DOE/EIA-0581(2000)

The National Energy Modeling System:
An Overview 2000

March 2000

Energy Information Administration
Office of Integrated Analysis and Forecasting
U.S. Department of Energy
Washington, DC 20585

This publication is on the WEB at:
www.eia.doe.gov/oiaf/aeo/overview/index.html

PREFACE

The National Energy Modeling System: An Overview provides a summary description of the National Energy Modeling System (NEMS), which was used to generate the forecasts of energy production, demand, imports, and prices through the year 2020 for the *Annual Energy Outlook 2000* (*AEO2000*), (DOE/EIA-0383(2000)), released in November 1999. *AEO2000* presents national forecasts of energy markets for five cases—a reference case and four additional cases that assume higher and lower economic growth and higher and lower world oil prices than in the reference case. The *Overview* presents a brief description of the methodology and scope of each of the component modules of NEMS. The model documentation reports listed in the appendix of this document provide further details.

The *Overview* was prepared by the Energy Information Administration (EIA), Office of Integrated Analysis and Forecasting under the direction of Mary J. Hutzler (mhutzler@eia.doe.gov, 202/586-2222), Director of the Office of Integrated Analysis and Forecasting; Susan H. Holte (sholte@eia.doe.gov, 202/586-4838), Director of the Demand and Integration Division; James M. Kendell (jkendell@eia.doe.gov, 202/586-9646), Director of the Oil and Gas Division; Scott Sitzer (ssitzer@eia.doe.gov, 202/586-2308), Director of the Coal and Electric Power Division; and Andy S. Kydes (akydes@eia.doe.gov, 202/586-2222), Senior Technical Advisor. Detailed questions concerning NEMS may be addressed to the following analysts:

AEO2000	Susan H. Holte (sholte@eia.doe.gov, 202/586-4838)
Integrating Module/Carbon Emissions	Daniel H. Skelly (dskelly@eia.doe.gov, 202/586-1722)
Macroeconomic Activity Module	Ronald Earley (rearley@eia.doe.gov, 202/586-1398)
International Energy Module	G. Daniel Butler (gbutler@eia.doe.gov, 202/586-9503)
Residential Demand Module	John Cymbalsky (jcymbals@eia.doe.gov, 202/586-4815)
Commercial Demand Module	Erin Boedecker (eboedeck@eia.doe.gov, 202/586-4791)
Industrial Demand Module	T. Crawford Honeycutt (choneycu@eia.doe.gov, 202/586-1420)
Transportation Demand Module	David Chien (dchien@eia.doe.gov, 202/586-3994)
Electricity Market Module	Jeffrey Jones (jjones@eia.doe.gov, 202/586-2038)
Renewable Fuels Module	David Schoeberlein (dschoebe@eia.doe.gov, 202/586-2349)
Oil and Gas Supply Module	Ted McCallister (tmccalli@eia.doe.gov, 202/586-4820)
Natural Gas Transmission and Distribution Module	Joseph Benneche (jbennech@eia.doe.gov, 202/586-6132)
Petroleum Market Module	Thomas White (twhite@eia.doe.gov, 202/586-1393)
Coal Market Module	Zia Haq (zhaq@eia.doe.gov, 202/586-2869)

AEO2000 is available on the EIA Home Page on the Internet (http://www.eia.doe.gov/oiaf/aeo/index.html). Assumptions underlying the projections are available in *Assumptions to the Annual Energy Outlook 2000* at http://www.eia.doe.gov/oiaf/aeo/assumption/index.html. Tables of regional projections and other underlying details of the reference case are available at http://www.eia.doe.gov/oiaf/aeo/supplement/index.html. Model documentation reports and *The National Energy Modeling System: An Overview* are also available on the Home Page at http://www.eia.doe.gov/bookshelf/docs.html.

For ordering information and for questions on energy statistics, please contact EIA's National Energy Information Center.

National Energy Information Center, EI-30
Energy Information Administration
Forrestal Building
Washington, DC 20585
Telephone: 202/586-8800
FAX: 202/586-0727
TTY: 202/586-1181
9 a.m. to 5 p.m., eastern time, M-F
E-mail: *infoctr@eia.doe.gov*
World Wide Web Site: *http://www.eia.doe.gov*
FTP Site: *ftp://ftp.eia.doe.gov*

CONTENTS

CONTENTS

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 2020. 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 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 2020. 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 can vary widely across the United States. To address these differences, NEMS is a regional model. The basic regional structure is that of the nine Census divisions; however, the different modules of NEMS represent a variety of regional structures. The regional disaggregation for each module reflects the availability of data and the regions used by other energy analysts in that area, as well as the regions determined to be most useful for policy analysis.

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 assume that all existing legislation, regulations, and policies remain unchanged. Analyses are also prepared in response to requests for special studies by the 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,*[1] which extended to 2010. This report describes the version of NEMS used for the *Annual Energy Outlook 2000*.

