INTRODUCTION

The National Energy Modeling System (NEMS) is a computer-based, energy-economy modeling system of U.S. energy markets for the midterm period through 2025. NEMS projects the production, imports, conversion, consumption, and prices of energy, subject to assumptions on macroeconomic and financial factors, world energy markets, resource availability and costs, behavioral and technological choice criteria, cost and performance characteristics of energy technologies, and demographics. NEMS was designed and implemented by the Energy Information Administration (EIA) of the U.S. Department of Energy (DOE).

The National Energy Modeling System: An Overview 2003 presents an overview of the structure and methodology of NEMS and each of its components. This chapter provides a description of the design and objectives of the system, followed by a chapter on the overall modeling structure and solution algorithm. The remainder of the report summarizes the methodology and scope of the component modules of NEMS. The model descriptions are intended for readers familiar with terminology from economics, operations research, and energy modeling. More detailed model documentation reports for all the NEMS modules are also available from EIA (Appendix, "Bibliography").

Purpose of NEMS

NEMS is used by EIA to project the energy, economic, environmental, and security impacts on the United States of alternative energy policies and of different assumptions about energy markets. Projections are made for each year from the present through 2025. The forecast horizon is periodically extended to approximately 20 to 25 years into the future. This time period is one in which technology, demographics, and economic conditions are sufficiently understood in order to represent energy markets with a reasonable degree of confidence. NEMS provides a consistent framework for representing the complex interactions of the U.S. energy system and its response to a wide variety of alternative assumptions and policies or policy initiatives. As an annual model, NEMS can also provide the impacts of transitions to new energy programs and policies.

Energy resources and prices, the demand for specific energy services, and other characteristics of energy markets vary widely across the United States. To address these differences, NEMS is a regional model. The regional disaggregation for each module reflects the availability of data, the regional format typically used to analyze trends in the specific area, geology, and other factors, as well as the regions determined to be the most useful for policy analysis. For example, the demand modules (e.g., residential, commercial, industrial and transportation) use the nine Census divisions, the Electricity Market Module uses 15 supply regions based on the North American Electric Reliability Council (NERC) regions, the Oil and Gas Supply Module uses 7 onshore and 3 offshore supply regions based on geologic breakdowns, and the Petroleum Market Module uses 3 regions based on combinations of the five Petroleum Administration for Defense Districts.

Baseline forecasts are developed with NEMS and published annually in the *Annual Energy Outlook*. In accordance with the requirement that EIA remain policy-neutral, the *Annual Energy Outlook* projections are based on Federal, State, and local laws and regulations in affect at the time of the forecast. Analyses are also prepared in response to requests for special studies by the White House, U.S. Congress, the DOE Office of Policy, other offices in DOE, and other government agencies. The first version of NEMS, completed in December 1993, was used to develop the forecasts presented in the *Annual Energy Outlook 1994,* This report describes the version of NEMS used for the *Annual Energy Outlook 2003*,[1] which was extended to 2025 for the first time.

The forecasts produced by NEMS are not considered to be statements of what will happen but of what might happen, given the assumptions and methodologies used. Assumptions include, for example, the estimated size of the economically recoverable resource base of fossil fuels, changes in world energy supply and demand, the rate at which new energy technologies are developed and the rate and extent of technology adoption and penetration.

Analytical Capability

NEMS can be used to analyze the effects of existing and proposed government laws and regulations related to energy production and use; the potential impacts of new and advanced energy production, conversion, and consumption technologies; the impacts

[1] Energy Information Administration, *Annual Energy Outlook 2003*, DOE/EIA-0383(2003) (Washington, DC, January 2003).

and costs of carbon emissions reductions, the impacts of increased use of renewable energy sources; the potential savings from increased efficiency of energy use; and the changes in emission levels that are likely to result from such policies as the Clean Air Act Amendments of 1990, regulations on the use of alternative or reformulated fuels, and climate change policy. Specific energy topics that can be, or have been, addressed by NEMS include the following:

- Impacts of existing and proposed energy tax policies on the U.S. economy and energy system
- Impacts on energy prices, energy consumption, and electricity generation in response to carbon mitigation policies such as carbon fees, limits on carbon emissions, or permit trading systems
- Responses of the energy and economic systems to changes in world oil market conditions as a result of changing levels of foreign production and demand in the developing countries
- Impacts of new technologies on consumption and production patterns and emissions
- Effects of specific policies, such as mandatory appliance efficiency and building shell standards or renewable tax credits, on energy consumption
- Impacts of fuel-use restrictions, for example, required use of oxygenated and reformulated gasoline or mandated use of alternative-fueled vehicles, on emissions and energy supply and prices
- Impacts on the production and price of crude oil and natural gas resulting from improvements in exploration and production technologies
- Impacts on the price of coal resulting from improvements in productivity.

