

## CHAPTER 2

## Our Approach

The Climate 2030 Blueprint provides a path for reducing U.S. heat-trapping emissions through 2030, based on scientific findings about the long-term cuts in emissions necessary to avoid the worst consequences of global warming (see Chapter 1). The long-term goals of that path are:

- To reduce annual U.S. emissions at least 80 percent from 2005 levels by 2050.
- To constrain cumulative U.S. emissions to the mid-range of a 2000–2050 U.S. “carbon budget” of 165–260 gigatons CO<sub>2</sub> equivalent.

The Blueprint shows how to achieve near-term and medium-term cuts in emissions through 2030 consistent with those long-term goals.

To produce the Blueprint, we considered how to curb global warming emissions from most major sources, including electricity, industry, buildings, and trans-

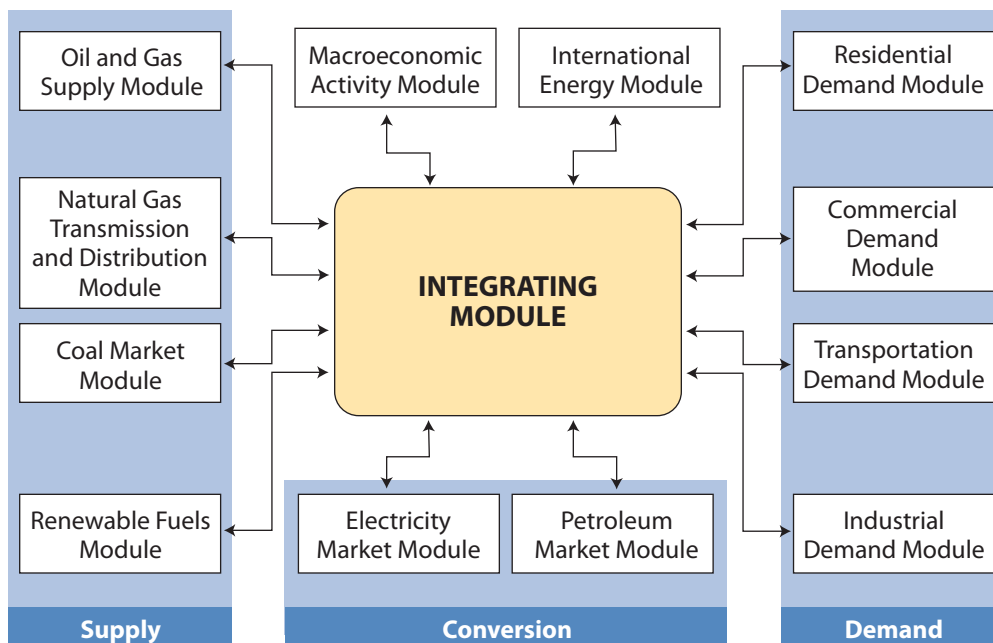
portation, as well as some opportunities for storing carbon in U.S. forests and agricultural lands. This chapter describes how we evaluated the costs and benefits of various technologies and policies for moving along that path.

### 2.1. Our Model

To analyze potential cuts in U.S. emissions, we relied primarily on a modified version of the National Energy Modeling System (NEMS), developed by the Energy Information Administration (EIA), an independent division of the U.S. Department of Energy (DOE).

NEMS is a comprehensive model that forecasts U.S. energy use and emissions from the electricity, transportation, industrial, and buildings (residential and commercial) sectors. The model works by applying a variety of assumptions about technological progress and household and business behavior. It then

FIGURE 2.1. National Energy Modeling System (NEMS)



The Climate 2030 Blueprint uses a modified version of NEMS to create a forecast of the next 20 years under existing conditions. New climate, energy, and transportation policies and more advanced technologies were then added to the model to evaluate their carbon emissions-cutting potential. The Blueprint also supplemented the NEMS model with additional energy efficiency and biomass analyses.

selects the technologies that can best enable the nation to meet its projected energy needs, given the assumed constraints.

The EIA uses NEMS each year to forecast U.S. energy production, demand, imports, prices, and expenditures—as well as carbon emissions—through 2030. The resulting report, known as the Annual Energy Outlook (AEO), includes a reference case based on policies in place at the time, and several “sensitivity” cases based on changes to key assumptions. The EIA also receives numerous requests from Congress to use NEMS to assess the effects of proposed climate and energy legislation.

Our approach is similar, in that we used a modified version of NEMS to create a forecast under existing policy conditions, which we call our Reference case. We then applied new climate, energy, and transportation policies to evaluate their impact in cutting heat-trapping emissions, which we call our Blueprint case.

We call our modified model UCS-NEMS (see Appendices A–G online for more on how we modified the model). We supplemented UCS-NEMS with separate analyses of the potential for making industry and buildings more efficient, and of the biomass resources potentially available to produce electricity and liquid fuel for transportation.

