry as part of the political deal-making required to move climate legislation forward. Yet now, for example, the European Union is in the midst of a radical transition toward auctioning almost all of the carbon allowances in the European Trading System, and the Regional Greenhouse Gas Initiative states auction more than 85 percent of their allowances. The point of this cautionary tale is that policymakers need to understand what is being given up when policies are designed for their political acceptability and recognize the potential for large trade-offs with costs.

9.2 Price Volatility

The potential for volatility in fuel prices and other economic factors has implications for the costs of policies to control both CO_2 emissions and oil use.

9.2.1 Price Uncertainty in C&T Systems

One of the central concerns about a carbon C&T system in its pure form is that the future price of emissions allowances will be volatile and difficult to project because it will depend on a whole range of uncertain factors. Uncertainty over future emissions prices may undermine the durable and substantial incentives that are needed to encourage emissions-saving technology investments with high up-front costs.

Moreover, year-to-year volatility in emissions prices can significantly raise the costs over time of a given cumulative target for emissions reduction. According to Fell and Morgenstern (2009), allowance price volatility might raise the overall costs of a C&T system (with stringency similar to that of our Central C&T policy discussed in Chapter 6) by up to about 15 percent over time relative to costs under a CO_2 tax that fixes the price of emissions. The costs of meeting a given emissions cap can vary substantially with economic conditions—costs can be relatively high during times of rapid economic expansion or when new low-carbon technologies are slow in entering the marketplace, and vice-versa during periods of depressed economic activity and low prices for clean fuels. A more flexible system—one that allows emissions to exceed the cap during periods in which the costs of meeting the cap would be high and offsets those with fewer emissions when the costs would be relatively low—helps to contain policy costs over time.

Several methods are available for reducing the potential for price volatility inherent in C&T systems. One is to allow for banking and borrowing of allowances over time; this intertemporal flexibility makes the current supply of allowances more elastic and thus can dampen price volatility. Such provisions do not entirely eliminate volatility, however, not least because proposals typically embody penalties for, or limits on, allowance borrowing to limit default risk.

An alternative way to limit price volatility is to impose a price ceiling and floor, or *collar*. Under this approach, firms can buy additional permits from the government when the ceiling price is reached, thereby allowing higher emissions. Conversely, the government buys back allowances from the market when the price hits the floor, thereby reducing emissions. The primary issue with collars is to design them such that the environmental integrity of the system is not compromised, as expected emissions outcomes of the systems with collars are quite sensitive to the ceiling and floor levels (Fell and Morgenstern 2009). To reduce this emissions uncertainty, Murray et al. (2008) have suggested a strategic reserve system, similar to a *soft collar*, which limits the number of permits the government can release into the market when the permit price hits the price ceiling.

Another approach for enforcing a price floor if allowances are auctioned is through a reserve price in the auction below which no allowances would be sold.

9.2.2 Oil Price Volatility

Price volatility also has implications for the costs of policies directed at reducing oil use. Again, price-based approaches, like fuel taxes and feebates, are more flexible. They allow manufacturers to sell vehicle fleets with lower average fuel economy in periods when fuel prices are depressed and household demand for fuel-efficient vehicles is lower, and vice versa during times of high fuel prices. In contrast, fuel economy standards force manufacturers to meet the same requirements each year, regardless of consumers' willingness to pay for fuel-efficient vehicles. But again, the cost disadvantage of the standards-based approach can be addressed through flexibility provisions that allow manufacturers to bank and borrow fuel economy credits over time (these provisions will probably be extended in pending reforms to the CAFE regulation).

9.3 Ancillary Benefits of Policies

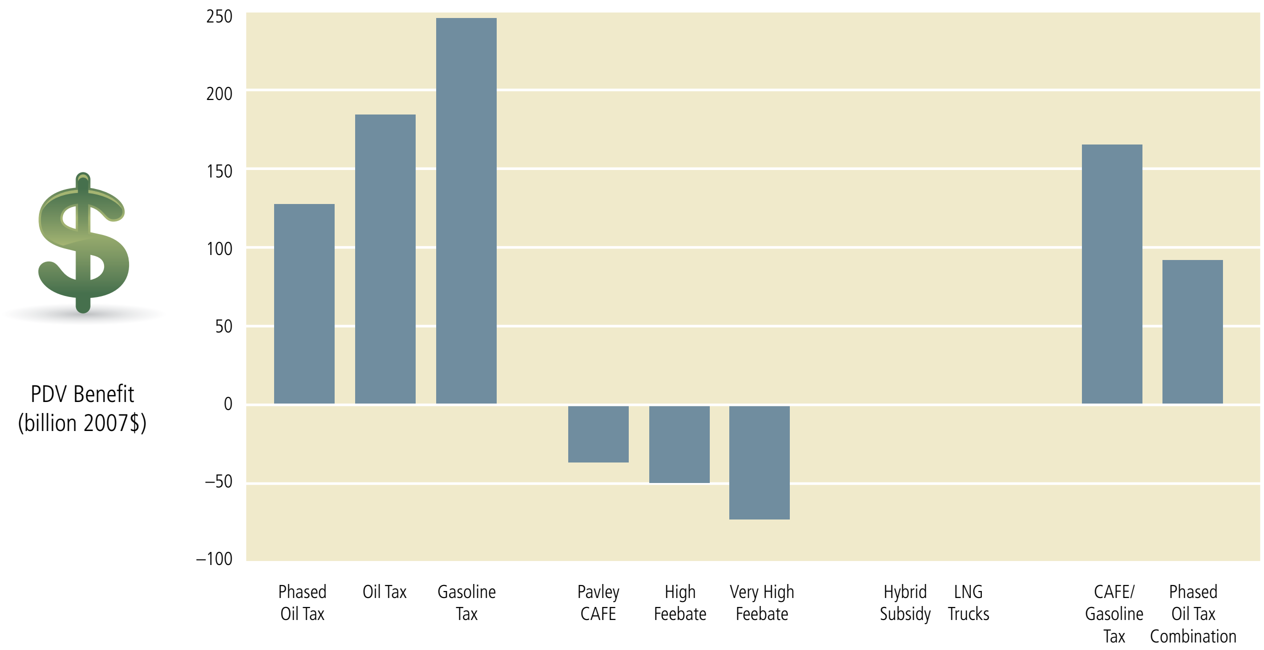
Some of the policies examined in this study have quantitatively important benefits beyond the reductions in oil use or CO_2 emissions they cause. This is particularly the case for policies affecting the use of highway vehicles. For example, *ancillary* societal benefits from fuel taxes include (slightly) reduced highway congestion, traffic accidents, and local pollution emissions. As we shall see, consideration of such benefits can, for some policies, turn net costs into net benefits, whereas for others it can actually raise costs.

On the other hand, local air pollution effects of policies affecting the power sector, and perhaps other sectors, appear to be minor in relative terms. Considering the power sector, NRC (2009d) puts the local air pollution damages from power generation (which is a total damage concept, not a marginal damage concept as is of issue in our report) at about 1.5¢ per kWh on average (coal plants account for most of this pollution, and increased mortality risks account for most of the damages). However, most of the quantifiable damage is from sulfur dioxide converting to fine particulates (less than 2.5 micrometers in diameter) in the air and affecting human mortality. Because these emissions are capped for the United States by the sulfur trading program, the total quantity of emissions would not be affected by new policies impacting the power sector. In addition, there is a new cap on emissions of nitrogen oxides, further limiting the need to focus on ancillary pollution benefits from new carbon reduction policies.

Although we feel that it is appropriate to add ancillary benefits or costs of air pollution to the "direct" costs of transportation policies and not do so for policies that basically operate in the power sector, it is not necessarily appropriate to conclude that comparing policies to reduce oil with those to reduce carbon is fair. This is because both sets of policies have a wide variety of negative externalities that are not being quantified, including, for the power sector, (a) health effects and effects on fish from mercury emitted when burning coal; (b) nuclear waste and proliferation; (c) effects on the landscape, watersheds, and ecosystems from generating power by wind and the sun; and (d) ecological effects from using water to generate electricity and from spoil creation when mining for coal (and uranium). Regarding oil, unquantified ancillary externalities include those from oil spills, refining, groundwater effects, and so on. A good source for discussion of all of the externalities associated with electricity (including oil used for electricity) is NRC (2009d).

Whether ancillary benefits should be netted out from our direct cost estimates is not entirely clear. The broader effects of vehicle use really call for policy instruments other than higher fuel taxes. For example, urban road fees that vary according to time of day are a far better way to address traffic congestion, which varies substantially across different urban centers and between peak and off-peak periods. And automobile insurance

Figure 9.1: PDV of Ancillary Benefits from Oil Policies



reform that would charge motorists by the mile, with the charge scaled by their collision risk rating, would be a more efficient way to reduce the incidence of traffic accidents than taxes on fuel use (Bordhoff and Noel 2008). Nonetheless, until these more efficient policies are widely implemented, a case can be made for netting out these ancillary benefits in the evaluation of policy costs.

Figure 9.1 shows the PDV of ancillary benefits of reduced automobile use resulting from the oil policies analyzed in Chapter 5, based on values for these benefits in Small (2010).[68]

All policies, and combinations, involving oil taxes and higher gasoline taxes yield very substantial ancillary benefits between $92 and $250 billion in present value over the period 2010 to 2030. In contrast, the Feebate and CAFE policies on their own lead to ancillary costs of $37 to $74 billion in present value over the period, through their effect increasing VMT. Thus, taking into account the ancillary benefits greatly strengthens the case for preferring tax-based approaches over EE policies, whether they address oil use or CO_2 emissions. In fact, for the Gasoline Tax case, for example, ancillary benefits over the period are significantly greater than the PDV costs discussed in Chapter 5 (as shown in Figure 9.2). This reflects the failure of current fuel taxes to capture the congestion and other societal costs of automobile use.

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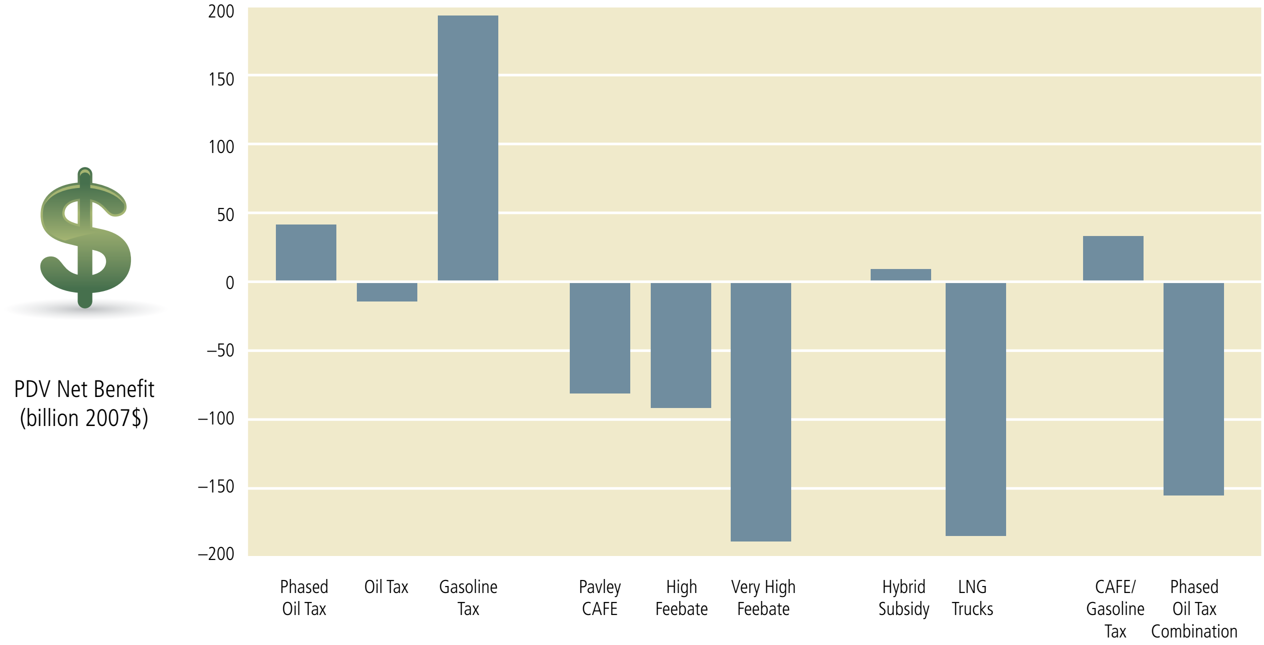
[68] These figures do not take into account congestion and other ancillary benefits from reduced VMT by heavy trucks and aircraft.

Figure 9.2: PDV of Net Benefits (Partial Market Failure Rate)



Users of these data may opt to put more faith in the relative comparisons of costs and effectiveness across policies than in the absolute levels of these metrics. Although we acknowledge the inherent uncertainty in our findings, we feel confident about our policy comparisons—which are the heart of our study—because they are based on the same assumptions and modeling algorithms; in other words, they are apples-to-apples comparisons.

10. Conclusion

This study set out to evaluate a large set of feasible policies that could reduce CO_2 emissions and oil use. Although the list of policies covered is by no means exhaustive, the study does cover much of the relevant policy territory—from oil taxes to hybrid vehicle subsidies, renewable energy policies to building codes, several variants of C&T policies, and more. Perhaps of greatest use to policymakers, we also assess several crosscutting policy combinations.

10.1 Summarizing the Results

We emphasize two broad conclusions from our policy analyses:

- **A single policy instrument will not efficiently reduce both oil use and CO_2 emissions to meet the selected targets.** We find that policies that target oil use—even broad-based pricing policies such as an oil or gasoline tax—do provide some CO_2 benefits, but they are far less beneficial in this regard than direct carbon policies. Similarly, although carbon pricing policies lead to some reductions in oil use, the remaining carbon policies (EE, nuclear, and renewables) do little if anything in this regard.
- **Combinations of policies, in contrast, are by design more effective at reducing both oil use and CO_2 emissions, meeting or exceeding both reduction benchmarks laid out in this study.** Costs differ widely depending on the underlying policies included; this creates opportunities to choose efficient solutions to our energy problems. Pricing policies deliver the greatest reductions in oil use or CO_2 emissions for a given cost, achieving 33 percent more carbon reductions than the study target, while also meeting the target oil reduction. Pricing instruments do well on costs because they provide incentives on all margins of behavior, including fuel substitution, energy efficiency, and conservation. They also spur industry and consumers to find the most cost-effective combination of these approaches and (although not illustrated in our modeling) can spur oil- and CO_2-saving R&D.

Several regulatory policies can complement Pure Pricing in ways that achieve greater reductions than pricing alone. For example, the Blended Portfolio combination of the Phased Oil Tax, CEPS–All, an LNG Trucks mandate (at half the penetration rate used in the Regulatory combination), and other energy efficiency policies achieves a 70 percent greater oil reduction than the study target and 62 percent more than the Pure Pricing mechanism. It also nearly meets the CO_2 target (98 percent), albeit at a higher cost.