In addition to producing the analyses in the *Annual Energy Outlook*, NEMS is used for one-time analytical reports and papers, such as *Measuring Changes in Energy Efficiency for the Annual Energy Outlook 2002*,[2] which describes the construction of an aggregate energy efficiency index based on projections of sectoral and subsector energy consumption and subsector–specific energy service indicators. The results are compared with the ratio energy to real gross domestic product, which typically is presented as a measure of energy intensity. Other analytical papers on topics of current interest in energy markets are prepared, which either underlie the assumptions and methodology of NEMS or are applications of NEMS to current issues. In the past, some of these papers have been collectively published in *Issues in Midterm Analysis and Forecasting*, and in the future they will be available at http://www.eia.doe.gov/ oiaf/analysis.html.

NEMS has also been used for a number of special analyses at the request of the White House, U.S. Congress, other offices of DOE and other government agencies, who specify the scenarios and assumptions for the analysis. Some recent examples include:

- *Analysis of Corporate Average Fuel Economy (CAFE) Standards for Light Trucks and Increased Alternative Fuel Use*,[3] requested by Senator Murkowski to analyze the effects of proposed provisions in S. 1766 and H.R. 4 calling for more stringent corporate average fuel economy standards on energy supply, demand, and prices, import dependence, and emissions.
- *Analysis of Efficiency Standards for Air Conditioners, Heat Pumps, and Other Products*,[4] requested by Senator Murkowski to evaluate the effects of the provisions in H.R. 4 and S. 1766 that pertain to efficiency in the

[2] Energy Information Administration, *Measuring Changes in Energy Efficiency for the Annual Energy Outlook 2002*, (Washington, DC, 2002).

[3] Energy Information Administration, *Analysis of Corporate Average Fuel Economy (CAFE) Standards for Light Trucks and Increased Alternative Fuel Use*, SR/OIAF/2002-05 (Washington, DC, March 2002).

[4] Energy Information Administration, *Analysis of Efficiency Standards for Air Conditioners, Heat Pumps, and Other Products*, SR/OIAF/2002-01 (Washington, DC, February 2002).

residential, commercial and industrial sectors.

- *Analysis of Strategies for Reducing Multiple Emissions from Electric Power Plants With Advanced Technology Scenarios,*[5] requested by Senators Jeffords and Lieberman to analyze the impacts of technology improvements and other market–based opportunities on the costs of emissions reductions.

- *Impact of Renewable Fuels Standard/MTBE Provisions of S. 1766*,[6] requested by Senator Murkowski to evaluate the Renewable Fuels Standard and methyl teritirary butyl ether provisions of S. 1766.

- *Impact of Renewable Fuels Standard/MTBE Provisions of S. 517*,[7] was completed as an addendum to the service report *Impact of Renewable Fuels Standard/MTBE Provisions of S. 1766*[6] for Senators Murkowski and Daschle. The addendum to the service report providws additional analysis of the impact of the Renewable Fuels Standard (RFS) and methyl tertiary butyl ether (MTBE) ban provisions of S. 517. The projected consumer cost of the S. 517 provisions is compared with a Reference Case that assumes a 2 percent oxygen requirement is maintained and that already–scheduled MTBE restrictuons or bans become effective in 14 States.

- *Analysis of Strategies for Reducing Multiple Emissions from Power Plants: Sulfur Dioxide, Nitrogen Oxides, and Carbon Dioxide*[8], requested by the U.S. House Subcommittee on National Economic Growth, Natural Resources, and Regulatory Affairs to analyze the potential costs of multi–pollutant strategies to reduce the emissions from electric power plants.

- *Impacts of a 10–Percent Renewable Portfolio Standard*,[9] requested by Senator Murkowski to examine the Renewable Portfolio Standard (RPS) called for in S. 1766. The analysis includes scenarios with a 10 percent RPS, as provided in S. 1766, and a 20 percent RPS.

- *Impacts of the Kyoto Protocol on U.S. Energy Markets & Economic Activity*,[10] requested by the U.S. House Committee on Science to analyze the impacts of the Kyoto Protocol on U.S. energy markets and the economy in the 2008 to 2012 time frame.

- *Reducing Emissions of Sulfur Dioxide, Nitrogen Oxides, and Mercury from Electric Power Plants*,[11] requested by Senators Smith, Voinovich, and Brownback that describes the impacts of scenarios with alternative power sector emission caps on nitrogen oxides, sulfur dioxides, and mercury.