## 2.2. The Reference Case

We began our analysis with the version of NEMS used to produce *Annual Energy Outlook 2008* (EIA 2008a). The Reference case in that version of the model includes the EIA’s estimates of the effects of the 2007 Energy Independence and Security Act. That law will deliver significant cuts in carbon emissions from the transportation sector by increasing fuel economy standards for cars and light trucks, and by creating a renewable fuel standard with a low-carbon requirement for most biofuels.

To establish our Reference case, we applied a variety of modifications and updates to the *AEO 2008* version of the NEMS model. For example, we modified its assumptions about the costs and performance of several energy and transportation technologies, based on data from actual projects, information from more recent studies, and input from experts. We also used the EIA’s assumptions from its *AEO 2008* High Price case, which assumes higher energy prices and commodity costs. These values are more in line with the reference case forecast in *AEO 2009*, released in April 2009 (EIA 2009).

We further updated the model to include tax credits for renewable and conventional energy technologies in



**Insulating homes saves energy and decreases heating and cooling bills. In the Climate 2030 Blueprint, reductions in energy use resulting from efficiency measures were calculated in a separate analysis and then modeled in NEMS to determine net energy bill savings from using less electricity and fuel in homes, businesses, and industrial facilities.**

the Economic Stimulus Package signed into law in October 2008, new state renewable electricity standards, and the existing \$18.5 billion nuclear loan guarantee program. However, our Reference case does not include the tax credits and incentives in the American Recovery and Reinvestment Act of 2009. (See Chapter 7 for the results of the Reference case, and the online appendices for more information on these and other modifications.)

## 2.3. The Climate 2030 Blueprint Case

We then developed a Blueprint case to examine the impact of bundling a cap-and-trade program with a range of complementary energy and transportation policies. We chose policies that other analyses—and real-life experience—have shown are effective in surmounting market barriers to deploying technologies that would lower energy bills and the costs of a cap-and-trade program for households and businesses (see Box 2.1). These policies stimulate improvements in energy efficiency and more widespread use of renewable energy in the industry and buildings and electricity sectors, along with cleaner cars and trucks, better transportation choices, and low-carbon fuels in the transportation sector.

We relied on an analysis by the American Council for an Energy-Efficient Economy (ACEEE) to

calculate the energy and cost savings that result from the efficiency improvements in industry and buildings.<sup>17</sup> UCS-NEMS modeled the energy savings as drops in electricity demand and direct fuel use in industry and buildings.

The Blueprint case also included at least eight large-scale carbon-capture-and-storage (CCS) demonstration projects with advanced coal plants—consistent with the recommendation in the UCS report *Coal Power in a Warming World* (Freese, Clemmer, and Noguee 2008). Such projects can help address the technical, regulatory, and commercialization challenges of large-scale CCS technology.

The Blueprint case also accounted for existing incentives to develop and build advanced coal and nuclear plants. These include tax credits for both technologies as well as a range of risk-shifting and regulatory subsidies for nuclear plants, such as loan guarantees, insurance against licensing delays, and limits on liability.

After running the model with these modifications, we then used it to produce a “sensitivity” case—which we called the No Complementary Policies case—that stripped out the Blueprint’s complementary energy and transportation policies.

## 2.4. The Blueprint Cap on Global Warming Emissions

A key input in the Blueprint and sensitivity cases was a trajectory for cuts in heat-trapping emissions under a cap-and-trade program beginning in 2011. We

defined the U.S. cap on such emissions as a reduction of 26 percent below 2005 levels by 2020, and a drop of 56 percent below 2005 levels by 2030 (see Figure 2.2).<sup>18</sup>

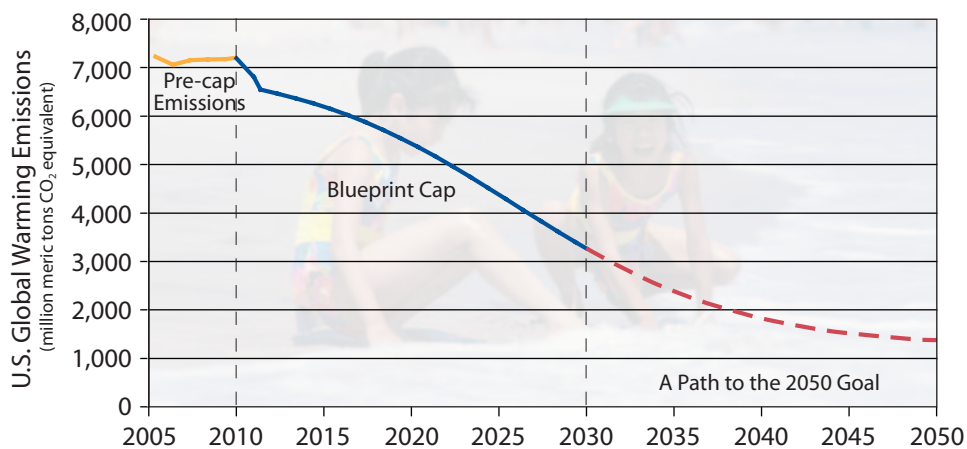
The cumulative U.S. emissions defined by the cap—in tons of CO<sub>2</sub> equivalent—were direct inputs to the NEMS model (see Table 3.1 for annual values). The model then chose the most cost-effective way to comply with the cap within the constraints we imposed. Complementary policies in various sectors of the economy help deliver the cuts set by the cap more cost-effectively—they do not reduce emissions further.