The relative weight given by policymakers to reducing oil consumption versus CO_2 emissions, as well as the political feasibility of various policies, are key additional considerations in evaluating combinations of policies.

As for the individual policies, several other results from this study merit emphasis:

- **Several alternatives to C&T appear to be reasonably cost-effective, capable of achieving substantial reductions in emissions, or both.** In particular, the CEPS–All does reasonably well when compared to C&T.
- **Compared to policies targeting CO_2 reductions, fewer options exist to efficiently reduce oil use.** Further gains from tighter CAFE standards for light-duty vehicles appear

limited and to come at high cost, given the ramp-up that has already been adopted in recent years. Similarly, Feebates, which use a form of pricing incentives to improve fuel economy rather than the mandates found under Pavley CAFE, provide limited oil reductions relative to a broad-based Oil Tax.

- **Hybrid Subsidies alone show no progress in reducing oil.** Although they lead to greater market penetration of hybrids, they ease the burden on manufacturers of meeting CAFE standards with conventional gasoline-powered vehicles.
- **The cost-effectiveness of EE policies depends critically on how we interpret observed market behavior.** We find the welfare cost estimates to vary significantly with these assumptions, in some cases ranging from negative average costs (that is, savings in lifetime energy expenditures that outweigh up-front purchase costs) to positive and comparatively high average costs. Given the enormous importance of energy efficiency to overall energy use and the array of policy options for promoting energy efficiency in vehicles, buildings, appliances, and other equipment, we feel strongly that this issue needs additional research attention.

10.2 Key Findings on Individual and Combination Policies

Figure 10.1 summarizes the projected effectiveness of individual policies in reducing oil use in 2030 and their projected cost-effectiveness (welfare cost per barrel) averaged over the 2010–2030 period, using the Partial Market Failure case applied to policies significantly affecting energy efficient investments. Figure 10.2 shows similar information for domestic energy-related CO_2 reductions, with effectiveness measured in terms of cumulative CO_2 reductions from 2010 to 2030 and cost-effectiveness as welfare cost per ton. Both figures array the policies in order of their effectiveness, from the largest impact on the left to smallest on the right. (See the Key Metrics Table, Appendix B, for all of the numbers depicted in these figures.)

As shown in Figure 10.1, transportation policies generally deliver the greatest oil reductions, although carbon pricing policies also reduce oil consumption significantly (both directly, through higher oil prices, and indirectly through, for example, a reduction in the rail transportation of coal). The largest oil reductions come from our aggressive scenario mandating the penetration of heavy-duty trucks fueled by LNG into the U.S. fleet, which delivers a reduction of more than 2 mmbd in 2030.

The Phased Oil Tax/Feebate/Hybrid Vehicle Subsidy combination is nearly as effective. The Feebate gives a direct boost to efficiency in the light-duty vehicle market, whereas the Phased Oil Tax operates on all behavioral margins (including vehicle mileage and oil consumption outside of the automobile sector) to reduce oil consumption. In terms of average welfare cost per barrel, LNG Trucks again looks quite competitive, as do the Phased Oil Tax and the Gasoline Tax (in the latter policy, gasoline taxes are increased immediately rather than progressively over time).

Figure 10.2 shows that C&T or Carbon Tax policies are most effective in reducing domestic energy-related CO_2 emissions over the projection period. This is particularly true without offsets or in cases where we permitted the cap (set in terms of total GHGs) to be met only with domestic energy-related CO_2. Although these pricing policies do not have the lowest cost per ton reduced, their average cost would be lowest if the less expensive policies (e.g., nuclear loan guarantees) could be scaled to deliver identical reductions in CO_2. Indeed, some EE policies feature negative costs and cost-effectiveness, although with minor reductions in CO_2. Other power sector policies, such as the RPS and most of the CEPS variations, do well on cost-effectiveness grounds but, again, achieve comparatively few reductions in CO_2.

For policies affecting EE investments with very long lifetimes and where the ratio of investment cost to annual fuel savings is relatively low, the

Figure 10.1: Effectiveness (in 2030) and Cost-Effectiveness (2010–2030) in Reducing Oil Consumption

This figure combines effectiveness and cost-effectiveness of each policy. Bar height indicates effectiveness in reducing oil consumption; bar color indicates the cost/barrel reduced. Cost-effectiveness is calculated at the Partial Market Failure rate.

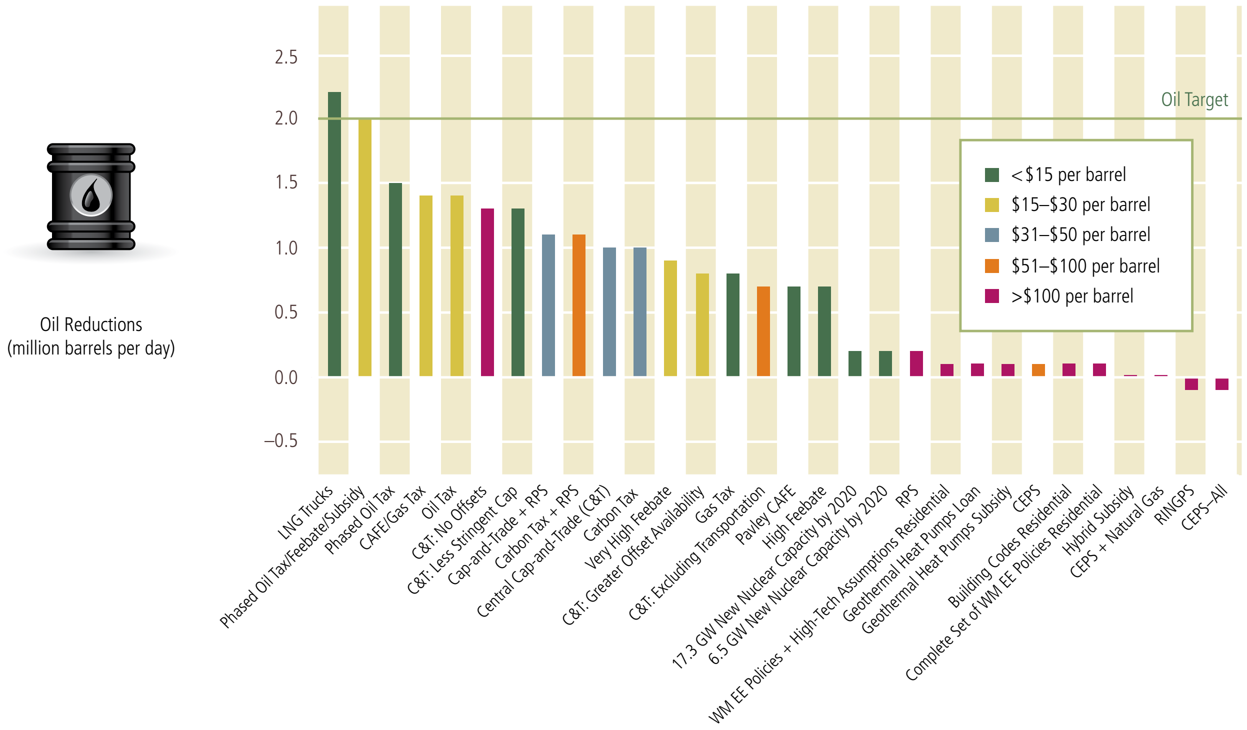
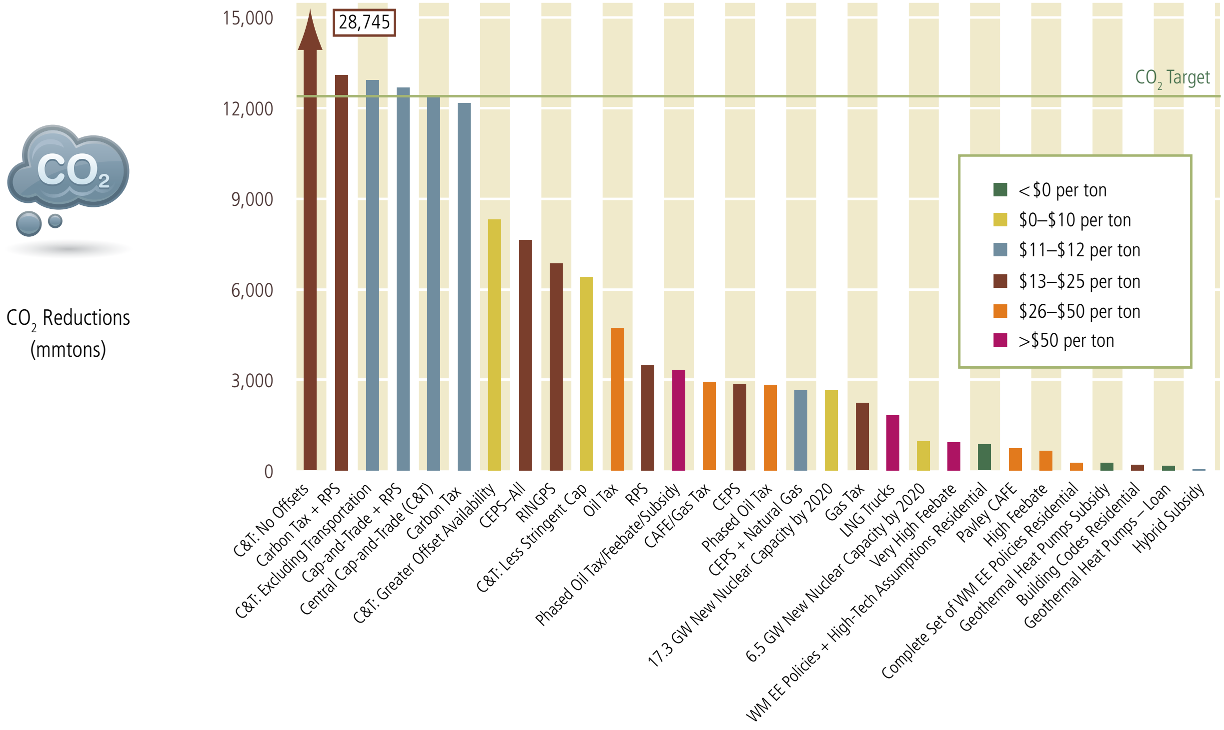


Figure 10.2: Effectiveness and Cost-Effectiveness in Reducing CO_2 Emissions, 2010–2030

This figure combines effectiveness and cost-effectiveness of each policy. Bar height indicates effectiveness in reducing CO_2 emissions; bar color indicates the cost/ton reduced. Cost-effectiveness is calculated at the Partial Market Failure rate.



Complete and No Market Failure cases lead to substantially lower and higher costs, respectively, than our Partial Market Failure case. The Building Codes policy is a good example: with Complete Market Failure, this policy has a cost-effectiveness of –\$15/ton CO_2, against our Partial Market Failure case of \$25/ton and our No Market Failure case of \$51/ton. In contrast, for LNG Trucks, costs are lower by only 10 percent and higher by only 12 percent in the Complete Market Failure and No Market Failure cases, respectively.

Pricing Policies

Pricing policies do well against our metrics. The Phased Oil Tax achieves a 1.5 mmbd reduction in oil consumption by 2030 at a welfare cost of \$13/barrel (Partial Market Failure rate), with total welfare costs of \$88 billion over the period. Our Central C&T program delivers CO_2 reductions that meet our CO_2 target at \$12/ton, at a total cost of \$142 billion.

Within the category of pricing policies, we offer several additional observations:

- *Comparing gasoline taxes vs. oil taxes.* Taxing only gasoline, rather than all oil products, overlooks more than half of the oil market, which also includes uses of oil by industry, trucking, aviation, and other sectors. We find that the Gasoline Tax option reduces oil use by 0.8 mmbd in 2030, whereas Oil Taxes of the same scale in 2030 reduce oil use by 1.4 mmbd. Taxing products other than gasoline is usually not a part of the policy conversation; our results suggest that it should be.
- *The importance of offsets in C&T regimes.* Allowing offsets in a C&T system substantially lowers costs to domestic emitters. We have quantified this cost reduction: \$559 billion (in present value terms over the 2010–2030 time period) with no offsets permitted, compared to only \$142 billion with one billion offsets permitted, where both policies achieve the same total level of reductions in GHG emissions. Indeed, with two billion offsets, twice as many as in the Central C&T case, costs fall to about half of this amount. Given these differences in cost, our estimates (and those of other studies) illustrate the critical importance of handling the issues—namely, measurement and verifiability concerns—in the international and domestic offset markets.
- *Options for revenue neutrality.* It is politically challenging to levy new taxes, particularly on commodities that are as fundamental to the American economy as oil. To make such a tax more politically and socially palatable, tax revenues might be returned, or recycled, back to the public. Some economists recommend using new revenues to offset existing taxes, like income taxes, that distort labor supply and capital investment decisions. Another option would be to return revenues in the form of rebate checks (referred to as *lump-sum recycling*). Several of the scenarios modeled here include this lump-sum recycling option.

How the revenues from all the tax policies are used has very important implications for the overall costs and feasibility of these policies, as well as the burden they impose on different household income groups. However, as noted, NEMS is limited in its ability to analyze the cost and distributional implications of recycling revenues; accordingly, Chapter 9 provides some broad quantitative sense of the significant trade-offs involved in alternative revenue recycling options.

Alternatives to Pricing Policies

Federal policymakers seem reluctant to adopt policies that overtly raise the price of energy. Although doing so is an effective means of promoting conservation—and conservation plays an important role in any cost-effective approach to reducing oil use or GHG emissions—an evaluation of alternatives to pricing is a necessary and practical component of our study.

In terms of oil use, the Pavley CAFE and High Feebate policies are about equally effective and cost-effective. Feebates however, provide greater ongoing incentives than Pavley CAFE for manufacturers to improve the efficiency of individual vehicles, as each vehicle that exceeds the Feebate's pivot point—the level of fuel economy at which vehicles switch between paying a fee and receiving a rebate—earns money. This is in contrast to Pavley CAFE, where fuel economy can be sacrificed on some vehicles as long as the fleetwide standard is met. For this reason, Feebates are also more compatible with other policies, such as incentives for hybrids, whereas fuel savings from selling more hybrids tend to be offset under Pavley CAFE as manufacturers can lower the fuel economy of their gasoline vehicles and still be in compliance.

Our welfare cost calculations indicate that current rules for implementing CAFE standards are sufficiently flexible that they no longer have a cost disadvantage relative to Feebates—both policies, for example, encourage the equalization of marginal compliance costs across different manufacturers. Here again, whether market failures are associated with fuel economy investments makes a significant difference to the costs of these policies; without market failures, the Pavley CAFE policy costs $33/barrel, or about double the cost of the Phased Oil or Gasoline Tax. However, with a Partial Market Failure, Pavley CAFE becomes competitive with pricing policies.