The forecasts produced by NEMS are not considered to be absolute predictions of the future. They are contingent on the key assumptions made about U.S. energy systems. 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 their adoption and penetration, and existing or prospective government actions or policies.

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 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

[1] Energy Information Administration, *Annual Energy Outlook 2000*, DOE/EIA-0383(2000) (Washington, DC, December 1999).

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 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, 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 *Electricity Prices in a Competitive Environment: Marginal Cost Pricing of Generation Services and Financial Status of Electric Utilities*,[2] EIA's own analysis of electricity industry restructuring and competitive prices. 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 U.S. Congress, other offices of DOE and other government agencies, who specify the scenarios and assumptions for the analysis. Some recent examples include:

- *The Comprehensive Electricity Competition Act: A Comparison of Model Results*,[3] requested by the Secretary of Energy to evaluate the impacts of the Administration's restructuring proposal using NEMS with the assumptions from the Policy Office Electricity Modeling System analysis
- *Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity*,[4] requested by the Committee on Science of the U.S. House of Representatives to analyze the Kyoto Protocol, focusing on U.S. energy use and prices and the economy in the 2008 to 2012 time frame
- *Analysis of the Impacts of an Early Start for Compliance with the Kyoto Protocol*,[5] requested by the Committee on Science of the U.S. House of Representatives to evaluate the impacts of an earlier start date for the United States to begin to take action to reduce carbon

[2] Energy Information Administration, *Electricity Prices in a Competitive Environment: Marginal Cost Pricing of Generation Services and Financial Status of Electric Utilities*, DOE/EIA-0614 (Washington, DC, August 1997).

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

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

[5] Energy Information Administration, *Analysis of the Impacts of an Early Start for Compliance with the Kyoto Protocol*, SR/OIAF/99-02 (Washington, DC, July 1999).

emissions, relative to the date in the October 1998 analysis

- *Analysis of the Climate Change Technology Initiative*,[6] requested by the Committee on Science of the U.S. House of Representatives to evaluate the impact of the President's Climate Change Technology Initiative, as defined for the 2000 budget

- *Energy Consumption Projections for Selected Industries of the Future*,[7] requested by the Office of Industrial Technologies, Office of Energy Efficiency and Renewable Energy, DOE, to provide projections of output and delivered energy consumption for selected industries included in the Industries of the Future Program

- *The Impacts of Increased Diesel Penetration in the Transportation Sector*,[8] requested by the Office of Transportation Technologies, Office of Energy Efficiency and Renewable Energy, DOE, to analyze the impacts on petroleum prices of increased demand for diesel fuel as a result of higher penetration of diesel engines

- *Analysis of S. 687, the Electric System Public Benefits Protection Act of 1997*,[9] requested by Senator James Jeffords of Vermont to analyze the provisions of proposed legislation, creating a renewable portfolio standard and emissions limits on carbon dioxide, sulfur dioxide, and nitrogen oxide

- *Analysis of Carbon Stabilization Cases,*[10] requested by the Office of Policy and International Affairs, DOE, to analyze the impacts of carbon stabilization at 1990 levels on U.S. energy markets and the economy

- *The Impacts on U.S. Energy Markets and the Economy of Reducing Oil Imports*,[11] requested by the General Accounting Office to evaluate the impacts of reducing oil imports on U.S. energy markets and the economy

- *An Analysis of FERC's Final Environmental Impact Statement for Electricity Open Access and Recovery of Stranded Costs*,[12] requested by Senator James Jeffords of Vermont to analyze the impacts of open access regulatory changes on the electricity industry

- *An Analysis of Carbon Mitigation Cases*,[13] requested by the Office of Air and Radiation, Environmental Protection Agency, to analyze the potential of accelerated technology improvement and adoption to reduce carbon emissions.

[6] Energy Information Administration, *Analysis of the Climate Change Technology Initiative*, SR/OIAF/99-01 (Washington, DC, April 1999).

[7] Energy Information Administration, *Energy Consumption Projections for Selected Industries of the Future*, SR/OIAF/99-05 (Washington, DC, November 1999).

[8] Energy Information Administration, *The Impacts of Increased Diesel Penetration in the Transportation Sector*, SR/OIAF/98-02 (Washington, DC, August 1998).

[9] Energy Information Administration, *Analysis of S. 687, the Electric System Public Benefits Protection Act of 1997*, SR/OIAF/98-01 (Washington, DC, February 1998).

[10] Energy Information Administration, *Analysis of Carbon Stabilization Cases*, SR/OIAF/97-01 (Washington, DC, October 1997).

[11] Energy Information Administration, *The Impacts on U.S. Energy Markets and the Economy of Reducing Oil Imports*, SR/OIAF/96-04 (Washington, DC, September 1996).