[5] Energy Information Administration, *Analysis of Strategies for Reducing Multiple Emissions from Electric Power Plants With Advanced Technology Scenarios*, SR/OIAF/2001-05 (Washington, DC, October 2001).

[6] Energy Information Administration, *Impact of Renewable Fuels Standard/MTBE Provisions of S. 1766*, SR/OIAF/2002-06 (Washington, DC, March 2002).

[7] Energy Information Administration, *Impact of Renewable Fuels Standard/MTBE Provisions of S. 517*, SR/OIAF/2002-06 Addendum (Washington, DC, April 2002).

[8] Energy Information Administration, *Analysis of Strategies for Reducing Multiple Emissions from Power Plants: Sulfur Dioxide, Nitrogen Oxides, and Carbon Dioxide*, SR/OIAF/2000-05 (Washington, DC, December 2000).

[9] Energy Information Administration, *Impacts of a 10–Percent Renewable Portfolio Standard*, SR/OIAF/2002-03 (Washington, DC, February 2002).

[10] Energy Information Administration, *Impacts of the Kyoto Protocol on U.S. Energy Markets & Economic Activity*, SR/OIAF/98-03 (Washington, DC, October 1998).

[11] Energy Information Administration, *Reducing Emissions of Sulfur Dioxide, Nitrogen Oxides, and Mercury from Electric Power Plants*, SR/OIAF/2001-04 (Washington, DC, September 2001).

- *The Effects of the Alaska Oil and Natural Gas Provisions of H.R. 4 and S. 1766 on U.S. Energy Markets,*[12] requested by Senator Murkowski to evaluate the effects of the provisions in H.R. 4 proposing crude oil production in the Arctic National Wildlife Refuge and provisions in S. 1766 concerning the construction of a pipeline bringing Alaskan natural gas to the Lower–48 States.
- *The Transition to Ultra–Low–Sulfur Diesel Fuel: Effects on Prices and Supply*,[13] requested by U.S. House Committee on Science to assess the possible impact of the new sulfur requirements on the diesel fuel market, specifically the implications for vehicle fuel efficiency, production, distribution, and cost.
- *The Comprehensive Electricity Competition Act: A Comparison of Model Results,*[14] requested by Secretary of Energy Bill Richardson to evaluate the effects of the Clinton Administration's restructuring proposal using the parameter settings and assumptions from the Policy Office Electricity Modeling System analysis.
- *U.S. Natural Gas Markets: Mid–*Term *Prospects for Natural Gas Supply*,[15] requested by Secretary of Energy, Spencer Abraham describes the recent behavior of natural gas markets with respect to natural gas prices, their potential future behavior, the potential future supply contribution of liquefied natural gas and increased access to Federally restricted resources, and the need for improved natural gas data.
- *U.S. Natural Gas Markets: Recent Trends and Prospects for the Future*,[16] requested by Secretary of Energy, Spencer Abraham examines recent trends and prospects for the future of the U.S. natural gas markets in response to the dramatic increase in natural gas prices during 2000 and early 2001 that raised concerns about the future of natural gas prices and the potential for natural gas to fuel the growth of the U.S. economy.

Representations of Energy Market Interactions

NEMS is designed to represent the important interactions of supply and demand in U.S. energy markets. In the United States, energy markets are driven primarily by the fundamental economic interactions of supply and demand. Government regulations and policies can exert considerable influence, but the majority of decisions affecting fuel prices and consumption patterns, resource allocation, and energy technologies are made by private individuals who value attributes other than life cycle costs or companies attempting to optimize their own economic interests. NEMS represents the market behavior of the producers and consumers of energy at a level of detail that is useful for analyzing the implications of technological improvements and policy initiatives.

Energy Supply/Conversion/Demand Interactions

NEMS is designed as a modular system. Four end-use demand modules represent fuel consumption in the residential, commercial, transportation, and industrial sectors, subject to delivered fuel prices, macroeconomic influences, and technology characteristics. The primary fuel supply and conversion modules compute the levels of domestic production, imports, transportation costs, and fuel prices that are needed to meet domestic and export demands for energy, subject to resource base character-

[12] Energy Information Administration, *The Effects of the Alaska Oil and Natural Gas Provisions of H.R. 4 and S. 1766 on U.S. Energy Markets,* SR/OIAF/2002-02 (Washington, DC, February 2002).

[13] Energy Information Administration, *The Transition to Ultra–Low–Sulfur Diesel Fuel: Effects on Prices and Supply*, SR/OIAF/2001-01 (Washington, DC, May 2001).