In terms of carbon, implementing a broad-based clean energy portfolio standard (CEPS–All) is a promising alternative to a C&T program or Carbon Tax, assuming that renewable energy credit trading provisions are in place. Although the CEPS–All reduction of 7,632 mmtons is only 62 percent of the CO_2 emissions reductions of the Central C&T—because CEPS–All covers only electricity generation and does little to reduce electricity demand—it is a relatively low-cost policy at $15/ton of CO_2 reduced, versus $12/ton for our Central C&T policy. Notably, in a side case testing CEPS–All against a C&T policy scaled down to achieve equal CO_2 emissions reductions, we find that CEPS–All costs are 68 percent higher than the scaled C&T scenario.

The other variants of a portfolio standard policy—the CEPS, CEPS–NG, RINGPS, and RPS—are not as promising as the CEPS–All, on either effectiveness grounds, cost-effectiveness grounds, or both. For example, the CEPS–NG has a lower average cost per ton than the CEPS–All, but it achieves only 35 percent of the reductions obtained under the CEPS–All (or 21 percent of the reductions obtained under the Central C&T policy).

What is the potential role for nuclear power? We know that nuclear power has advantages over fossil fuels in terms of carbon emissions, but no one knows yet whether a streamlined approval system, new technologies, and investor confidence will combine to win rapid approvals and relatively quick operational status for the many planned plants. Our research findings suggest that using loan guarantees to spur new nuclear plant construction appears to be a very low-cost way to reduce carbon emissions. A loan guarantee that reduces the required ROE to potential investors to 14 percent has an average cost of just 43¢/ton of CO_2 reduced, whereas a policy that reduces the ROE to 11 percent has an average cost of $1.59/ton.[69] Effectiveness is low: the 14 percent ROE policy leads to a cumulative CO_2 reduction of just 958 mmtons, and the 11 percent ROE policy leads to a cumulative CO_2 reduction of 2,643 mmtons. In addition, more research is needed on the important issues associated with risks and waste storage.

The EE policies we analyze center mainly on residential Building Codes, although we also evaluate an option that includes some additional minor lighting and appliance codes. We draw two main conclusions about these policies. First, the Building Codes option is not very cost-effective at a cost per ton of $25 (under the Partial Market Failure case); these high costs are due primarily to the fact that the codes apply to *new* buildings and thus take a while to have an impact. However, the model also predicts that the costs of meeting the code, through changes in building shells and appliances and equipment, are relatively high. On the other hand, under alternative high-tech model assumptions or the Complete Market Failure case, the costs of the EE policies are greatly reduced (or even negative). This highlights the need for an analysis of the technology investments needed to bring about these high-tech outcomes.

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[69] These costs do not take into account liabilities in case of default.

We also explore the impacts of a small-scale EE policy: incentives to purchase GHPs, considered a promising technology to reduce the amount of energy used to heat and cool indoor spaces. We evaluate a straightforward GHP Subsidy to buy these systems for residential use, as well as a policy that would provide Zero-Interest Loans with a seven-year payback period to buy the systems. Although the *amortization* approach of the Loan policy leads to less penetration of the technology than the Subsidy does, the welfare cost of the Loan is between $6 and $17 per ton lower, depending on the assumed rate of market failure. This type of policy is similar to ideas embodied in the federal government's Property-Assessed Clean Energy program (U.S. DOE n.d. b), in which households pay back up-front investments in energy efficiency over time in their property tax bills. Our results suggest that this approach should be explored for other energy efficiency investments.

Less Promising Alternative Policies and Policy Combinations

This study aims not only to identify the most promising policies and policy combinations, but also to identify policies that are high cost, relatively ineffective, or even redundant. Illustrations of these less promising approaches follow.

Policies to stimulate the purchase of HEVs and PHEVs are not very effective. In the presence of binding CAFE standards, these policies result in lower efficiency gains from gasoline vehicles, such that overall fuel economy and oil use stay roughly the same. Moreover, the NEMS–RFF baseline shows a significant penetration of hybrid vehicles in the future, even in the absence of policy incentives beyond the CAFE requirements already in place.

The combination of an RPS and a C&T system, which is part of some proposed legislation, is not particularly effective or cost-effective. In the presence of a cap on carbon, an RPS is redundant and increases costs.

It is worth noting that some technologies not in widespread use, including PHEVs, many kinds of renewable energy, or GHPs, may benefit from greater demand (to spur technological progress) or the cost reductions that come from both experience and economies of scale. Although this is a possible rationale for implementing policies that favor these technologies, this choice may come with substantial costs. Policymakers need to judge whether the benefits are worth the costs.

Crosscutting Combinations

As noted, this study illustrates that no single policy will simultaneously and significantly reduce both oil consumption *and* CO_2 emissions. The crosscutting policies we examined, however, were explicitly designed to make progress on both metrics simultaneously. We modeled four crosscutting combinations, including Pure Pricing (combining oil and carbon pricing policies), Pure Pricing + EE (adding residential building efficiency and automobile fuel economy policies to the aforementioned pricing policies), Regulatory Alternatives to Pricing (combining a host of non-pricing options), and our Blended Portfolio (bringing together both pricing and regulatory options).

The results of our crosscutting policy analysis echo lessons learned about individual policies: pricing policies achieve results at least cost, and while energy efficiency policies may lead to some additional reductions, they often do so at a relatively high cost. The Regulatory Alternatives package achieved substantial oil reductions due to the inclusion of the LNG Trucks policy; with the LNG Trucks policy removed for comparability, however, Regulatory Alternatives is the least effective of all the combinations. Finally, combining regulatory and pricing options may lead to significant reductions—particularly illustrated in the combination of a Phased Oil Tax and an LNG Trucks mandate in our Blended Portfolio—but these combinations will again come at a higher overall welfare cost.

Chapter 7 presents an important caveat in envisioning other crosscutting policies beyond those examined here: although it may be tempting to simply sum the oil and CO_2 reductions and the costs to obtain an estimate for a combination, several issues arise. Both because of the starting point issue and because of price interactions, combinations are often more costly and (modestly) less effective than the sum of their parts. The NEMS–RFF model accounts for these market interactions when assessing the impacts of the policy combinations, and we also account for them in our welfare cost calculations.

10.3. A Cautionary Note about Uncertainty

In most cases, we present forecasts of energy use and CO_2 emissions generated by NEMS–RFF for our various policy scenarios as single point estimates, but a great deal of uncertainty surrounds these numbers. Explicit and implicit model parameters—such as elasticities of demand, elasticities of substitution across fuels, underlying resource estimates, appliance and equipment costs, and a host of other factors—are all uncertain to varying degrees, as are future oil prices and technological advances across fuels and sectors. The NEMS model, however, is not set up to incorporate these uncertainties or to provide a distribution of outcomes; instead, the model's management team at EIA chooses best-estimate parameters, and the model produces outputs that use those parameters.

We were able to capture some aspects of uncertainty, however. We identified factors that we felt had the greatest relevance for our results and ran the model under alternative assumptions. These assumptions include an alternative low oil price scenario, natural gas resource estimates that incorporate much larger shale gas resources and the possibility of associated lower extraction costs, lower HEV battery costs, high-tech assumptions for our EE analysis, and alternative discount rates.

These sensitivity analyses reveal some interesting findings. Low oil prices will make it much more difficult for any policy to reduce oil consumption, especially to the level of the relatively aggressive target laid out in this study. We find that greater natural gas resources affect a variety of policies but not always in straightforward ways.[70] Assumptions about rapid improvements in technology and a lowering of battery costs alter the cost-effectiveness of the EE and Hybrid Subsidy policies, respectively, and highlight the benefits that could be achieved if R&D were to bring about those technological advances.

Although we acknowledge the inherent uncertainty in our findings, we feel confident about our policy comparisons—which are the heart of our study—because they are based on the same assumptions and modeling algorithms; in other words, they are apples-to-apples comparisons. Although changing oil prices or technology costs may lead to more or less progress toward our effectiveness targets, they are unlikely to change the order in which policies may be ranked. Thus, users of these data may opt to put more faith in the relative comparisons of costs and effectiveness across policies than in the absolute levels of these metrics.

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[70] For example, although natural gas has considerably lower carbon content than coal, increasing shale gas supplies can actually lead to a small increase in CO_2 emissions compared to the Reference case. This is because these greater resources reduce the price of natural gas, increasing overall energy consumption and reducing the use of nuclear and renewables in electric power generation (Brown et al. 2009).

Appendix A: Policies Modeled

Table A1: Policies Modeled

Reference Case	The reference case is based on *AEO 2009* + stimulus and also includes advancing of fuel economy standards mandating that new light-duty vehicles achieve 35.5 mpg from 2020 to 2016.
Transportation/Oil Policies	
Gasoline Tax	Raises the gasoline tax by $1.27 per gallon in 2010 and increases it in real terms at an annual rate of 1.5 percent a year, adding $1.73 to the cost of a gallon by 2030. The revenues from this tax, and taxes or auctioned allowances described below, are returned in lump-sum payments to individuals (they are therefore considered to be revenue neutral). We discuss the implications of alternative revenue recycling possibilities in the main report.
Immediate Oil Tax	Applies the above level of gasoline tax to all refined oil products used in the United States, including imported petroleum products (exported products are exempt). The tax is based on British thermal unit (Btu) equivalence. This tax is revenue neutral.
Phased Oil Tax	A variant of the immediate oil tax, which eventually reaches $1.73 per gallon of gasoline equivalent on all oil products by 2030. This tax begins at 8¢ per gallon in 2010 and rises by approximately 8¢ per gallon each year out to 2030. This tax is revenue neutral.
Pavley CAFE	Features an increase of 3.7 percent a year in fuel economy standards for both cars and light trucks for 2017 through 2020. From 2021 to 2030, the policy further tightens standards by 2.5 percent a year, reaching an average standard of 52.2 mpg for light-duty vehicles in 2030.
High Feebate[1]	Fee assessed on vehicles that do worse than the Pavley CAFE standard in each year and rebate to those vehicles that do better. Basic rate is $2,000 per 0.01 gallon/mile, phased in progressively between 2017 and 2021 and thereafter rising (in real terms) at 2.5 percent a year, so that it reaches $2,969 per 0.01 gallon/mile in 2030.

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[1] In this study, we assumed that feebates were imposed at the manufacturer level. Alternatively, they could be imposed at the consumer level, though either would be equivalent within the NEMS–RFF modeling framework (as would some combination of consumer and manufacturer feebates, for which there are advocates).

Table A1: Policies Modeled (continued)

Very High Feebate	Sets the feebate rates in each year exactly twice as large as in the High Feebate case.
Hybrid Subsidy	Establishes a vehicle purchase subsidy of $3,000 for each 0.01 gallon/mile saved between the hybrid electric or plug-in hybrid electric vehicle and its gasoline-equivalent vehicle, with the subsidy constant in real terms from 2010 to 2030.
Pavley CAFE/Gasoline Tax	Combines the Pavley CAFE policy with the Gasoline Tax.
Phased Oil Tax/Feebate/Hybrid Subsidy	Combines the Phased Oil Tax, High Feebate, and Hybrid Subsidy.
LNG Trucks	Assumes that 10 percent of new Class 7 and 8 heavy-duty trucks bought in 2011 run on natural gas, rising to 20 percent of new trucks bought in 2012, up to 100 percent of new trucks bought in 2020 and beyond. This case is modified in one of the policy combinations to rise at half the penetration rate (rising by 5 percent per year to reach 100 percent by 2030 rather than 2020). This scenario can be viewed as a policy mandate or subsidy.
CO_2 Pricing Policies	
Central Cap-and-Trade (C&T)	Reduces all GHGs by 17 percent below 2005 levels in 2020 and 40 percent below this base by 2030; covers all energy-related CO_2 and all industrial and agricultural sources of non-CO_2 emissions; covers all major sectors; allows 500 million tons each for domestic and international offsets per year; allows banking and borrowing of allowances with a zero bank balance in 2030; and auctions allowances, returning the revenue to households in lump-sum rebate checks.
C&T: Excluding Transportation	Same requirements for total cumulative reductions under the cap, but excludes the transportation sector from the policy.
C&T: Alternative Cases for Offset Availability	One case allows 1 billion tons each of domestic and international offsets per year, and another does not allow the use of any offsets in meeting the overall cap.
C&T: Less Stringent Cap	Required cumulative reductions for all GHGs are 33 percent lower than in the central case.
Carbon Tax	A tax per ton of CO_2 emissions that mimics the time path of allowance prices under the central C&T policy.
Energy Efficiency (EE) Policies	
New Construction Building Codes	Calls for a 30 percent reduction in energy use by new buildings upon enactment of the law, a 50 percent reduction from residential buildings by 2014 and from commercial buildings by 2015, and a 5 percent reduction at 3-year intervals thereafter up until 2029. This policy is consistent with the Building Code provisions in the Waxman–Markey (WM) bill, H.R. 2454.

Table A1: Policies Modeled (continued)

Complete Set of WM Energy Efficiency (EE) Policies	Adds retrofit requirements; standards for outdoor lighting, portable light fixtures, and incandescent reflector lamps; and new standards and testing procedures for appliances to Building Code provisions similar to those represented by the Energy Information Administration's analysis of the WM bill.
Complete Set of WM EE Policies + "High Tech" Assumptions	A modification of the set of WM energy efficiency policies, which assumes accelerated technical progress (beyond that already found in the reference case) across the board. This manifests in higher efficiencies for most energy-using equipment.
Residential Geothermal Heat Pumps—Subsidy	Models a $4,000 direct consumer subsidy for the purchase and installation of a geothermal heat pump (GHP) system in the residential sector.
Residential Geothermal Heat Pumps—Loan	Models a zero-interest $4,000 loan for the purchase and installation of a GHP in the residential sector, paid back over a seven-year period.
Nuclear Power: Loan Guarantee	
6.5 Gigawatt (GW) New Nuclear Capacity by 2020	Reduces the return on equity assumed in NEMS–RFF from 17 percent (in the reference case) to 14 percent, which leads to an expansion of 6.5 GW of nuclear power by 2020.
17.3 GW New Nuclear Capacity by 2020	Reduces the return on equity assumed in NEMS–RFF from 17 percent (in the reference case) to 11 percent, which expands nuclear power by 17.3 GW by 2020.
Renewable Energy Technologies	
Production Tax Credit	Models an extension of the current production and investment tax credits for renewables (a 2.1¢ tax credit for wind, geothermal, and closed-loop biomass, and a 1.1¢tax credit for landfill gas, other forms of biomass, and hydrokinetic energy).
Renewable Portfolio Standard (RPS)	Calls for 25 percent of total generation (excluding generation from hydro and municipal solid waste [MSW] plants) to come from non-hydro renewables nationwide by 2025, with interim targets leading up to this ultimate goal. Renewable Energy Credits (RECs) are used as a way to achieve these targets.
Clean Energy Portfolio Standard (CEPS)	Broadens the portfolio standard to include other "clean" fuels besides renewables, including incremental generation from nuclear power plants and natural gas and coal plants that have carbon capture and storage (CCS) technology.
CEPS + Natural Gas (CEPS–NG)	Broadens the CEPS to include new natural gas capacity (without CCS) in the portfolio. New natural gas capacity receives a fraction of a clean energy credit, dependent on the CO_2 emissions from the technology.