[12] Energy Information Administration, *An Analysis of FERC's Final Environmental Impact Statement for Electricity Open Access and Recovery of Stranded Costs*, SR/OIAF/96-03 (Washington, DC, September 1996).

[13] Energy Information Administration, *An Analysis of Carbon Mitigation Cases*, SR/OIAF/96-01 (Washington, June 1996).

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 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 characteristics, 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 explicit treatment of individual technologies and their characteristics, such as initial cost, operating cost, date of availability, efficiency, and other characteristics specific to the sector. In addition, for new generating technologies, the electricity sector accounts for technological optimism in the capital costs of first-of-a-kind plants and for a decline in the costs 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 limitations on the availability of data on individual technologies. In the industrial sector, technology in the energy-intensive industries is 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 trend-based improvement 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 RS/6000 workstations under the AIX Version 4.2 operating system. The archive file provides the source language, input files, and output files to replicate the *Annual Energy Outlook* runs on an identically equipped computer; however, it does not include proprietary mathematical libraries from an external vendor. Following the *Annual Energy Outlook 2000*, EIA is transferring NEMS to a new computing platform using networked personnel computers and servers, running the Microsoft Windows NT operating system and the Compaq Visual Fortran compiler. The new computer system will be used for the *Annual Energy Outlook 2001.* NEMS, or portions of it, is installed at the National Renewable Energy Laboratory, the Lawrence Berkeley National Laboratory, other national laboratories, the Electric Power Research Institute, and several private consulting firms.

Page Intentionally Left Blank

NEMS represents domestic energy markets by explicitly representing the economic decision making involved in the production, conversion, and consumption of energy products. Where possible, NEMS includes explicit representation of energy technologies and their characteristics.

Since energy costs and availability and energy-consuming characteristics can vary widely across regions, considerable regional detail is included. Other details of production and consumption categories are represented to facilitate policy analysis and ensure the validity of the results. A summary of the detail provided in NEMS is shown below.

Major Assumptions

Each module of NEMS embodies many assumptions and data to characterize the future production, conversion, or consumption of energy in the United States. Two major

Energy Activity	Categories	Regions
Residential demand	Fourteen end-use services Three housing types Thirty-four end-use technologies	Nine Census divisions
Commercial demand	Ten end-use services Eleven building types Ten distributed generation technologies Sixty-four end-use technologies	Nine Census divisions
Industrial demand	Seven energy-intensive industries Eight non-energy-intensive industries Cogeneration	Four Census regions, shared to nine Census divisions
Transportation demand	Six car sizes Six light truck sizes Fifty-nine conventional fuel-saving technologies for light-duty vehicles Gasoline, diesel, and thirteen alternative-fuel vehicle technologies for light-duty vehicles Twenty vintages for light-duty vehicles Narrow and wide-body aircraft Six advanced aircraft technologies Medium and heavy freight trucks Ten advanced freight truck technologies	Nine Census divisions
Electricity	Eleven fossil technologies Seven renewable technologies Conventional and advanced nuclear Marginal and average cost pricing Generation capacity expansion	Fifteen electricity supply regions Nine Census divisions for demand
Renewables	Wind, geothermal, solar thermal, solar photovoltaic, municipal solid waste, biomass, conventional hydropower	Fifteen electricity supply regions
Oil supply	Conventional onshore and shallow offshore Conventional deep offshore Enhanced	Six lower 48 onshore regions Three lower 48 offshore regions Three Alaska regions
Natural gas supply	Conventional onshore and shallow offshore Conventional deep offshore Coalbed methane Gas shales Tight sands Canadian, Mexican, and liquefied natural gas	Six lower 48 onshore regions Three lower 48 offshore regions Three Alaska regions Five liquefied natural gas terminals
Natural gas transmission and distribution	Core vs. noncore Peak vs. offpeak Pipeline capacity expansion	Twelve lower 48 regions Ten pipeline border points
Refining	Five crude oil categories Seven product categories Thirty-three technologies Refinery capacity expansion	Three refinery regions aggregated from Petroleum Administration for Defense Districts
Coal supply	Three sulfur categories Four thermal categories Underground and surface mining types	Eleven supply regions Thirteen demand regions Sixteen export regions Twenty import regions

assumptions concern economic growth in the United States and world oil prices, as determined by world oil supply and demand.

The five comprehensive, integrated cases in the *Annual Energy Outlook 2000 (AEO2000)* are defined by setting assumptions that lead to a high, mid, or low economic growth rate for the domestic economy and to a high, mid, or low world oil price path. The reference case uses the mid-range assumptions for both the economic growth rate and the world oil price. Higher and lower economic growth and higher and lower world oil prices define the other four cases. The primary determinants for different economic growth rates are the growth rates of the labor force and productivity, while different assumptions on oil production in the Organization of Petroleum Exporting Countries (OPEC) lead to different levels of world oil prices.