Although our modeling horizon is 2030, Figure 2.2 extends the trajectory of cuts in emissions to 2050, to show that the United States will have to continue to reduce its emissions after 2030. Cuts in emissions called for by the cap accelerate each year through 2030, as the ability to manufacture and deploy low-carbon technologies grows over time. The cap continues to tighten after 2030, but at a reduced annual rate.

Other scenarios could be designed to meet the same criteria—or even show more aggressive cuts in heat-trapping emissions.

In our approach, we allowed capped firms to bank and withdraw carbon allowances (permits to emit one ton of carbon). That is, if it is cost-effective to do so, firms can choose to over-comply with the cap and bank the excess allowances for use in later years to lower emissions and costs. The result is an *actual* trajectory for emissions that differs from the trajectory specified

FIGURE 2.2. U.S. Emissions Cuts under the Blueprint Cap



**For the years 2005 to 2010, this trajectory reflects the Reference case. For the years 2011 to 2030, we modeled the impact of a cap on cumulative emissions. The trajectory beyond 2030 simply continues the deep reductions needed to stay within a long-term carbon budget, though we did not actually model what would happen from 2030 to 2050.**

17 ACEEE conducted this analysis on our behalf. See Appendix C online for more details.

18 This differs from the recommendation in Chapter 1, which encompasses more possibilities for cutting emissions than UCS-NEMS could model, such as curbs on tropical deforestation.

by the inputs.<sup>19</sup> We assumed that the bank has no allowances left by 2030: that is, that there is a zero terminal bank balance. That means firms are exactly in compliance with the cap at that point.

Other studies have assumed that banks do have allowances remaining at the end of the modeling period. If the nation needs deeper cuts in emissions beyond the modeling horizon, such banked allowances could help capped firms meet their cap in those years.

For example, the EIA modeling of the cap-and-trade system in the proposed 2008 Lieberman-Warner Climate Security Act assumed an ending balance of 5 billion metric tons of CO<sub>2</sub> (EIA 2008). While valid, that choice is somewhat arbitrary. To accurately assess the “right” terminal bank balance, we would need precise information on the availability and cost-effectiveness of technologies for reducing emissions after 2030. In light of these uncertainties, our choice of a zero balance

<sup>19</sup> While the model ran without constraining borrowing, the results show only banking and withdrawing. That is, the model shows no negative bank balances in any given year. This is actually the preferred policy approach because it prevents the capped sectors from delaying technological change, and also prevents the buildup of unsustainable levels of borrowing.

### BOX 2.1.

## Understanding Market Barriers to Climate Solutions

**M**any studies have documented market barriers to the development and use of cost-effective energy efficiency, conservation, and renewable energy solutions (see Chapters 4–6).

One major market failure is that energy prices do not include all the environmental, health, and national security costs of burning fossil fuels—which greater reliance on energy efficiency, conservation and renewable energy would avoid.

A second major market failure is “risk aversion”: the reluctance of households and businesses to invest in climate solutions that have high up-front costs but long-term financial benefits.

A third major market failure is “split incentives” between building owners and renters. Owners do not make efficiency improvements because they do not pay the utility bills. Renters will not make the up-front investment because they are unlikely to occupy the building for long. These split incentives also exist between home developers and purchasers, and in other parts of the economy.

Other market barriers include:

- Lack of information and expertise on solutions to global warming
- Lack of capital needed for up-front investments in global warming solutions
- Lack of a core infrastructure and manufacturing capacity to support increased use of renewable energy, energy efficiency, advanced vehicle technologies, and expanded mass transit

Specific policies targeted at increasing energy efficiency, conservation, and renewable energy, such as those



**Energy prices in the United States do not include all the health, environmental, and national security costs of burning fossil fuels. Burning coal to generate electricity and gasoline in cars, for example, are significant causes of poor air quality, which in turn contributes to asthma and other respiratory problems. Increased energy efficiency and use of renewable energy can help avoid these costs.**

in the Climate 2030 Blueprint, can directly address these market failures and barriers. Such policies can reduce consumers’ overall costs more than energy price signals—such as those resulting from a cap-and-trade program—alone.



To determine net energy bill savings by households and businesses, the Climate 2030 Blueprint started with the combined savings on energy bills (from reduced energy use), then subtracted out the cost of purchasing more energy-efficient products such as appliances and vehicles, as well as the carbon costs passed through to consumers and businesses from their energy providers.

allows us to test the feasibility and cost-effectiveness of efforts to exactly meet the cap. However, other scenarios deserve exploration.