Table A1: Policies Modeled (continued)

RINGPS	Combines a 25 percent RPS with a 20 percent Incremental Natural Gas Portfolio Standard, meaning that 25 percent of total electricity generation (excluding generation from hydro and municipal solid waste plants) must come from renewables and 20 percent must come from new natural gas plants.
CEPS–All	Seeks to replicate the share of generation produced by technologies other than coal (with the exception of coal with CCS) obtained under the Central Cap-and-Trade policy. The scope of CEPS–All is larger than CEPS and includes generation from new and existing noncoal generators. Unlike the CEPS and CEPS–NG policies, there is no cap on the price of clean energy credits, and the clean generation share target is applied to all generation, including hydro and MSW.
Cap-and-Trade + RPS	Combines the 25 percent RPS with the Central Cap-and-Trade policy.
Carbon Tax + RPS	Combines the 25 percent RPS with the Carbon Tax policy.
Crosscutting Policy Combinations	
Pure Pricing	Combines the Phased Oil Tax with the Carbon Tax.
Pure Pricing + EE Measures	Combines the Phased Oil Tax and Carbon Tax with the Building Codes and the Pavley CAFE policy.
Regulatory Alternatives	Combines the LNG Trucks policy, the Building Codes, the Pavley CAFE policy, and CEPS-All.
Blended Portfolio	Combines the Phased Oil Tax, High Feebate, Hybrid Subsidy, Building Codes, GHP Subsidy, and CEPS–All with a modified LNG Trucks policy at half the original penetration rate (5 percent per year rather than 10 percent).

Appendix B: Key Metrics Table

(The table is shown on the following pages.)

Table B1: Key Metrics, By Policy

	Progress on Oil Target		Aggregate Reductions	PDV Welfare Cost: No Market Failure	PDV Welfare Cost: Partial Market Failure	PDV Welfare Cost: Complete Market Failure	Cost-Effectiveness, Oil: No Market Failure	Cost-Effectiveness, Oil: Partial Market Failure	Cost-Effectiveness, Oil: Complete Market Failure	Cost-Effectiveness, CO_2: No Market Failure	Cost-Effectiveness, CO_2: Partial Market Failure	Cost-Effectiveness, CO_2: Complete Market Failure
	Reduction from 2007 (mmbd)		CO2 emissions (mmtons)	(billion 2007$)	(billion 2007$)	(billion 2007$)	(2007$/ barrel)	(2007$/ barrel)	(2007$/ barrel)	(2007$/ton CO_2)	(2007$/ton CO_2)	(2007$/ton CO_2)
	In 2020	In 2030	to 2030	to 2030	to 2030	to 2030	a.	a.	a.	a.	a.	a.
Reference Case	2.1	2.0	–	–			–			–	–	
	Incremental reductions to Reference case											
Policies to Reduce Oil Consumption												
TRANSPORTATION POLICIES												
Phased Oil Tax	0.9	1.5	2,828	112.0	88.0	64.0	17	13	10	37	29	21
Oil Tax	1.6	1.4	4,715	263.4	200.5	137.6	24	18	13	53	40	28
Gasoline Tax	0.8	0.8	2,224	91.0	53.3	15.6	17	10	3	38	22	6
Pavley CAFE	0.1	0.7	722	120.9	44.6	–31.7	33	12	–9	85	31	–22
High Feebate	0.1	0.7	637	121.3	41.9	–37.5	35	12	–11	100	35	–31
Very High Feebate	0.2	0.9	919	233.3	116.8	0.3	47	23	< 1	134	67	< 1
Hybrid Subsidy	0.0	0.0	0	4.3	–8.2	–20.7	b.	b.	b.	b.	b.	b.
CAFE Gasoline Tax	0.8	1.4	2,919	210.5	134.2	57.9	26	17	7	48	31	13
Phased Oil Tax/Feebate/ Hybrid Subsidy	1.0	2.0	3,319	360.0	250.0	140.0	34	24	13	78	54	30
NATURAL GAS VEHICLES												
LNG Trucks	1.1	2.2	1,821	209.4	186.4	168.8	16	14	13	85	76	69
Policies to Reduce Greenhouse Gas Emissions												
CARBON PRICING POLICIES												
Central Cap-and-Trade (C&T)	0.3	1.0	12,366	142.3			45			12		
C&T: Excluding Transportation	0.2	0.7	12,948	153.3			71			12		
C&T: Greater Offset Availability	0.2	0.8	8,320	68.1			28			8		
Carbon Tax	0.2	1.0	12,181	141.6			47			12		
C&T: No Offsets	0.6	1.3	28,745	559.4			119			19		
C&T: Less Stringent Cap	0.3	1.3	6,404	45.8			14			7		
ENERGY EFFICIENCY POLICIES												
Building Codes — Residential	0.0	0.1	179	31.7	15.7	–9.2	c.	c.	c.	51	25	–15
Complete Set of WM EE Policies — Residential	0.0	0.1	249	46.9	26.6	–5.2	c.	c.	c.	60	34	–7

WM EE Policies + High Tech Assumptions — Residential	0.0	0.1	847	45.4	–42.2	–178.4	c.	c.	c.	18	–17	–72
Geothermal Heat Pumps — Loan	0.0	0.1	138	3.0	–11.7	–38.5	c.	c.	c.	9	–36	–117
Geothermal Heat Pumps — Subsidy	0.1	0.1	245	20.2	–5.1	–51.4	c.	c.	c.	36	–9	–92
NUCLEAR POWER: LOAN GUARANTEE												
6.5 GW New Nuclear Capacity by 2020 (14% ROE)	0.0	0.2	958	0.7			1			< 1		
17.3 GW New Nuclear Capacity by 2030 (11% ROE)	0.0	0.2	2,643	4.5			6			2		
RENEWABLES POLICIES												
RPS	0.0	0.2	3,489	47.5			106			14		
CEPS	0.0	0.1	2,851	40.2			100			14		
CEPS–NG	0.0	0.0	2,652	29.8			377			11		
RINGPS	0.0	–0.1	6,860	162.1			c.			24		
CEPS–All	0.1	–0.1	7,632	116.2			4,385			15		
Cap-and-Trade + RPS	0.2	1.1	12,697	151.0			46			12		
Carbon Tax + RPS	0.3	1.1	13,103	170.0			52			13		
Policy Combinations												
Pure Pricing	1.0	2.1	15,070	324.4	253.4	182.4	d.	d.	d.	d.	d.	d.
Pure Pricing + EE Measures	1.1	2.5	15,544	433.0	341.0	248.0	d.	d.	d.	d.	d.	d.
Regulatory Alternatives	1.2	2.7	10,077	492.8	388.6	277.6	d.	d.	d.	d.	d.	d.
Blended Portfolio of Policies	1.4	3.4	12,102	594.3	401.4	195.4	d.	d.	d.	d.	d.	d.
Regulatory Alternatives — no LNG Trucks	0.1	0.5	8,256	273.9	183.0	83.9	d.	d.	d.	d.	d.	d.
Blended Portfolio of Policies — no LNG Trucks	0.8	2.3	11,192	526.7	376.3	196.6	d.	d.	d.	d.	d.	d.

a. Oil and emissions reductions are counted over the investment lifetime or to 2050, whichever comes sooner.
b. Cost-effectiveness for the hybrid subsidy is not calculated, as reductions in both oil and CO_2 are essentially zero.
c. Cost per barrel for policies in this category are not calculated because of the small cumulative reductions in oil use.
d. Cost-effectiveness is not calculated for crosscutting combinations, as costs cannot be assigned to individual effectiveness measures.

Appendix C: Procedures for Measuring the Welfare Costs of Policies

We measure the welfare costs of policies using various applications and extensions of widely accepted formulas in public finance, first derived by Harberger (1964).[2] The beauty of these formulas is that they can be applied to any model, regardless of the model's complexity in terms of sectoral disaggregation. To apply the formulas, all we need to know (as read from the model output) is the magnitude of important sources of preexisting distortions in the economy (e.g., tax rates), any quantity changes in markets affected by these preexisting distortions, and information on new sources of distortions created by policies in directly affected markets.[3]

Nonetheless, some caveats apply to our welfare cost measurement. The formulas provide welfare measures that are reasonable but approximate, rather than exact. For example, the formulas are based on the assumption that demand and supply curves in markets affected by new policies are linear over the range of behavioral responses; this, of course, is an approximation (and a particularly good one when changes are small). In addition, some sources of market distortion in a complex model like NEMS–RFF are too difficult to capture in simple formulas. For example, prices in NEMS–RFF are sometimes above and sometimes below marginal costs in regional electricity markets; in principle, this has implications for the welfare effects of regional changes in electricity demand. We assume that such welfare changes wash out in the aggregate, as we lack the detailed data necessary to estimate marginal production costs in regional markets. More generally, we make a number of additional simplifications (described below) to keep our task manageable, given the large number of policies evaluated as part of the project.

Here we discuss our procedures for estimating the welfare costs of general, broad-based pricing policies.[4] Next, we discuss specific issues in cost measurement of oil and carbon policies, and then we discuss the policy combinations. Finally, we comment briefly on some additional components of welfare effects that are not included as part of the main study but are discussed in Chapters 8 and 9. These relate to policy impacts on preexisting tax distortions in factor markets, ancillary benefits (e.g., local pollution effects), and clean technology R&D.

General Pricing Policies

Oil Tax. Consider first the welfare cost, in a given year, of a tax on all oil products where, for the moment, we leave aside the implications of preexisting fuel taxes and market failures.

Figure C.1 depicts the combined demand for, and supply of, all oil products in the economy. The height of the demand curve at any given point reflects the benefit to oil users from an extra barrel of oil consumption, as reflected in the price, or their willingness to pay for that barrel. The

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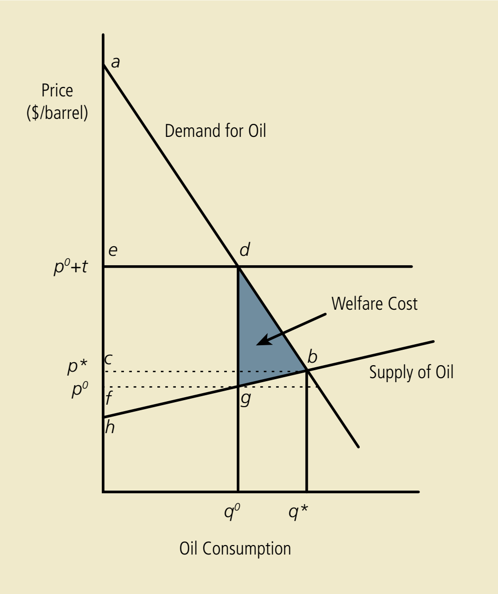
[2] See Just et al. (2004) for a more recent discussion of welfare cost measurement.

[3] Here we say that policies distort markets because we are not considering the broader social benefits (e.g., the value of reduced CO_2 emissions) that might warrant such policies. When these broader benefits are taken into account, the policy may improve economic efficiency overall (i.e., generate benefits in excess of economic costs).

[4] Note that we do not net out the environmental and security benefits from reduced oil consumption and CO_2 emissions.

Figure C.1



demand is downward sloping, as lower prices encourage additional consumption of oil products with progressively lower value to oil users. The height of the supply curve at any given point reflects the cost of producing an extra barrel of oil products—the price of the crude oil, refinery and transportation costs, and so on. As drawn, the supply curve has a slight upward slope representing, for example, the rising cost of expanding refinery capacity in areas with high land value, or the increase in the world price of oil as U.S. consumption expands.[5] In the absence of policy intervention, the free market would achieve the economically efficient level of oil consumption, denoted by q^*. This is the point at which the benefit to oil users from the last barrel consumed equals the cost of supplying the last barrel.

Now consider the imposition of a specific tax of t per barrel imposed on all products that causes oil consumption to fall to q^0, the price to oil users to rise from p^* to $p^* + t$, and the price received by oil producers to fall from p^* to p^0 in Figure C.1. The welfare cost of the policy can be interpreted in a couple of ways.

First, the welfare cost can be viewed as the reduction in benefits to oil consumers less the savings in costs to oil producers. The reduction in benefits to oil users is the area under the demand curve between q^* and q^0, whereas the savings in production costs is the area under the supply curve between q^* and q^0. Therefore, the welfare cost is indicated by the shaded triangle (*bdg*) in Figure C.1.

Second, the welfare cost can be interpreted as the net loss of economic *surplus* to consumers, producers, and the government. Consumer surplus measures the benefits to oil users—the area under the demand curve—net of what they pay for oil products. Consumer surplus at the initial price is given by area *abc* in Figure C.1, and falls to area *ade* following the price increase, implying a surplus loss given by the trapezoid *edbc*. Producer surplus (a loose measure of profits) reflects the revenue from oil sales to firms (net of any tax liabilities) less production costs or the area under the supply curve. At the initial price, producer surplus is area *cbh* and falls to area *fgh* as the tax lowers the price received by producers, implying a surplus loss given by the trapezoid *cbgf*. The government obtains tax revenue equal to tq^0. Netting the gain to the government out from the loss in surplus to consumers and producers again leaves an overall welfare cost given by the shaded triangle.

Third, Figure C.2 provides yet another way of summarizing the welfare cost of the Oil Tax. Here the higher upward-sloping curve is the *marginal* (welfare) cost from reducing oil under the tax. The area under this curve, between the origin and the reduction in oil use, $q^* – q^0$, corresponds to the total welfare cost of a given oil tax of rate t—that is, the shaded triangle in Figure C.1. The height of the marginal cost curve in Figure C.2 is the welfare cost of reducing oil use by an extra barrel—the difference between the demand and

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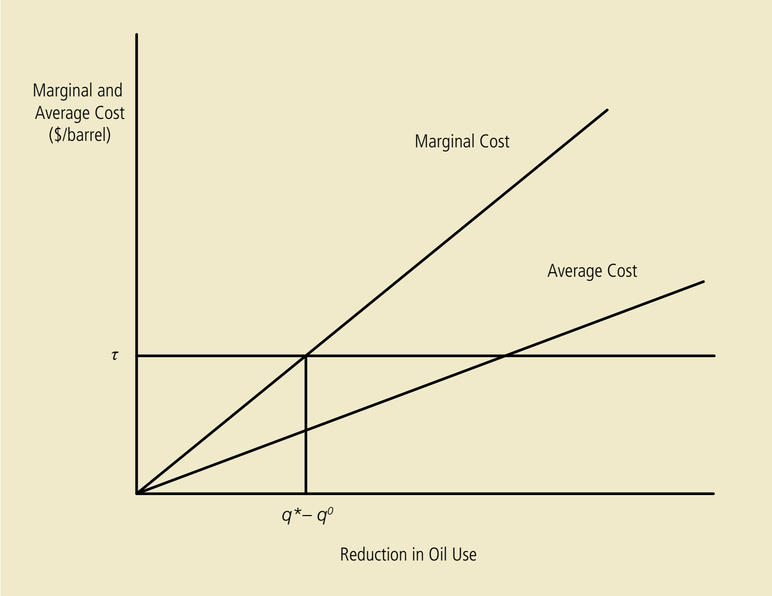
[5] As discussed in Small (2010), our welfare costs for oil taxes do not account for a possible transfer of wealth from oil-exporting countries to the United States as reduced domestic consumption puts downward pressure on world oil prices. Besides being difficult to measure (given the enormous range of variables affecting world oil markets) this potential income transfer is typically counted as a possible broader benefit from reduced oil consumption (rather than debited from the cost side).