[14] Energy Information Administration, *The Comprehensive Electricity Competition Act: A Comparison of Model Results, SR/OIAF/99-04 (Washington, DC, September 1999).*

[15] Energy Information Administration, *U.S. Natural Gas Markets: Mid–Term Prospects for Natural Gas Supply*, SR/OIAF/2001-06 (Washington, DC, December 2001).

[16] Energy Information Administration, *U.S. Natural Gas Markets: Recent Trends and Prospects for the Future*, SR/OIAF/2001-02 (Washington, DC, May 2001).

istics, industry infrastructure and technology, and world market conditions. The modules interact to solve for the economic supply and demand balance for each fuel. Because of the modular design, each sector can be represented with the methodology and the level of detail, including regional detail, that is appropriate for that sector. The modularity also facilitates the analysis, maintenance, and testing of the NEMS component modules in the multi-user environment.

Domestic Energy System/Economy Interactions

The general level of economic activity, represented by gross domestic product, has traditionally been used as a key explanatory variable or driver for projections of energy consumption at the sectoral and regional levels. In turn, energy prices and other energy system activities influence economic growth and activity. NEMS captures this feedback between the domestic economy and the energy system. Thus, changes in energy prices affect the key macroeconomic variables—such as gross domestic product, disposable personal income, industrial output, housing starts, employment, and interest rates—that drive energy consumption and capacity expansion decisions.

Domestic/World Energy Market Interactions

World oil prices play a key role in domestic energy supply and demand decision–making and oil price assumptions are a typical starting point for energy system projections. The level of oil production and consumption in the U.S. energy system also has a significant influence on world oil markets and prices. In NEMS, an international energy module represents world oil production and demand, as well as the interactions between the domestic and world oil markets, and this module calculates the average world crude oil price and the supply of specific crude oils and petroleum products. As a result, domestic and world oil market projections are internally consistent. Imports and exports of natural gas, electricity, and coal—which are less influenced by volatile world conditions—are represented in the individual fuel supply modules.

Economic Decision making Over Time

The production and consumption of energy products today are influenced by past investment decisions to develop energy resources and acquire energy-using capital stock. Similarly, the production and consumption of energy in a future time period will be influenced by decisions made today and in the past. Current investment decisions depend on expectations about future markets. For example, expectations of rising energy prices in the future increase the likelihood of current decisions to invest in more energy-efficient technologies or alternative energy sources. A variety of assumptions about planning horizons, the formation of expectations about the future, and the role of those expectations in economic decision making are applied within the individual NEMS modules.

Technology Representation

A key feature of NEMS is the representation of technology and technology improvement over time. Five of the sectors—residential, commercial, transportation, electricity generation, and refining–include extensive treatment of individual technologies and their characteristics, such as the initial capital cost, operating cost, date of availability, efficiency, and other characteristics specific to the sector. Technological progress is lighting technologies results in a gradual reduction in cost and is modeled as a function of time in these end–use sectors. In addition, the electricity sector accounts for technological optimism in the capital costs of first-of-a-kind generating technologies and for a decline in cost as experience with the technologies is gained both domestically and internationally. In each of these sectors, equipment choices are made for individual technologies as new equipment is needed to meet growing demand for energy services or to replace retired equipment.

In the other sectors—industrial, oil and gas supply, and coal supply—the treatment of technologies is more limited due to a lack of data on individual technologies. In the industrial sector, only the combined heat and power and motor technologies are explicity considered and characaterized. Cost reductions resulting from technological progress in combined heat and power technologies is represented as a function of time as experience with the technologies grows. Technological progress is not explicity modeled for the industrial motor technologies. Other technologies in the energy-intensive industries are represented by technology bundles, with technology possibility curves representing efficiency improvement over time. In the oil and gas supply sector, technological progress is represented by econometrically estimated improvements in finding rates, success rates, and costs. Productivity improvements over time represent technological progress in coal production.

External Availability

In accordance with EIA requirements, NEMS is fully documented and archived. EIA has been running NEMS on three EIA workstations under the Windows 2000 operating system. The archive file provides the source language, input files, and output files to replicate the *Annual Energy Outlook* reference case runs on an identically equipped computer; however, it does not include the proprietary portions of the model, such as the Global Insights, Inc. (formerly DRI/WEFA) macroeconomic model and the optimization modeling libraries. NEMS can be run on a high–powered individual PC as long as the required proprietary software resides on the PC. Because of the complexity of NEMS, and the relatively high cost of the proprietary software, NEMS is not widely used outside of the Department of Energy. However, NEMS, or portions of it, is installed at the Lawrence Berkeley National Laboratory, Oak Ridge National Laboratory, the Electric Power Research Institute, the National Energy Technology Laboratory, the National Renewable Energy Laboratory, and several private consulting firms.