## 2.5. The Blueprint Analysis of Energy Efficiency

As noted, the Blueprint includes a supplemental analysis by the American Council for an Energy-Efficient Economy that accounts for the savings in energy and costs of nine policies and programs aimed at making industry and buildings more energy efficient.

We used the resulting national energy savings to reduce electricity demand and direct fossil fuel use in each economic sector each year. The model then distributed the energy savings across different regions of the country. In the residential sector, the model also distributed energy savings proportionally across different end-use categories, such as space heating and water heating. The model then determined the impact of the energy savings on electricity generation, the amount of fossil fuel used to produce electricity, carbon dioxide emissions, energy prices, and energy bills.

Finally, the Blueprint subtracted the investment and policy costs resulting from the efficiency analysis from savings on energy bills to determine the net savings on energy bills for consumers and businesses. (For more information, see Appendix C online.)

## 2.6. The Blueprint Analysis of the Biomass Supply Curve

The Blueprint also relied on a separate analysis of the amount of biomass from plant cellulose that is potentially available for use in producing electricity and

liquid fuel for transportation at different prices. Marie Walsh, an agricultural economist with the University of Tennessee, and formerly of Oak Ridge National Laboratory (ORNL), conducted this analysis.

Walsh and her colleagues at ORNL developed the original supply curves used by the EIA for each of the main biomass feedstocks: energy crops (switchgrass), agricultural residues (corn stover and wheat straw), forestry residues, urban wood waste, and mill residues. The EIA model included a supply curve for each biomass feedstock for each year through 2030, and for 13 U.S. regions. The model added the data from those curves to get a total biomass supply curve for each region, and for the nation as a whole.<sup>20</sup>

Walsh and her colleagues at the University of Tennessee updated the supply curves for energy crops, agricultural residues, and corn for the EIA's 2007 analysis. That analysis assumed that the nation would enact policies requiring 25 percent of the electricity and energy used for transportation to come from renewable sources by 2025 (EIA 2007). The report based the supply curves on new runs of an economic forecasting model for agriculture called POLYSYS. Starting with a 2006 baseline forecast by the U.S. Department of Agriculture, the POLYSYS model projected the tonnage of all major crops and calculates changes in land use, based on the price of biomass and corn in each of 305 agricultural statistical districts.

We used those supply curves, with one exception. We reduced the amount of biomass available from energy crops by 50 percent, to account for potential indirect land-use effects that would increase carbon emissions. Such effects occur when energy crops are

<sup>20</sup> The supply curve for corn is separate from that for cellulosic biomass. However, some sources of cellulosic biomass can be grown on land that could otherwise be used to grow corn, creating competition for land that can drive up the price of corn crops. UCS-NEMS does not capture this impact.



**The Blueprint includes a supplemental analysis of cellulosic biomass energy that is potentially available for energy use in the United States. Biomass feedstocks are energy crops (switchgrass), agricultural residues (corn stover and wheat straw), forestry residues, and urban wood waste and mill residues.**

grown on lands that could otherwise be used to grow food crops. That shift drives up the price of food crops and spurs the conversion of forests and other lands to cropland in the United States and other countries.

## 2.7. The Bottom Line

We chose policies for our modeling exercise with great potential to deliver critical science-based cuts in emissions cost-effectively, without other harmful consequences. We have tried to make all our assumptions transparent, so others can evaluate them on their merits. Other assumptions and combinations of technologies and policies are also possible. Analysts who investigate those alternatives should do so in a similarly transparent manner.

The rest of this chapter summarizes our major technology and policy assumptions, for quick reference. Chapters 3–6 explore these assumptions in more detail and with more context, while the appendices provide additional information. Chapter 7 presents the results of our analysis.

## 2.8. Summary of Blueprint Assumptions

### 2.8.1. Key Assumptions for the Cap-and-Trade Program

We used UCS-NEMS to model a cap-and-trade program broadly in keeping with the design criteria outlined in Chapter 3, except when constrained by specific

limitations in the model. We made the following assumptions (see Appendix B online for more details):