Figure C.2



supply curve in Figure C.1, or the tax *wedge*. The marginal cost curve comes out of the origin given that, with no tax, the benefit to oil users from the last barrel exactly offsets the cost of producing it. And marginal costs increase with the amount of oil reduction (which increases as *t* increases), as oil uses with progressively higher values are given up.

Also shown in Figure C.2 is the *average* (welfare) cost of the Oil Tax, given by the total cost divided by the oil reduction. This is less than the marginal cost because it reflects the average of the incremental costs over all barrels of oil reduction, rather than just the cost of the last barrel reduced. Importantly, the average cost rises with the scale of the policy (i.e., the amount of oil reduced).

Our procedure for estimating the welfare costs of the Oil Tax policies involves, in part, estimating the welfare cost triangles in each year of the study period, given by one-half times the oil reduction in that year times the tax rate.[6] We discount these annual costs back to the start of the study period using the social rate (5 percent), and then aggregate them to obtain our measure of the PDV cost. As discussed below, however, we also take into account some additional components of the welfare cost of the Oil Tax.

Carbon Policies. For the C&T (with full allowance auctions) and Carbon Tax policies, we also measure welfare costs in a given year by an analogous formula: one-half times the reduction in energy-related CO_2 emissions times the CO_2 price. We then discount annual costs to 2010 at the social rate and aggregate them. The rationale for this formula is analogous to that for the Oil Tax. Figures C.3 and C.4 provide more insight on underlying components of welfare costs for CO_2 pricing policies.

Consider Figure C.3, which depicts the welfare costs of the policy in the economywide electricity market. Here the demand curve is shown as downward sloping and, for simplicity, the supply curve is shown as flat. (The latter assumption

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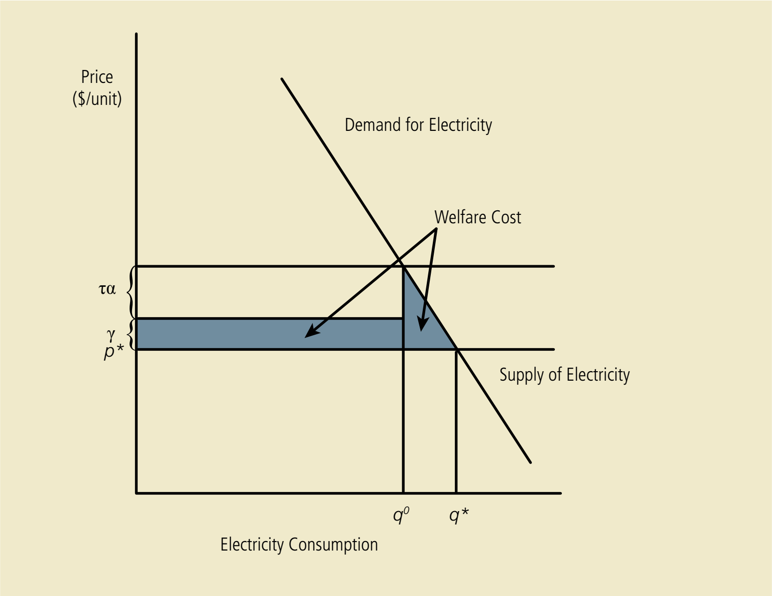
[6] Again, this cost measure assumes that the oil demand and supply curves are linear over the range of oil reductions. This approximation eliminates the need for collecting and analyzing large amounts of information from NEMS–RFF, which does not function with explicit demand and supply curves for aggregate oil use.

Figure C.3



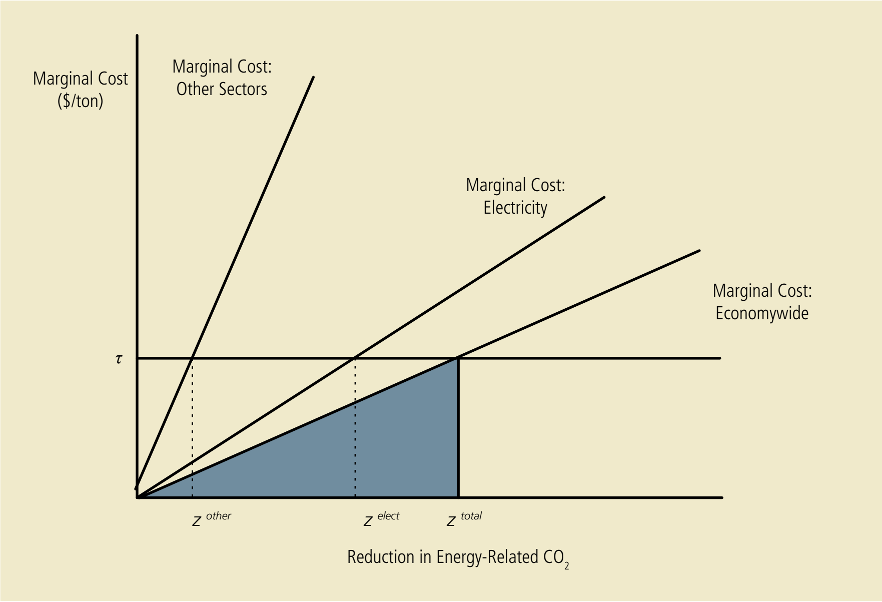
implies, for example, that increasing electricity output by 10 percent would increase total electricity generation costs by 10 percent.) Also, for now, suppose that power generators price competitively so that, in the absence of policy intervention, the electricity price would be p^* where demand equals supply. If a price is now placed on CO_2 emissions, the electricity price will increase by $\tau\alpha + \gamma$, and electricity consumption will fall from q^* to q^0 in Figure C.3. Here α is CO_2 emissions per unit of electricity generation, so $\tau\alpha$ is payments for CO_2 allowances, or CO_2 taxes, per unit of power generation. γ is the increase in resource costs per unit of power generation due to the switching away from high-carbon, but low-cost, fuels (coal) toward lower- or zero-carbon, but higher-cost, fuels like renewables, natural gas, and nuclear.

In this simplified setting, the welfare cost of the CO_2 pricing policy has two components. The first component is the increase in resource costs for generating electricity, indicated by the shaded rectangle, with height equal to γ times the new level of electricity production. Note that the allowances, or carbon tax payments, are not part of the welfare cost—instead they are a transfer payment from electricity consumers to the government (or to entities granted free allowances). The second part of the welfare cost, analogous to that in Figure C.1, reflects the loss of benefits to electricity users from the reduction in consumption (a trapezoid under the demand curve), less the resulting savings in supply costs (a rectangle under the supply curve).

In Figure C.4, the middle curve represents the marginal cost curve for CO_2 reductions in the power sector. For the given CO_2 price of τ, the reduction in emissions from electricity, denoted z^{elect}, reflects some combination of reduced electricity demand and reductions in emissions per unit of electricity. The welfare cost of the policy in the power sector, the area under this marginal cost curve between the origin and z^{elect}, is the total welfare cost of the policy in a given year, reflecting the sum of the two welfare cost components in Figure C.3.

The upper curve in Figure C.4 represents the marginal cost curve for reducing CO_2 emissions from all other sectors combined—primarily transportation and industry. Suppose, under the CO_2 price of τ, that these reductions from the rest of

Figure C.4



the economy would be z^{other}. The economywide emissions reductions are therefore $z^{total} = z^{elect} + z^{other}$, and the economywide marginal cost curve, the horizontal summation of those for electricity and other sectors, is shown by the lower curve in Figure C.4. The total cost of the CO_2 pricing policy is represented by the shaded area under this curve.

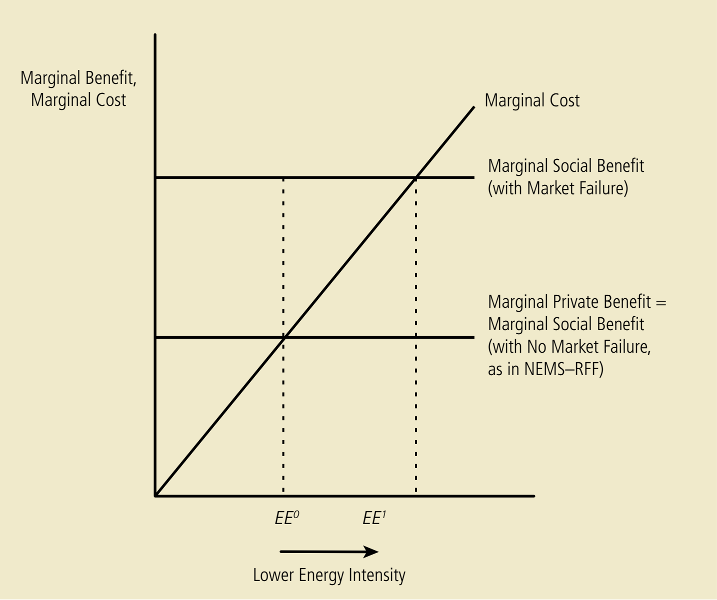
Implications of Preexisting Fuel Taxes. In calculating the cost of oil-reducing policies, we need to take into account preexisting taxes on oil products, namely federal and state excise taxes on gasoline and diesel fuel consumption. To the extent that revenues from these taxes fall in response to new policies, there will be a loss of surplus to the government. Put another way, the economic cost of reducing gasoline or diesel fuel by a gallon is not zero initially, but rather the preexisting tax wedge, reflecting the difference between the benefit of the last gallon of fuel used and the cost of supplying that gallon. We calculate the revenue losses and add them to welfare costs, using a gasoline tax of 38¢/gallon and a diesel tax of 44¢/gallon, where these preexisting tax rates are assumed constant in real terms over the study period (although new oil taxes increase them). We ignore these revenue losses in reporting the economywide cost of CO_2 pricing policies because, in this case, they are small in relative terms, given that only a minor portion of CO_2 reductions comes from the reduced use of transportation fuels.

Market Failures in energy efficiency. In our scenarios with market failures associated with energy efficiency decisions, we make one further adjustment to the welfare costs of pricing policies for oil and CO_2.

To understand this adjustment, consider Figure C.5. The horizontal axis represents reductions in the energy intensity (energy input per unit of output) of a new, energy-using durable product like vehicles, in a given future year. The upward-sloping curve represents the marginal cost of installing technologies in the product to reduce energy intensity—for example, the costs of progressively integrating available technologies to improve automobile fuel economy (these costs are passed forward into higher product prices in NEMS–RFF).

The lower horizontal curve is the marginal private benefit from reductions in energy intensity

Figure C.5



(that is, the value of these savings to households and firms). Specifically, this reflects the reduction in energy costs over the product lifespan discounted at the high rates typically assumed in the NEMS–RFF model (for example, about 20 percent for efficiency improvements in the power sector).[7] In the NEMS–RFF model, prior to policy intervention, energy intensity would be EE^0 in Figure C.5; that is, where the willingness on behalf of households and firms to pay for additional improvements (as reflected in the height of the marginal private benefit curve) equals the cost of those additional improvements (the height of the marginal cost curve).

In the No Market Failure case, the marginal private benefit curve in Figure C.5 reflects the "true" marginal social benefits from reductions in energy intensity, after taking into account implicit hidden costs. In this case, the private sector achieves the economically optimal level of energy efficiency, leaving aside security and environmental concerns. Here we make no adjustment to the welfare cost measures of the broad pricing policies discussed above.

In the Market Failure case, the private sector, for whatever reason (e.g., imperfect information), undervalues the benefits from reductions in energy intensity. In this case, the marginal social benefit curve lies above the marginal private benefit curve, again as depicted in Figure C.5. Now there is a source of welfare gain from improvements in energy efficiency, represented by the difference in marginal social and marginal private benefits and integrated over the reduction in energy intensity.[8] The optimal amount of energy intensity in this case would be at EE^1.

Following Parry et al. (2010), an approximation for this welfare gain, expressed per unit of energy savings over the product lifespan, is given by the current (post-tax) price of energy, times the *non-internalization* fraction. The latter refers to the

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[7] We choose these rates, based on expert judgment, to ensure that the existing and future adoption of energy-saving technologies projected by NEMS is consistent with currently observed, and expected future changes in, EE.

[8] Again, this is a standard application of the well-known formulas in Harberger (1964). If we also took into account security and climate benefits, we would find a larger gap between the marginal social and private benefits, and a larger source of welfare gain.

portion of the social benefit of the energy savings that is not taken into account by the private sector because of market failures.

For the Oil Tax policies, we assume that the only relevant source of potential market failures is in regard to the fuel economy of automobiles.[9] Under NEMS assumptions, households value only the first three years of fuel savings from improvements in the fuel economy of new automobiles, with savings in years two and three discounted at a 15 percent rate. This private valuation is about 75 percent below the value of fuel savings compared with the case in which these savings are discounted over the entire vehicle life (15 years) and at a social discount rate of 5 percent.[10]

Following Small (2010), we assume that 50 percent of this discrepancy in fuel savings valuation under the two procedures is due to market failures, while the other 50 percent is due to hidden costs. Under these assumptions, the noninternalization fraction is 0.375 (i.e., 50 percent of 0.75). Using this, we count as a welfare gain the gasoline savings in that year resulting from improvements in new-vehicle fuel economy, multiplied by 0.375, and by the prevailing (post-tax) gasoline price.

The above expression provides an annualized approximation of the welfare gain due to policies addressing possible market failures associated with fuel economy decisions. It is an approximation that obviates the need to track the flow of future energy savings from fuel economy investments in each period, including savings that extend beyond the study period.[11] In the detailed estimates for automobile policies discussed below (though not for Oil Tax policies), we take a more sophisticated approach that does in fact track the future time profile of energy savings.

The above methodology is valid, even in the presence of partially or fully binding fuel economy standards (see Parry et al. 2010). These regulations reduce the responsiveness of fuel economy to higher fuel prices—for example, some manufacturers for whom the standards are binding will not increase the fuel economy of their automobile fleets in response to higher fuel prices. However, these standards do not affect any potential difference between the social and private valuation of fuel savings from a given improvement in fuel economy.

For the CO_2 pricing policies, we consider the possibility of market failures associated with efficiency improvements in the power sector.[12] Analogous to the above, we multiply reductions in electricity demand attributable to efficiency improvements in each period by the prevailing electricity price and by an assumed noninternalization fraction (again, see Parry et al. 2010 for a discussion of this adjustment to welfare cost). We take this fraction to be 0.426, based on a comparison of the value of energy savings for a long-lived investment using NEMS discount rates (typically around 20 percent for electricity-using products) with the value of these savings when we use our compromise discount rate of 10 percent (recommended by our EE experts) for savings in electricity use.[13]

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[9] For other oil-using sectors, primarily trucking, air travel, and industrial users, strong competitive pressures encourage firms to exploit all EE technologies that pay for themselves in terms of energy savings.

[10] This follows from basic formulas for the sum of a geometric progression; allowing for rising energy prices and falling product usage over time does not make much difference to the relative valuation of fuel savings under these two alternative discounting procedures.

[11] If energy prices are rising over time, this measure understates the welfare gain, though this is counteracted to the extent that the usage of automobiles declines with automobile age. Either way, the degree of bias is relatively small and makes very little difference for the overall costs of oil tax policies.

[12] Allowing for market failures associated with automobile fuel economy choices makes little difference in this case, given the small share of economywide CO_2 reductions attributable to this margin of response.

[13] As noted, some of our experts used a compromise discount rate to take into account market failures. Other experts instead chose to make an assumption about the extent of hidden costs and to subtract those from energy savings evaluated at the social discount rate. These two approaches are essentially equivalent (with one caveat noted below).

Further Details on Measuring the Costs of Transportation Policies

One way to measure the welfare cost of gasoline taxes would simply be to follow the above procedure for oil taxes, taking account of preexisting fuel taxes and possible welfare gains due to differences in the marginal social and marginal private valuation of fuel economy. However, our experts used a different, more detailed approach (outlined below) to measure the welfare costs of gasoline taxes and the other automobile policies (fuel economy standards, feebates, and subsidies for hybrid vehicles). Besides providing a little more precision (as noted above), this alternative approach is useful in that it sheds more light on various components of welfare cost. The approach, which is outlined in more detail in Small (2010) and McConnell and Turrentine (2010), is used for all policies examined by our experts affecting the automobile sector and involves categorizing costs into several different components, as follows.

As regards the welfare effects of policy-induced reductions in the fuel intensity of new vehicles (such as from a more strict fuel economy standard), note from Figure C.5 that these can be calculated using information on increased vehicle costs (which corresponds to the relevant area under the marginal cost curve) and the social value of energy savings (which corresponds to the relevant area under the marginal social benefit curve).

New-Vehicle Costs. These are the extra costs of incorporating fuel-saving technologies into new vehicles. We obtain added vehicle costs for the different model classes distinguished in NEMS–RFF by comparing new-vehicle prices in a given year in which the new policy is in place to those costs in the Reference case (without the new policy). We also take into account a component reflecting a welfare loss due to the reduction in vehicle demand in response to higher vehicle prices (or higher fuel prices), though this is very small in relative terms.

Energy Savings. This is a benefit, reflecting the savings in fuel costs in any given year due to motorists driving more efficient vehicles, as a result of previous and current improvements in vehicle fuel economy. Our experts chose not to separate out the erosion of preexisting fuel tax revenues in response to new policies as its own cost category (as in the procedure above for oil taxes). In this case, it is appropriate to value fuel savings at the *pretax* fuel price prevailing in the respective period. This makes sense because the pretax price reflects the avoided fuel production costs to the economy, whereas the tax component of the fuel price is a savings to motorists but is offset by a loss of revenue to the government. We track fuel savings beyond the study period to take full account of future savings implied by fuel economy improvements up to 2030, based on extrapolations of vehicle survival rates and fuel prices after 2030 (see Small 2010 for details).

Hidden Costs. As already discussed, our experts assumed that hidden costs explain half of the discrepancy between the value of fuel savings over the entire vehicle life (discounted at an assumed market rate of 5 percent) and consumers' actual valuation of fuel savings in NEMS–RFF (equal to the value of savings over the first three years discounted at 15 percent). In the absence of better evidence, this assumption represents a compromise between the two bounding cases for the magnitude of market failures.

The remaining cost components reflect other behavioral responses directly caused by transportation policies.

Losses from Reduced Driving. We include any losses to motorists from policy-induced reductions in vehicle mileage as a cost, though they are partly offset by savings in travel time costs and fuel costs. Tighter fuel economy standards lower the cost of driving and create a benefit to motorists. Higher gasoline or oil taxes raise the per-mile cost of driving and lower miles driven, creating losses to consumers. Any fuel savings from reduced driving impose a cost on the government as they reduce tax revenue. See Small (2010) for more details on this calculation.

Loss of Value from Light Trucks. Some policies cause a shift in demand from light trucks to cars, which entails some cost to motorists who would rather drive trucks. We approximate this cost by the value of the fuel savings, though it is very small relative to other cost categories.

We discount all of the above categories (including offsetting energy savings) back to 2010 using the social rate (5 percent) and then aggregate them to obtain our PDV cost measure.

LNG Trucks Mandate. We base offline estimates of the added costs due to the assumed penetration of LNG trucks, rather than diesel-fueled vehicles, into the heavy-duty fleet on available evidence and conversations with industry experts (see Krupnick [2010] for details). We apply these to projected truck fleets in the NEMS–RFF model (given the assumed penetration rate of LNG trucks into the new-vehicle fleet). We also include an estimate of the welfare gain to alternative goods transportation methods due to reduced usage of heavy trucks, though this is very small. We base fuel savings from investments in a given year on the price of diesel and natural gas generated from the NEMS–RFF model with LNG penetration discounted at the high rate in NEMS–RFF (31 percent) assuming No Market Failure, a 10 percent rate (allowing for Partial Market Failure), and a 5 percent rate (assuming Complete Market Failure). We track energy savings beyond 2030 for all investments made in the projection period. We discount net costs in a given investment year back to 2010 using the social discount rate (5 percent).[14]

Transportation Policy Combinations. One way to compute the welfare effects of policy packages is to add up the welfare changes for sequential changes in policy, where outcomes from a particular policy change are compared with outcomes prior to that change in the policy sequence and the end result is not affected by the ordering of the policy sequence (Harberger 1964). For the CAFE/Gasoline Tax combination, we first imagine imposing the Pavley CAFE policy, with the resulting welfare cost as computed in the Pavley CAFE run on its own. On top of that, we then consider the Gasoline Tax policy, where welfare costs from additional fuel reductions (compared with the Pavley CAFE outcome) are computed by the relevant area in the gasoline market (as indicated in Figure C.1), taking into account the loss of revenue from preexisting gasoline taxes and possible welfare gains from the (limited) further increase in fuel economy in the scenario with market failures.

We compute welfare costs for the Phased Oil Tax/Feebate/Hybrid Subsidy combination by adding up the costs from the High Feebate run and adding to these the welfare losses from additional gasoline and nongasoline oil reductions resulting from the Phased Oil Tax and from the distortion in the hybrid vehicle market created by the Subsidy.

Further Details on Measuring the Costs of CO_2 Policies

Renewables and Clean Energy Policies. We consider two types of policies to promote renewables and other no CO_2- or low CO_2-emitting sources of electricity generation. The main type is a portfolio standard policy that requires that a minimum percentage of either total electricity sales or some subset of total sales be supplied by a set of eligible renewable generators or a broader class of clean energy generators. The second type of policy is an indefinite extension of the renewables Production Tax Credit for certain classes of renewable generators. We also consider policies that combine an RPS with the Central C&T case or Carbon Tax.

In the case of the stand-alone portfolio standard policies, the welfare cost calculations have two components. By imposing a requirement that a

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[14] We apply the high, medium, and low discount rates to obtain the present value of the energy savings as of the year in which that stream of savings was created. In turn, this present value is then discounted from that year back to 2010 using the social discount rate. Failure to adopt this "double discounting" procedure would lead to an unequal and incorrect treatment for discounting the benefits and costs of future investments back to 2010. In effect, using a rate higher than the social rate to discount a flow of future benefits from the future year in which the investment is made back to 2010 would be equivalent to assuming, erroneously, that there is a stream of hidden costs between the investment year and 2010. The same issue arises for some of the carbon policies discussed below.

minimum percentage of every kWh of electricity sold be produced using an eligible renewable or clean energy generator, this policy essentially imposes a tax on generation that is not included in the portfolio, where the revenue is used to fund a subsidy for renewable and other clean sources of generation that are included in the portfolio standard (see Fischer and Newell 2008 and Fischer 2010 for further discussion). The tax part of the policy can produce an increase in electricity price that results in welfare losses in the market for electricity. We calculate the welfare losses to consumers as the change in electricity price resulting from the policy times the change in electricity supply times one-half.

The welfare cost of the subsidy to renewable (clean energy) generation is just the renewable (clean energy) credit price times the number of credits per kWh of generation, times the change in generation from eligible renewables between the policy case and the Reference case, times one-half. This latter calculation is straightforward for the RPS, where each kWh of eligible generation earns one renewable energy credit, but can be a bit more complicated for the CEPS policies, where the number of credits earned per kWh of generation varies depending on the technology type. When this is the case, the distortions created by the subsidy for clean energy are calculated separately and then summed together.

To capture the effects of the portfolio standard policy on preexisting distortions created by the existing renewable production tax credit, we also calculate the change in subsidy payments between the policy scenario and the baseline and add that to the welfare cost. In most cases, the size of this cost is a very small portion of the total welfare costs.

For the policy that extends the existing tax credits, the welfare cost of the policy is simply the change in subsidy costs associated with the extension times one-half.

For the policies that combine the RPS with the Central C&T or equivalent Carbon Tax, the costs of the two policies are additive; that is, the total welfare cost is the sum of the costs of the C&T or Carbon Tax policy and the incremental cost of the RPS or CEPS compared to the C&T or Carbon Tax alone. The cost of the preexisting distortion due to the production and investment tax credits, just described, is added to each of these cost calculations.

EE Incentives. We can use Figure C.5 again to illustrate the costs of an energy efficiency mandate for buildings and electricity-using durables more generally. Assuming that a standard is set at EE^1, we measure the cost of meeting the standard—that is, moving from the market outcome at EE^0 to EE^1—as the area under the marginal cost curve between EE^0 and EE^1. In our calculations, we estimate welfare costs based on procedures similar to those used to calculate the first two cost components described above for the transportation policies. We take the up-front investment costs from NEMS–RFF output for the relevant classes of energy-using equipment and building shells. We also calculate, from NEMS–RFF model output, savings in electricity and natural gas use as a result of these investments up to the year 2030. We project the potential savings out to 2050 based on extrapolations from 2030 using building survival rates (see Auffhammer and Sanstad 2010 for details).[15] We estimate the value of the energy savings at alternative discount rates as described above.

Because the GHP policies are consumer purchase subsidies, we use NEMS–RFF output on the number of additional GHPs purchased each year and calculate the standard deadweight loss triangle in the GHP market—that is, the subsidy amount ($4,000) multiplied by one-half times the additional GHPs purchased over the Reference case. This is similar to the approach we take for LNG Trucks and for the portfolio standard policies. It differs from the Building Codes policies described

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[15] One detail, mentioned in Chapter 7, is the fact that the NEMS–RFF model does not provide equipment costs for all changes that are made to meet the code (see Auffhammer and Sanstad 2010 for more detail). For the residential sector, the costs are fairly complete, and we are able to extrapolate to reasonably estimate the full costs in that sector. For the commercial sector, a significant portion of the investments made are lacking costs; thus, we calculate and report only welfare costs and cost-effectiveness for the residential sector, though the policy is applied to both.

above, however, though the two methodologies are roughly equivalent. In the Building Codes case, we choose to add up the cost of the multiple investments made to meet the code because more than a single market is affected, in contrast to the GHP case (and LNG Trucks case), and because the cost varies across all of the different equipment.

As discussed above, to the extent that the social benefits of the energy savings from GHPs exceed the private benefits, incomplete internalization of the energy savings by households results in a downward adjustment to welfare cost. We compute this as the difference between the value of future fuel savings discounted at our chosen rate (10 percent in the Partial Market Failure case) and the value of these savings discounted at the No Market Failure rate (20 percent).

Complication. From the NEMS–RFF model output, we cannot infer the flow of energy savings across future years attributable to EE investments that occur in a given year. This is problematic because a double discounting procedure is required to avoid bias in converting the present value of benefits from an investment in some future year back to 2010. To get around this problem, consider the following expression: $PV_{2010} = \sum_{t=0}^{N-1} \frac{PV_N^{10}}{(1.05)^t}$. PV_N^{10} denotes the present value of a stream of benefits that are created *N* years into the study period, where these benefits occurring in years *N*+1, *N*+2, and so on are discounted at 10 percent, our preferred rate for the Partial Market Failure case. PV_{2010} denotes the present value of this stream discounted back to 2010 using the social discount rate (5 percent). Now multiply and divide the right-hand side of the equation by PV_N^5, which denotes the present value of benefits when the investment occurs, but discounted at the social rate. This gives $PV_{2010} = \beta \bullet \sum_{t=0}^{N-1} \frac{PV_N^5}{(1.05)^t}$ where $\beta = PV_N^{10} / PV_N^5$. Based on the above expression, we simply discount future energy savings at the social rate across all years prior to and after the investment is made, and then multiply all of this by fraction β. This fraction is the ratio of energy savings over the life of the investment discounted at 10 percent relative to lifetime energy savings discounted at the social rate. Given an expected investment life, taken to be 20 years, this fraction is 0.6.[16]

Incentives for Nuclear. We compute welfare costs of the nuclear Loan Guarantee program assuming that three financial instruments are available: (a) *private equity*, with a nominal rate of return of 17 percent (in NEMS), 14 percent, or 11 percent; (b) *private debt*, with a nominal 8 percent rate of interest; and (c) *public debt*, with a nominal 0 percent rate of interest on a 20-year first mortgage (this implies a federal subsidy—a welfare cost—to cover the difference between 0 percent and the U.S. government borrowing rate). Rothwell (2010) assumes that financing is done with a mix of these instruments (roughly one-third each).

Crosscutting Policy Combinations

Pure Pricing. Again following formulas in Harberger (1964), we measure the welfare costs of the Phased Oil Tax and Carbon Tax in the Pure Pricing combination, in the case of No Market Failure, by the welfare losses associated with the reduction in oil consumption and in CO_2 emissions—that is, one-half times the price wedge times the respective reductions in oil and CO_2 in the combination compared with the Reference case.[17] We compute these losses for each year in the study period and aggregate them, after discounting back to 2010 using the social discount rate. In addition, we include welfare losses resulting from reductions in revenue from preexisting taxes on highway fuels.