- The United States places a cap on global warming emissions starting in 2011. This cap declines to 26 percent below 2005 levels by 2020, and 56 percent below 2005 levels by 2030. The cap ensures that the nation is on track to stay within a mid-range carbon budget—that is, cumulative emissions—of 160–265 gigatons CO<sub>2</sub> equivalent from 2000 to 2050 (see Table 3.1).
- The sectors of the economy covered by the cap include electricity generation, transportation, and the industrial, commercial, and residential sectors. Household emissions from sources other than electricity are not covered.
- The cap covers emissions of all major heat-trapping gases, including CO<sub>2</sub> from energy production and use; CO<sub>2</sub> from cement and lime production; methane (CH<sub>4</sub>) from landfills, coal mining, natural gas and oil systems, stationary and mobile combustion, and livestock; nitrous oxide (N<sub>2</sub>O) from agriculture, stationary and mobile combustion, industrial sources, and waste management; and hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF<sub>6</sub>).
- Capped firms can rely on carbon “offsets” to satisfy up to 15 percent of their allowance obligations. That is, rather than cutting their emissions directly, capped companies can offset them by paying uncapped third parties to reduce their emissions or increase carbon storage. We divided the allowable offsets between domestic (a maximum of 10 percent of the cap) and international (a maximum of 5 percent of the cap).
- The federal government auctions all allowances for firms to emit carbon. However, UCS-NEMS did not allow us to channel the revenues from such auctions to investments in energy efficiency and renewable energy, or to households and businesses that may be disproportionately affected by the cap-and-trade system. We therefore simply assumed that all the proceeds from the allowance auctions would be recycled back into the economy in a general way.
- The Blueprint cap-and-trade system does not include a “safety valve”—that is, an upper limit on the price of carbon. Nor does it impose an auction reserve price, which would set a minimum price for allowances.
- Firms can bank and borrow allowances to emit carbon. We assumed that no allowances would remain in that bank in 2030. That is, the capped firms

together exactly meet the target for emissions by that year.

UCS-NEMS did not allow us to model U.S. links to international cap-and-trade programs to reduce heat-trapping emissions. We were also unable to model any “leakage” of emissions: that is, undercounting of emissions stemming from imports and exports of energy-intensive goods.

### 2.8.2. Key Assumptions for Energy Efficiency

See the table on page 28.

### 2.8.3. Key Assumptions for Electricity

#### 2.8.3.1. Key Assumptions for Technologies Used to Produce Electricity

**Escalation of construction costs.** We included recent increases in construction and commodity costs for all technologies, based on data from actual projects, input from experts, and power plant cost indices. We assumed that the costs of all technologies continue to rise 2.5 percent per year (after accounting for inflation) until 2015.

**Wind.** We included land-based, offshore, and small wind technologies. We based our capital costs on a large sample of actual projects from a database at Lawrence Berkeley National Laboratory (LBNL). We used an analysis from the National Renewable Energy Laboratory (NREL), conducted for the EIA, to develop regional wind supply curves that include added costs for siting, transmitting, and integrating wind power as its use grows.

We also assumed increases in wind capacity factors (a measure of power production) and a 10 percent reduction in capital costs by 2030 from technological learning, based on assumptions from a report from the DOE on producing 20 percent of U.S. electricity from wind power by 2030 (EERE 2008).

**Solar.** We assumed expanded use of concentrating solar power (CSP) and distributed (small-scale) and utility-scale photovoltaics through 2020, based on actual proposals. We also assumed faster learning for solar photovoltaics, to match the EIA’s assumptions for other emerging technologies. We assumed that the amount of heat that CSP can store to produce electricity during periods of high demand rises over time.

**Bioenergy.** Key technologies included burning biomass along with coal in existing coal plants, dedicated biomass gasification plants, the use of biomass to produce combined heat and power in the industrial sector, and the use of methane gas from landfills.

**Geothermal.** We included a supply curve for hydrothermal and enhanced geothermal systems in the West, developed by NREL and other experts. This supply curve incorporates recent increases in the costs of exploring potential sites, drilling, and building geothermal power plants.

**Hydropower.** We assumed incremental amounts of hydropower from upgrades and new capacity at



Farmers and property owners who lease their land for wind farms—such as these landowners in Somerset, PA—enjoy a steady stream of extra income, while nearby towns and communities benefit from a larger tax base.

The Searsburg, VT, wind project reduces CO<sub>2</sub> emissions in New England by more than 6,600 tons annually—the equivalent of taking over 900 cars off the road.

Key Policies for Improving the Energy Efficiency of Industry and Buildings	Total Savings in 2030 (in End-Use Quads)	Total Cost in 2030 (in Billions of 2006 Dollars)	
		Program	Investment
<b>Appliance and equipment standards:</b> The federal government upgrades energy efficiency standards or establishes new ones for 15 types of appliances and equipment over the next several years.	1.8	0.50	11.45
<b>Energy efficiency resource standard (EERS):</b> Federal standards rise steadily to 20 percent for electricity and 10 percent for natural gas by 2030.	3.7	1.63	16.26
<b>Building energy codes:</b> New codes cut energy use in new residential and commercial buildings 15 percent annually until 2020, and 20 percent annually from 2021 to 2030.	1.2	2.12	14.19
<b>Advanced buildings:</b> An aggressive program ramps up and results in an additional 15 percent drop in energy use in new residential and commercial buildings by 2023 (beyond minimum building codes), with savings continuing at that level through 2030.	1.1	3.96	21.78
<b>Research and development:</b> Annual R&D investments reach \$4.6 billion in 2030, and stimulate additional private-sector investments that reach \$18.5 billion that year. These investments result in a 4.4 percent reduction in U.S. energy use by 2030.	1.8	4.65	18.50
<b>Combined heat and power (CHP):</b> A range of barrier-removing policies and annual investments in federal and state CHP programs lead to about 88,000 megawatts of new capacity by 2030—an average annual addition of 4,000 megawatts.	0.6	0.06	27.57
<b>Industrial energy efficiency:</b> Expanded federal programs, combined with local programs that support plant-level efforts, reduce industrial fuel use 10 percent (beyond that achieved by EERS and CHP) by 2030.	1.7	0.36	2.58
<b>Rural energy efficiency:</b> The federal government expands its Farm Bill Section 9006 technical assistance grants.	0.01	0.003	0.02
<b>Petroleum feedstocks:</b> Wider use of recycled feedstocks cuts industrial use of petroleum feedstocks 20 percent by 2030.	0.3	0.02	0.15
<b>TOTAL</b>	12.1	13.40	113.55



existing dams, and counted both new sources of power as contributing to a national standard for renewable electricity.

**Carbon capture and storage.** We included this as an option for advanced coal gasification and natural gas combined-cycle plants, with costs and performance based on recent studies and proposed projects.

**Nuclear.** We assumed that existing plants are relicensed and continue to operate through their 20-year license extension, and that they are then retired, as the EIA also assumes. We based assumptions on the costs and performance of new advanced plants primarily on recent project proposals and studies.

**Transmission.** We included the costs of new capacity for transmitting electricity for all renewable, fossil fuel, and nuclear technologies. We also added costs for the growing amounts of wind power, based on the NREL analysis conducted for the EIA.

See Appendix D online for more details.

### 2.8.3.2. Key Assumptions for Electricity Policies

Policies in the Reference case include:

**State renewable electricity standards.** These specify the amount of electricity that power suppliers must obtain from renewable energy sources. We replaced the EIA's estimate with our own projections for state standards through 2030. We applied those projections to the 28 states—plus Washington, DC—with such standards as of November 2008.

**Tax credits.** We included the tax credit extensions for renewable energy and advanced fossil fuel technologies that were part of the Economic Stimulus Package (H.R. 6049) passed by Congress in October 2008.

**Nuclear loan guarantees.** We assumed that the \$18.5 billion in loan guarantees spur the construction of four new nuclear plants with 4,400 megawatts of capacity by 2020, based on applications received by the U.S. Department of Energy in October 2008.

Additional policies in the Blueprint include:

**Efficiency.** Policies to increase energy efficiency in buildings and industry (see Chapter 4) reduce electricity demand 35 percent by 2030, compared with the Reference case.

**Combined heat and power (CHP).** Policies and incentives to increase the use of natural gas combined-heat-and-power systems in industry and commercial buildings (see Chapter 4) enable this technology to provide 16 percent of U.S. electricity generation by 2030.

**National renewable electricity standard.** This standard requires retail electricity providers to obtain

40 percent of remaining electricity demand (after reductions for efficiency improvements and CHP) from renewable energy (wind, solar, geothermal, bioenergy, and incremental hydropower) by 2030.

**Coal with carbon capture and storage (CCS) demonstration program.** This new federal program provides \$9 billion to cover the incremental costs of adding CCS at eight new full-scale advanced coal plants—known as integrated gasification combined-cycle plants, which turn coal into gas—from 2013 to 2016 in several regions.

**Transmission.** We included the costs of new capacity for transmitting electricity for all renewable, fossil fuel, and nuclear technologies. We also added costs for the growing amounts of wind power, based on the NREL analysis conducted for the EIA.



**A combined-heat-and-power plant at the University of New Hampshire provides heating, cooling, and electricity to the majority of buildings on the main campus while reducing carbon emissions and saving money.**

#### 2.8.4. Key Assumptions for Transportation Technology

**Cars and light trucks.** We based the cost and performance of technology for improving the fuel economy of cars and light trucks on the NEMS advanced technology case. That case is slightly more pessimistic than UCS estimates, but it is more optimistic and includes more technology options than estimates by the National Research Council (NRC 2002).

**Medium- and heavy-duty truck technology.** We based the cost and performance of these vehicles on the NEMS advanced technology case. However, we modified the cost and performance of hybrids, and technologies to improve vehicle and trailer aerodynamics, based on discussions with the authors of a forthcoming report on the fuel-economy potential of heavy-duty vehicles (Cooper et al. forthcoming).

**Vehicle air conditioning.** We based the cost and performance of improved air conditioning on information from the California Air Resources Board (CARB 2008), and on a UCS research report (Bedsworth 2004). The latter assumed that manufacturers switch to HFC-152a, though a switch to HFO1234yf could provide even greater reductions in heat-trapping emissions.

**Biofuels.** Key technologies include ethanol from plant cellulose and biomass-to-liquid gasification technology. We initially based the costs for both on the NEMS High Commodity Cost case. However, we then reduced the cost of cellulosic ethanol by 38 percent, based on data from NREL. Biomass resources include crop residues and dedicated energy crops such as switchgrass. We excluded forest, urban, and mill residues because of limitations in the NEMS model. We also excluded 50 percent of crop-based resources, to reflect sustainability criteria and minimize indirect effects on land use.