Welfare costs for the Pure Pricing combination are somewhat higher than the sum of welfare costs for the individual Phased Oil Tax and Carbon Tax polices discussed in Chapters 5 and 6 because of policy interactions. In particular, the overall reduction in oil use under the combination policy

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[16] We assume that this fraction is constant over time. In practice, it may vary if the growth rate in energy prices, or in product usage, changes over time, but our cost-effectiveness estimates are not very sensitive to these complicating factors.

[17] Alternatively, we could compute the welfare change sequentially, although when a new policy is introduced we must account for any impact it has on compounding or offsetting distortions from a preexisting policy.

is somewhat larger than under the Phased Oil Tax alone because of the effect of carbon policies on raising oil prices; similarly, the reduction in CO_2 emissions under the crosscutting combination policy is larger because of the larger reduction in oil use.

To take into account partial market failures, we look at the effect of the crosscutting combination policy on improving energy efficiency for automobiles and electricity-using durables. We measure welfare gains here on an annualized basis as described above for the pricing policies, applying noninternalization fractions of 0.375 and 0.426, respectively. Annual fuel savings from improvements in new-vehicle fuel economy are easily obtained from NEMS–RFF. We calculate the share of reductions in electricity demand due to additional efficiency investments (as opposed to conservation or because of changes in the demand for such investments associated with changes in the housing stock) using NEMS–RFF. We compute efficiency improvements, multiplied by energy consumption associated with the relevant investment categories (e.g., space heating) in the policy and divide by the change in energy consumption associated with these investments. By 2030, the share rises to 0.47. We follow a similar approach for the Complete Market Failure case, where the noninternalization fraction is zero.

Pure Pricing + EE. In principle, the welfare costs of policy combinations could be computed (as for Pure Pricing) by comparing outcomes with the full set of new policy distortions to outcomes prior to any policy change. However, with price and regulatory combinations, it is a little easier to measure welfare costs sequentially.

Specifically, we first add the welfare cost of the Pavley CAFE policy simulation (in isolation) to that from the Building Codes provisions simulation (the automobile and power sectors can be viewed as decoupled for this purpose, hence costs are additive). We then follow the previous procedure for obtaining welfare costs from introducing the Phased Oil Tax and Carbon Tax.[18]

Regulatory Alternatives. In measuring the welfare cost of the Regulatory Alternatives combination, we make certain adjustments to the costs already calculated for the individual policies that constitute the package, and then add them up, as follows.

First, consider the Pavley CAFE policy. Fuel economy outcomes for new light-duty vehicles are essentially the same under Regulatory Alternatives and the Pavley CAFE case alone; the difference in any given year is, at most, 0.2 percent. The value of fuel savings from improvements in fuel economy will differ in the combination compared with the policy in isolation to the extent that gasoline prices are different. However in almost all years, gasoline prices differ by only 1 to 3 percent across the two cases, implying very minor differences in the value of fuel economy improvements. Hence, it is reasonable to use cost estimates from the Pavley CAFE policy in calculating the overall costs of this component of the policy combination.

Next, consider the LNG Trucks mandate. The costs of this policy depend on the value of energy savings for a given mandated phase-in of LNG vehicles, which in turn depends on future prices of natural gas and diesel. In a few years, toward the end of the study period, diesel prices are significantly lower in the crosscutting combination than in the LNG scenario alone (by around 10 percent or more), whereas natural gas prices are higher. This is a result of the CEPS–All policy causing a decline in the transportation of coal (and hence demand for diesel) and an increase in demand for natural gas. Therefore, we recompute the welfare cost of the LNG Trucks mandate, using the diesel and natural gas prices in the outcome with Regulatory Alternatives instead of those in the run with LNG Trucks penetration as the sole policy.[19]

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[18] In doing so, we compare changes in fuel use and fuel economy relative to outcomes in the Pavley CAFE policy alone; changes in EE in the power sector relative to those in the Building Codes policy alone; and reductions in oil use and CO_2 emissions between the combination outcome and the Reference case, after netting out the sum of reductions in the Pavley CAFE and Building Codes policies alone.

[19] One caveat here is that we make the (entirely reasonable) assumption that the penetration of LNG trucks in the absence of the mandate (but in the presence of other policies in Regulatory Alternatives) would be approximately the same as in the Reference case (with no policies at all). Given the way NEMS–RFF is designed, this outcome is preordained.

As discussed above, we compute the welfare cost of the CEPS–All policy accounting for various policy distortions in the power sector as well as changes in electricity output and the fuel mix. These quantity changes, along with clean generation credit prices, are different in the Regulatory Alternatives combination than in the CEPS–All run alone. For example, natural gas prices are higher as a result of the LNG Trucks mandate, making it more costly to meet the CEPS–All requirement; this is reflected in a higher credit price. We use the same methodology as described above for computing the costs of the CEPS–All component, but using model outputs from the combination run, rather than the CEPS–All run.

Finally, the net costs of the Building Codes policy (which saves on electricity use and home heating fuels) are smaller in the combination than when this policy is implemented on its own, given that electricity and natural gas prices are higher as a result of other policies (the effect of CEPS–All on raising natural gas, and hence electricity, prices). As with the LNG Trucks policy, we recompute the welfare costs of the Building Codes policy, using the electricity and natural gas prices from the Regulatory Alternatives simulation. Again, we make the (reasonable) assumption that any increase in building efficiency in response to higher electricity prices caused by the other policies in the combination would be small relative to the efficiency increase mandated by the building regulation. (If this were not the case, the welfare cost of the combination would be a little smaller.)

Blended Portfolio. Here we follow the above procedure for calculating the combined welfare cost of the Phased Oil Tax/Feebate/Hybrid Subsidy policy—the only difference being that we look at outcomes in the Blended Portfolio combination run, rather than in the transportation combination run. We also calculate the welfare costs of the remaining policies—LNG Trucks, Building Codes, GHP Subsidy, and CEPS–All—in the same manner as described above, but again using energy prices, quantities, and (in the case of CEPS–All) credit trading prices from the Blended Portfolio combination output. In this crosscutting policy, LNG Trucks costs are much lower than for the Regulatory Alternatives combination because (a) only half the penetration rate is assumed and (b) the Oil Tax creates a large price differential between diesel and natural gas prices, which increases fuel savings for LNG vehicles.[20]

Missing Components from Our (Main) Welfare Measures

Finally, the main welfare cost measures in the report omit three notable components that follow, inevitably, from the application of the Harberger (1964) formulas, but that are not represented in the NEMS–RFF model. One is interactions between new energy and climate policies and preexisting distortions in the economy created by the broader fiscal system. Another is the ancillary benefits of policies (aside from energy security and climate benefits), such as local pollution benefits and, in the case of fuel taxes, reductions in roadway congestion and accidents. We discuss both of these issues in Chapter 9, where we provide offline calculations to give some sense of how welfare costs would be affected. Third, to the extent that new policies encourage greater innovative efforts in developing cleaner technologies, they induce yet another source of welfare gain. This is because R&D markets are typically distorted in the sense that the societal benefits from new technologies exceed the private benefits, given that (despite the patent system) innovators cannot usually capture all of the spillover benefits of their technologies to other firms. Again, NEMS–RFF does not provide a way to quantify the welfare gains from policy-induced innovation. Nonetheless, other studies suggest that, over the long haul, induced innovation effects may not make a substantial difference to the overall welfare costs of environmental and energy policies (e.g., Parry et al. 2003). But this issue really needs more research on a case-by-case basis for different policies.

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[20] For variants of the Regulatory Alternatives and Blended Portfolio combinations in which the LNG Trucks policy is dropped, we simply subtract welfare costs associated with LNG Trucks in the Reference case for the variant of Regulatory Alternatives and half of this (reflecting the smaller penetration rate) for the Blended Portfolio, making an approximate adjustment in each case for differences in fuel prices.

Appendix D: Welfare Costs Breakdown

Throughout this report, we present welfare costs in the aggregate, without providing further breakdown of the cost components. In this appendix, however, we provide additional detail on cost breakdowns (for the Partial Market Failure assumption only) in 10 categories, although none of the policies has costs in all categories. Table D1 lists all the individual policies in the report in the first column and the cost categories in subsequent columns.[21] Positive values indicate costs and negative values indicate cost savings; the sum of costs and cost savings matches the aggregate costs presented in the report and Key Metrics Table (Appendix B).

As an example, take a policy encouraging specific investments—such as more fuel-efficient cars—to save energy. Here the first cost category (and column) is the cost of investments encouraged by the policy over and above the investment costs without the policy (what we term "Extra costs of new capital purchases"); these costs are captured in the year the investment is made.[22] Category 2 reflects the cost savings associated with the greater energy efficiency of those investments (what we term "fuel cost savings"); these savings are captured over time as the capital is used.

Categories 3 and 4 capture costs estimated using Harberger triangles (see Appendix C for more detail), for either the carbon market or the oil market. Notably, for some policies—the Phased Oil Tax, Oil Tax, CAFE/Gasoline Tax, and Phased Oil Tax/Feebate/Hybrid Subsidy combination—the Harberger triangle for reducing oil also includes the extra costs of new capital purchases and the fuel cost savings otherwise contained in Categories 1 and 2. This is simply another way of capturing and reporting the same costs.

Category 5, "Lost revenue from preexisting taxes/lost interest to government," reflects the fact that when a new policy affects something that is already being taxed, tax revenues (which are used to provide valuable services and goods for the American public) will change. For instance, if a policy reduces vehicle miles traveled and therefore the total amount of gasoline consumed, the government's gasoline tax revenues will be reduced. Lost interest revenues refer to the nuclear loan guarantee program, where the government receives less interest on its loans than the market rate, which, in effect, is a loss in revenue.

Category 6 covers losses or gains in consumer and producer surplus that are not otherwise picked up in the previous calculations. Category 7 is applicable to renewables policies, where mandating requirements for the use of cleaner technologies acts as an implicit subsidy to the mandated technologies. Category 8 covers costs associated with existing subsidy programs: specifically, the existing investment and production tax credits for renewables increase under various generation mandate policies (including cap and trade). This represents a loss in welfare, as those funds are not available for other purposes.

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[21] Small (2010) contains a more detailed explanation of cost components and calculations associated with many of the transportation policies.

[22] Column 1 also captures two other categories of losses found in Small (2010): utility losses from forcing consumers to buy cars that have lost valuable features (such as power), and the loss of consumer surplus in the light-duty truck markets, which is calculated separately from the light-duty automobile market.

Table D1: Welfare Cost Breakdown (PDV Costs of Policy, Billion 2007$)

Policy	1. Extra costs of new capital purchases including any hidden cost assumptions	2. Fuel cost savings	Total (1-2)	3. Harberger triangle for CO_2	4. Harberger triangle for oil	5. Lost revenue from preexisting taxes/lost interest to government	6. Other loss/gain of consumer and producer surplus	7. From implicit subsidy	8. From existing subsidies	9. Market failure adjustment	10. Other	11. Total
Phased Oil Tax					74.9	37.0				–24.0		88.0
Oil Tax					196.5	66.9				–62.9		200.5
Gasoline Tax	49.0	–74.5	–25.5			75.3	3.5 [a]					53.3
Pavley CAFE	232.9	–185.5	47.4			–2.8						44.6
High Feebate	238.7	–193.0	45.7			–3.8						41.9
Very High Feebate	405.4	–282.9	122.5			–5.7						116.8
CAFE/Gasoline Tax					176.4	34.1				–76.3		134.2
Phased Oil Tax/Feebate/Subsidy					297.9	61.9				–109.8		250.0
Central Cap-and-Trade				135.3					7.0			142.3
C&T: Excluding Transportation				145.5					7.8			153.3
C&T: Greater Offset Availability				65.1					3.0			68.1
Carbon Tax				134.6					7.0			141.6
C&T: No Offsets				538.3					21.1			559.4
C&T: Less Stringent Cap				43.3					2.5			45.8
RPS							0.0	46.4	1.1			47.5
CEPS							0.1	35.1	5.1			40.2
CEPS + Natural Gas							0.1	25.7	4.0			29.8
RINGPS							0.1	160.0	2.0			162.1
CEPS–All							1.1	99.1	16.0			116.2
Cap-and-Trade + RPS				135.3			0.0	11.9	3.8			151.0
Carbon Tax + RPS				134.6			0.0	9.9	3.9		21.6	170.0
Building Codes — Residential	53.2	–37.5	15.7									15.7
Complete Set of WM EE Policies — Residential	74.4	–47.8	26.6									26.6
WM EE Policies + High-Tech Assumptions — Residential	163.2	–205.2	–42.0									–42.0
Geothermal Heat Pumps — Loan				–11.7								–11.7
Geothermal Heat Pumps — Subsidy				–5.1								–5.1
6.5 GW New Nuclear Capacity by 2020 (14% ROE)						0.7						0.7
17.3 GW New Nuclear Capacity by 2020 (11% ROE)						4.5						4.5
Hybrid Subsidy					4.3					–12.5		–8.2
LNG Trucks	224.9	–33.7	191.2				–4.8					186.4

a. This represents the loss of consumer value due to shifting from cars to trucks (Small 2010).

Category 9 covers market failure adjustments. This category is used by Small (2010) to adjust his calculations in light of the assumption of partial market failure versus no market failure. Finally, Category 10 is only relevant for one policy, referencing the additional costs generated through interactions between the Carbon Tax and RPS when the two are combined.

In Chapter 9 we presented a short discussion of ancillary benefits and costs. Table D2 presents estimates of the ancillary benefits or costs associated with the transportation policies that appear in Small (2010). Small's categories are pollution, congestion, and accidents—all related to changes in vehicle miles traveled induced by the policies and all correcting for internalization of these externalities by policy or other means. These benefits or costs are captured in Categories 12, 13, and 14. We add a category of "Other" to address additional categories of ancillary benefits and costs; an example is the increased cost of road damages due to growth in VMT. Although we do not estimate these other damages, we feel they are worth noting.

Small (2010) also captures a subtle accident effect, noted in Category 17, in which policies that shift the mix of cars and trucks on the road can alter accident risks. Such risks are smallest when all vehicles are the same size and weight. Thus, depending on the starting mix, such shifts can increase or decrease accident risks. Total ancillary benefits and costs by policy are shown in Category 18, while Category 19 shows the net result of subtracting the ancillary benefits and costs from the main welfare costs associated with each policy. The general result is that pricing policies, which make driving more expensive, become much cheaper to society (or even have negative costs) when ancillary benefits are taken into account. This is in contrast to policies that increase fuel economy, which make driving cheaper and exacerbate welfare costs.

Finally, Table D3 provides a qualitative discussion of ancillary benefits and costs associated with the remaining policies examined in this report, with policies grouped by type.