**Refineries.** We assumed a 10 percent increase in refinery efficiency, based on an assessment of existing potential by analysts from the LBNL.

**Advanced vehicles.** The portfolio of potential advanced vehicles includes plug-in hybrids, battery-electric vehicles, and fuel cell vehicles. We used plug-ins as the sole technology for ease of modeling, rather than applying a performance-based requirement for advanced vehicles. However, other technologies with equal performance could substitute. We drew information on the cost and performance of plug-ins from research at MIT (Bandivadekar et al. 2008).

**Transit.** We based the costs of doubling the amount of public transit nationwide on estimates from the American Association of State Highway and Transportation Officials (AASHTO).

**Pay as you drive.** We based the driver response to pay-per-mile policies on studies from Cambridge Systematics (Coward 2008) and the Brookings Institution (Bordoff and Noel 2008). We used the analysis from the Brookings Institution to determine the costs of GPS-based odometer tracking.



**Moving containerized freight long distances by rail is far more energy-efficient than moving those goods by truck, releasing fewer carbon emissions and alleviating truck traffic on our nation's highways.**

<b>Fuel Economy Potential and Costs Used in the Climate 2030 Blueprint</b>	<b>Cars and Light-Duty Trucks</b>	<b>Medium-Duty Trucks</b>	<b>Heavy-Duty Trucks</b>
2005 Baseline Fuel Economy (mi/gallon gasoline eq)	26	8.6	6
2020 Fuel Economy for New Vehicles (mi/gallon gasoline eq)	42	11	8
2020 Incremental Cost vs. 2005 (2006 dollars)	\$2,900	\$6,000	\$15,800
2030 Fuel Economy for New Vehicles (mi/gallon gasoline eq)	55	16	9.5
2030 Incremental Cost vs. 2005 (2006 dollars)	\$5,200	\$14,900	\$40,500

Notes: These potentials and costs are based on assumptions in the AEO 2008 NEMS high technology case, as modified by the authors, and modeling runs of UCS-NEMS. The values in our Blueprint case model runs may not match these levels because of limitations in the model. See Appendix E online for details.

<b>Standards for Vehicle Global Warming Emissions</b>	<b>Cars and Light-Duty Trucks</b>	<b>Medium-Duty Trucks</b>	<b>Heavy-Duty Trucks</b>
<b>2005 Baseline Global Warming Emissions (g/mi CO<sub>2</sub>eq)<sup>a</sup></b>	<b>372</b>	<b>1,038</b>	<b>1,489</b>
Fuel Economy (mi/gallon gasoline eq)	24	8.6	6
Non-CO <sub>2</sub> Emissions Estimate (g/mi CO <sub>2</sub> eq)	2	5	8
<b>2020 Standard for Global Warming Emissions (g/mi CO<sub>2</sub>eq)<sup>a</sup></b>	<b>198</b>	<b>777</b>	<b>1,072</b>
Fuel Economy (mi/gallon gasoline eq)	42	11	8
CO <sub>2</sub> Emissions with Current Gasoline (g/mi CO <sub>2</sub> eq) <sup>b</sup>	212	808	1,111
Non-CO <sub>2</sub> Emissions Estimate (g/mi CO <sub>2</sub> eq) <sup>c</sup>	2	5	8
Credit for Improved A/C (g/mi CO <sub>2</sub> eq) <sup>d</sup>	-8	-8	-8
Credit for Low-Carbon Fuel Standard (g/mi CO <sub>2</sub> eq) <sup>e</sup>	-7	-28	-39
<b>2030 Standard for Global Warming Emissions (g/mi CO<sub>2</sub>eq)<sup>a</sup></b>	<b>139</b>	<b>497</b>	<b>842</b>
Fuel Economy (mi/gallon gasoline eq)	55	16	9.5
CO <sub>2</sub> Emissions with Current Gasoline (g/mi CO <sub>2</sub> eq) <sup>b</sup>	162	555	935
Non-CO <sub>2</sub> Emissions Estimate (g/mi CO <sub>2</sub> eq) <sup>c</sup>	2	5	8
Credit for Improved A/C (g/mi CO <sub>2</sub> eq) <sup>d</sup>	-8	-8	-8
Credit for Low-Carbon Fuel Standard (g/mi CO <sub>2</sub> eq) <sup>e</sup>	-16	-56	-94

Note: Values may not sum properly because of rounding.