Table D2: Ancillary Benefits and Costs of Transportation Policies (PDV Billions 2007$)

Policy	12. Pollution Damages[a]	13. Congestion Costs[b]	14. Accident Costs[c]	15. Other Externalities[d]	16. Sub-total (12+13+14)	17. Accidents from Shift in Car/Truck Mix on the Road	18. Total Ancillary Benefits (–)/ Costs (+)	19.Net Welfare Costs (11+18)
Phased Oil Tax	–30.4	–53.2	–45.6	not estimated	–129.2	N/A	–129.2	–41.2
Oil Tax	–43.9	–76.9	–65.9	not estimated	–186.7	N/A	–186.7	13.8
Gas Tax	–55.5	–97.1	–83.2	not estimated	–235.8	–13.8	–249.6	–196.3
Pavley CAFE	8.3	14.6	12.5	not estimated	35.4	2.2	37.6	82.2
High Feebate	11.1	19.4	16.6	not estimated	47.1	3.3	50.4	92.3
Very High Feebate	16.4	28.8	24.7	not estimated	69.9	4.7	74.6	191.4
CAFE/Gas Tax[e]	–39.3	–68.8	–58.9	not estimated	–167.0	N/A	–167.0	–32.8
Phased Oil Tax/Feebate/ Subsidy[e]	–21.8	–38.1	–32.6	not estimated	–92.5	N/A	–92.5	157.5

a. Each of these policies would reduce pollution in some form, including conventional air pollutants, oil leakage from vehicles, and/or a host of other damages up the supply chain, including from oil spills.

b. With lower VMT, congestion would be reduced, unless driving reductions only occurred during off-peak times. This is highly unlikely.

c. With lower VMT, accidents would be reduced unless speeds increased from lower congestion and this resulted in more serious accidents (with higher valued losses).

d. A good example is road damage from heavy trucks, where this damage is roughly equal to the fourth power of the proportion increase in axle weight. Road taxes paid by truckers are thought to be far too low to internalize such damage.

e. Net effect depends on what happens to VMT as fuel tax raises price of driving but more fuel-efficient vehicles lower the price of driving.

Table D3: **Ancillary Benefits and Costs of Additional Policies, by Policy Type**

Policy	12. Pollution Damages	13. Congestion Costs	14. Accident Costs	15. Other Externalities
Carbon Pricing and Renewables Policies	Conventional pollutant emissions are unlikely to change significantly because SO_2 and NO_x are both covered by caps. The geographic distribution of these pollutants can change but the direction is unknown. Pollutants not covered by a cap generally will be reduced because of the shift away from coal. Specialized pollutants, such as radioactive materials, could increase or decrease depending on the effect of a policy on total generation and its mix (e.g., nuclear generation).	N/A	Concern is primarily with nuclear accidents, accidents in coal mines, oil spills, and the like. To the extent nuclear generation increases, accident risks increase. Coal and oil are likely to be reduced in the generation mix and (and for oil, reduced use in transportation), leading to a somewhat lower probability of accidents. One overarching issue is whether accident costs are internalized already in fuel/generation prices.	Non-fossil fuel generators have a varied and, in some cases, unusual array of possible externalities (e.g., bats killed by wind turbines). The Cap-and-Trade (and RPS) approaches favor these generators and thus raise the risks associated with them.
Non-Transportation Energy Efficiency Policies	Because of reductions in electricity and other fossil fuel use, pollution levels would be reduced.	N/A	Again, where concern primarily centers on nuclear and coal mine accidents, an overall reduction in energy consumption would reduce the use of the fuels and associated risk of accidents.	N/A
Nuclear Power: Loan Guarantee	Increasing nuclear generation at the expense of coal substitutes some types of pollution for others.	N/A	To the extent nuclear generation increases, accident risks increase. One overarching issue is whether accident costs are internalized already in fuel/generation prices.	N/A
Hybrid Subsidy	Pollution would be reduced as hybrids replace gasoline vehicles, assuming any electricity drawn from the grid was, on average, cleaner per Btu than gasoline.	Possibly limited changes in the number of vehicles. But with the costs of driving lowered and VMT higher, these costs might rise.		N/A
LNG Trucks	Most conventional pollutants are regulated with emissions standards. If the standards are binding across diesel and LNG, then there will be no pollution advantage to either fuel. The very fine and potentially carcinogenic particulate pollutants emitted by diesel are not directly regulated, however, and probably are not emitted by LNG. On this account, pollution damages would be lower.	There are no obvious differentials in congestion costs unless performance of an LNG truck differs from that of a diesel truck.	There is no obvious reason for truck highway accidents to be higher or lower depending on fuel used unless performance is affected (an unknown). There are greater safety concerns with LNG as a fuel than with diesel, however. Hence, this could increase welfare costs of LNG trucks relative to diesel trucks.	A big source of externalities from trucking is road damages. Most studies conclude that road taxes on truckers do not fully internalize these damages to public roads. However, it is not obvious that an LNG truck would do any more or less damage to a road than a diesel truck. If an LNG truck were heavier, it would do additional damage to the fourth power of the proportional increase in axle weight.

Appendix E: Results of Similar Studies

Other Studies Using NEMS

Two recent studies use NEMS to carry out analyses similar to the ones presented in this study. Morrow, Gallagher, Collantes, and Lee (2010), or MGCL, focus on policies and policy combinations to reduce oil and GHG emissions, but only in the transportation sector. All scenarios assume that a C&T policy is in place. The Union of Concerned Scientists (UCS 2009), has developed a complex multipolicy strategy, called a *Blueprint*, and examines its effect on oil consumption and GHGs using a modified version of NEMS.

Policies Examined by MGCL. MGCL examine a scenario similar to this study's Reference case, except with higher oil prices, reaching $198 per barrel by 2030. They also examine a carbon tax policy similar to ours (with a $60 "price" in 2030, close to the $67 price in 2030 found in our Carbon Tax); the carbon tax policy combined with CAFE standards that reach 43.7 mpg by 2030 (for comparison, this study's Pavley CAFE case reaches 52 mpg by 2030); a crosscutting policy combining the carbon tax and a doubly stringent fuel (gasoline and diesel) tax, ramping up to $3.36 per gallon in 2030; and a crosscutting policy blending a carbon tax, fuel tax, and the CAFE standards described above. They also examine vehicle purchase tax credits for alternative vehicles (subsidies).

MGCL's Findings. Because they use the same model, MGCL would get the same results if they examined the same policies and looked at the same metrics found in this study. Insights can be gained for our study where MGCL examine different policies or the same policies with different stringencies, or where they examine different metrics.

MGCL use two different oil price baselines. Using the price path originally found in NEMS (and used in NEMS–RFF), imports fall by 2.8 mmbd from 2008 to 2030. Using a higher oil price path, imports relative to 2008 fall by 5.7 mmbd. Looking at policies, MGCL find that, in combining CAFE, the tax credits, and the carbon tax, oil imports are reduced by only about 0.5 mmbd in 2020 and 2030 relative to the reference case. Adding their fuel tax (which is twice ours) adds another 1.5-mmbd reduction.

Subsidies are the most expensive and poorest performers in terms of CO_2 reductions, impeding improvements in the fuel economy of conventional vehicles. Fuel taxes are the best performers because they operate on all margins, particularly VMT. These findings mirror the conclusions reached in our study.

Finally, rather than estimating welfare costs and cost-effectiveness, MGCL estimate GDP effects and GDP-effectiveness in terms of cumulative GHG reductions. Their results show the trade-off between GDP-effectiveness and overall effectiveness, and suggest that the fuel tax combines high performance with relatively low GDP effects per ton of CO_2 reductions. No similar analysis is provided with respect to oil reductions. Note that their "combined" model includes the very expensive alternative-fueled vehicle subsidy, which results in its large effects on GDP.

Policies Examined by UCS. The UCS Blueprint combines a variety of climate-related policies, including a C&T program, an RPS, required use of advanced coal technology and a pilot CCS program, a variety of EE standards and building codes, R&D, increased reliance on combined heat and power technologies, and programs to encourage more efficient industrial use of energy. On the oil side, the Blueprint includes a carbon emissions standard for vehicles, a low-carbon fuel standard, required use of alternative vehicles, implementation of smart growth policies, and pay-as-you-drive insurance. NEMS does not permit many of these Blueprint components to be modeled, so many of the technology penetration calculations and effectiveness calculations are made offline, with the use of NEMS mostly to provide a baseline and an accounting structure. The UCS reference case is based on *AEO2008*, so the Blueprint can take credit for CO_2 and oil reductions that would have occurred from policies implemented in 2009 that are included in our baseline.

UCS's Findings. Key metrics for UCS are "cost savings," CO_2 emissions reductions, and oil use per day. The term *cost savings* appears to indicate engineering estimates for the net costs of efficiency investments that do not take into account purchasers' behavior in demanding rapid payback periods and ignoring fuel savings beyond this period. Thus, this study finds huge cost savings from EE investments. They also count revenues from auctioning allowances, which are considered transfers by economists and are therefore not counted in this study as welfare benefits.

Because UCS combines so many policies within the Blueprint, it is difficult to understand the key drivers of the results—although some can be inferred. GHG emissions are reduced by 56 percent below 2005 levels by 2030 at a cost of $70 per ton in that year; this contributes a new "data point" to our study. Oil reductions fall from 2005 levels by 6 mmbd in 2030 and 3.4 mmbd by 2020, which implies very large reductions from the Blueprint as oil prices in *AEO2008* are lower than those in *AEO2009*. An offline use of a model for biofuels, as well as pay-as-you-go insurance, mandates for alternative fuels, smart growth policies, and, in effect, steep fuel economy standards (implicit in the use of carbon standards), are all responsible for this large reduction in oil use.

McKinsey Study

One of the most well-known diagrams in the area of energy policy is what McKinsey & Company calls its "Mid-range Abatement Curve — 2030," found in Creyts et al. (2007). This curve is actually a bar graph that arrays technologies for reducing GHG emissions from the most cost-effective to the least (i.e., from the lowest cost per ton reduction to the highest). The vertical axis is cost per ton (which for many policies is negative) and the horizontal axis is potential tons of GHG emissions reductions per year. The width of each bar varies depending on the technology's effectiveness in reducing GHG emissions.

The tops of the bars trace out a useful curve: one can decide on a desired level of reductions and read off the technologies that would deliver that reduction most cost-effectively, or one can use the curve to set a cost-effectiveness target (say, $50 per ton) and read off the emissions reductions from the technologies that are cheaper than the target.

Notably, the McKinsey abatement curve is largely populated with *technologies*, whereas our report focuses on *policies*—two very different analyses. Even a policy mandating the use of a technology will have a variety of stipulations and limitations that at least implicitly address concerns about cost and the speed of technology penetration. Nonetheless, an interesting and relevant comparison between the two studies can be made in looking at fuel economy standards for light-duty vehicles, as this is covered in both studies.

Creyts et al. calculate that their fuel economy standard (which would "enable light-duty vehicles to improve their average fuel economy from 25 to 40 miles per gallon in the mid-range case" [Creyts et al. 2007, 27]) has a cost-effectiveness of –$80 per ton and "potentially" delivers 0.13 billion tons of carbon reductions per year by 2030. In contrast, we find that costs are relatively large for our Pavley CAFE policy ($121 billion using the No Market Failure rate, dropping to $45 billion assuming Partial Market Failure, and turning negative with Complete Market Failure), leading to cost-effectiveness estimates ranging from $85 per ton to –$22 per ton. How can these differences be explained?

Creyts et al.'s negative costs are derived by adding up the extra costs for each vehicle class that are due to the adoption of fuel-saving technologies required to meet the tighter fuel economy standard. The value of lifetime fuel savings is then subtracted from these costs, where savings are discounted at a "market" rate of 7 percent. It turns out that the costs are negative in this case.

Our analysis has some similar components, in that we include the costs of fuel-saving technologies net of lifetime fuel savings. However, we go further by accounting for how consumers respond to the regulation. Our measure of social cost includes the loss of benefit to those households that now choose not to buy new (higher-priced) vehicles, net of savings in production costs. It also includes the loss of utility to consumers who shift away from their most preferred vehicles to more fuel-efficient vehicles as a result of the regulation. We also consider increases in vehicle usage in response to lower per-mile fuel costs—the rebound effect—when we compute lifetime fuel savings. And we include in social costs the loss of fuel tax revenue to the government from reduced gasoline demand.

Finally, based on observed behavior, NEMS assumes that consumers take into account fuel savings from improvements in new-vehicle fuel economy for only the first two to four years of the vehicle's life, which is equivalent to discounting fuel savings over the vehicle's entire life at around 40 percent. In our No Market Failure case, we assume that these higher discount rates implicitly reflect hidden costs, and therefore we implicitly use the high rates in computing the value of fuel savings. This will make these CAFE mandates very costly and may limit their penetration below that assumed by Creyts et al. We also implicitly use an alternative lower discount rate (10 percent) to account for the possibility that there are market failures when we calculate costs, and revert to a social discount rate of 5 percent for the Complete Market Failure case.

Appendix F: Technical and Background Papers

The findings in this study draw on various technical and background papers commissioned by Resources for the Future and the National Energy Policy Institute as part of this project. These papers are available on the RFF website (www.rff.org) and the NEPI website (www.nepinstitute.org).

- *Oil and Gas Security Issues.* John Deutch (Massachusetts Institute of Technology)
- *Estimating U.S. Oil Security Premiums.* Stephen P.A. Brown (Resources for the Future) and Hillard G. Huntington (Stanford University)
- *The Future of Natural Gas.* Steven Gabriel (University of Maryland)
- *Abundant Shale Gas Resources: Some Implications for Energy Policy.* Stephen P.A. Brown (Resources for the Future), Steven Gabriel (University of Maryland), and Ruud Egging (University of Maryland)
- *Energy Policies for Passenger Transportation: A Comparison of Costs and Effectiveness.* Kenneth A. Small (University of California–Irvine)
- *Hybrid Vehicles and Policies to Reduce GHG Emissions.* Virginia McConnell (Resources for the Future) and Tom Turrentine (Center for Transportation Studies, University of California–Davis)
- *The Prospective Role of Unconventional Liquid Fuels.* Joel Darmstadter (Resources for the Future)
- *Economics, Energy and GHG Implications of LNG Trucks.* Alan J. Krupnick (Resources for the Future)
- *Using Cap-and-Trade to Reduce Greenhouse Gas Emissions.* Lawrence H. Goulder (Stanford University)
- *Energy Efficiency in the Residential and Commercial Sectors.* Maximilian Auffhammer (University of California–Berkeley) and Alan H. Sanstad (Lawrence Berkeley National Laboratory)
- *Residential Retrofit Ground Source Heat Pump Benefits Assessment.* Xiaobing Liu (Oak Ridge National Laboratory)
- *Nuclear Energy in the US National Energy Modeling System: 2010–2030.* Geoffrey Rothwell (Stanford University)
- *Modeling Policies to Promote Renewable and Low Carbon Sources of Electricity.* Karen Palmer, Maura Allaire, and Richard Sweeney (Resources for the Future)
- *The Effects of State Laws and Regulations on the Development of Renewable Sources of Electric Energy.* Gary Allison (University of Tulsa) and John Williams (University of Tulsa)

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