- a We calculated global warming emissions as the sum of CO<sub>2</sub> and non-CO<sub>2</sub> emissions from today's gasoline, minus cuts in emissions from the use of better air conditioning and low-carbon fuels.
- b In converting fuel economy into CO<sub>2</sub> equivalent, we assumed 8,887 grams of CO<sub>2</sub> per gallon of today's gasoline burned.
- c We scaled up estimates of non-CO<sub>2</sub> heat-trapping emissions for medium- and heavy-duty trucks from those for light-duty vehicles based on relative fuel consumption. We expect to update these numbers as more accurate data become available. These estimates do not include black carbon.
- d Note that 8 grams per mile is a conservative estimate for cars and light trucks based on Bedsworth 2004 and CARB 2008. We have no data for medium- and heavy-duty vehicles. However, given that they have larger air conditioning systems (and thus greater potential for absolute savings) but travel farther (reducing the per-mile benefit), we used 8 grams per mile as a rough value pending more information.
- e All fuels achieve the average low-carbon standard in Table 6.4.



A Look at Cellulosic Ethanol in 2030			
Resource, Yield and Potential		Costs	
Biomass Resources Available for Transportation (million tons)	280	Fixed Production Costs (in 2006 dollars per gallon)	\$0.128
Ethanol Yield (gallons per ton)	110	Non-Feedstock Variable Costs (in 2006 dollars per gallon)	\$0.17
Maximum Biofuel Potential (billion gallons ethanol equivalent)	30	Initial Capital Cost (in 2006 dollars per gallon of capacity)	\$1.99

Note: In our Blueprint analysis, actual production of cellulosic ethanol may be lower, as it competes with biomass-to-liquids technology for access to biomass resources. However, the total volume of low-carbon biofuels will be similar.

Potential of Advanced Vehicles and Fuels	2020	2030
Low-Carbon Fuel Standard: Reduction in Carbon Intensity for All Transportation Fuels vs. 2005 <sup>a</sup>	3.5%	10%
Sales of Advanced Light-Duty Vehicles Spurred by Regulations <sup>b</sup>	2.0%	20%

Notes:

- a This standard would require a reduction in life-cycle grams of CO<sub>2</sub> equivalent per BTU of all fuel used for transportation, including cars and light trucks, medium- and heavy-duty vehicles, rail, air, shipping, and other miscellaneous uses. If the standard is restricted to highway vehicles (cars, light trucks, and medium- and heavy-duty vehicles), the figure for 2020 would be 4.5 percent, and that for 2030 would be 14 percent.
- b This represents the fraction of light-duty vehicles that are plug-in hybrids, or pure battery and fuel cell vehicles delivering equivalent benefits.

Potential for Reducing Vehicle Miles Traveled	2020	2030
<b>Assumed Policy Impact: Reduction in Annual Growth in Vehicle Miles Traveled (VMT)<sup>a</sup></b>		
Light-Duty Vehicles <sup>b</sup>	Reduce growth in VMT from baseline of 1.4% per year to 0.9% per year	
Trucks <sup>c</sup>	Reduce VMT by 0.1% per year, on top of all other policy effects	
<b>Policies and Costs for Light-Duty Vehicles</b>		
Transit <sup>d</sup>	Ramp up transit funding to reach \$21 billion per year by 2030	
Pay as You Drive		
Highway User Fee 1: Maintain Existing Funding Levels <sup>e</sup>	\$0.005 per mile	\$0.011 per mile
Highway User Fee 2: Congestion Mitigation Fee Used to Fund Transit <sup>d</sup>	\$0.004	\$0.006
Total User Fees	\$0.009 per mile	\$0.017 per mile
Pay-as-You-Drive (PAYD) Insurance <sup>e</sup>	\$0.07 per mile	\$0.07 per mile
Federal Funding for PAYD Pilot Programs	\$3 million per year for 5 years	
Tax Credit for PAYD Electronics	\$100 million per year for 5 years	
Smart Growth <sup>f</sup>	\$0.00	\$0.00
<b>Policies and Costs for Heavy-Duty Vehicles</b>		
Switch from Truck to Rail <sup>g</sup>	\$0.00	\$0.00

## Notes:

- a NEMS is unable to model the full suite of policies needed to address vehicle travel. Instead, we inserted the total reductions in vehicle miles traveled that could result from such policies into UCS-NEMS.
- b For the potential to reduce VMT from light-duty vehicles, we relied primarily on a recent analysis by Cambridge Systematics (Coward 2008), which found that growth in light-duty VMT could be reduced to 0.9 percent per year.
- c To evaluate the potential to reduce VMT from freight trucks, we assumed that policies can shift 2.5 percent of truck VMT to rail, based on potential highlighted in AASHTO 2007 and IWG 2000. This represents about a 0.1 percent annual reduction in freight truck travel. Actual freight truck travel will fall further as the economy shifts due to other policies, such as a cap-and-trade program and reduced oil use from higher vehicle efficiency.
- d The congestion mitigation fee provides this funding, so we did not count it as a cost above that fee.
- e Blueprint policies do not include these fees as a cost, because the Reference case would also need to raise the highway funding to pay for repair of existing roads, and would include the cost of insurance. Actual insurance costs would probably drop, because people would drive less under the Blueprint.
- f Smart-growth policies could actually reduce costs, so we assumed that they are cost-neutral.
- g Switching from truck to rail will likely entail some costs, but evaluating them was beyond the scope of our study.