In addition to the five baseline cases, *AEO2000* includes 32 other cases that explore the impacts of varying key assumptions in the individual components of NEMS. Many of these cases involve changes in the assumptions that impact the penetration of new or improved technologies, which is a major uncertainty in formulating projections of future energy markets. Other cases include potential legislative and regulatory changes, such as competitive pricing of electricity, renewable portfolio standards, gasoline standards, and equipment standards; changes in nuclear retirement assumptions; a sensitivity on electricity demand growth; changes to oil and gas technology; and changes to coal supply productivity and miner wages. Some of these cases exploit the modular structure of NEMS by running only a portion of the entire modeling system in order to focus on the first-order impacts of the changes in the assumptions.

NEMS Modular Structure

Overall, NEMS represents the behavior of energy markets and their interactions with the U.S. economy. The model achieves a supply/demand balance in the end-use demand regions, defined as the nine Census divisions (Figure 1), by solving for the prices of each energy product that will balance the quantities producers are willing to supply with the quantities consumers wish to consume. The system reflects market economics, industry structure, and energy policies and regulations that influence market behavior.

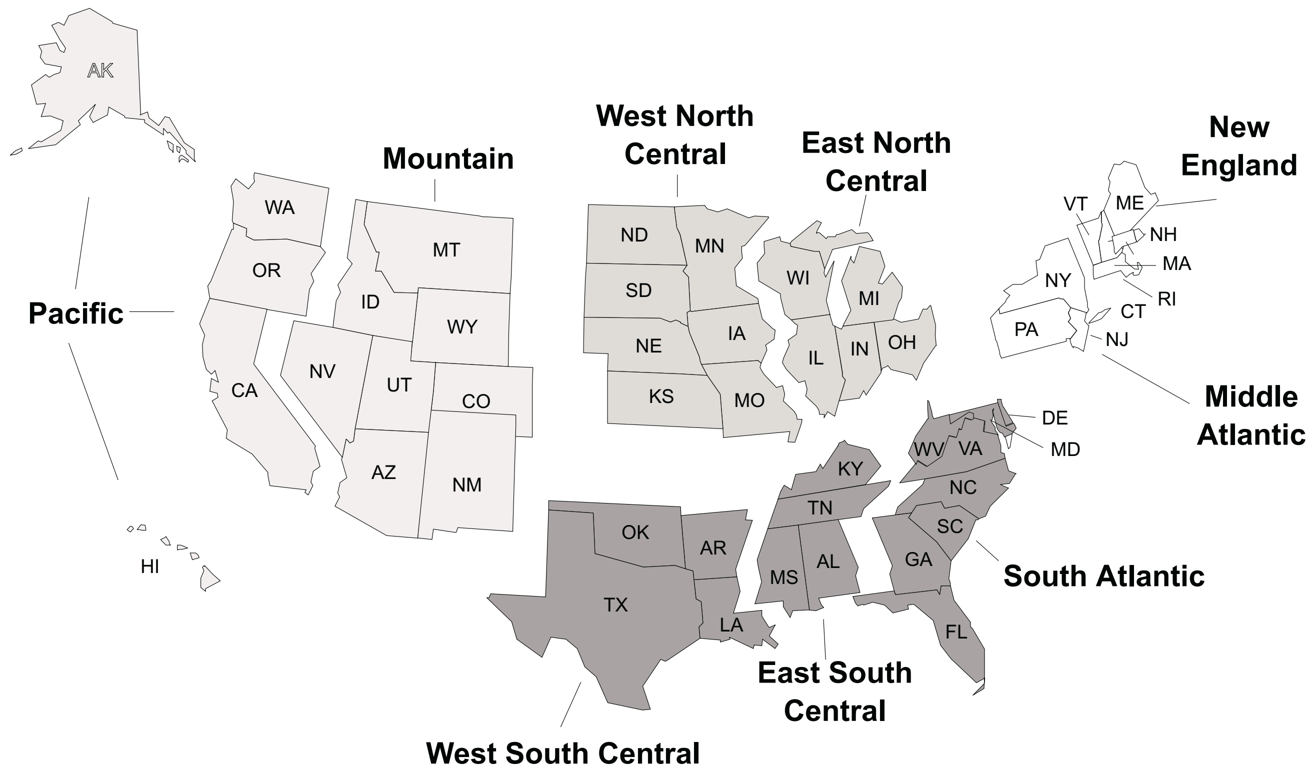
NEMS consists of four supply modules (oil and gas, natural gas transmission and distribution, coal, and renewable fuels); two conversion modules (electricity and petroleum refineries); four end-use demand modules (residential, commercial, transportation, and industrial); one module to simulate energy/economy interactions (macroeconomic activity); one module to simulate world oil markets (international energy activity); and one module that provides the mechanism to achieve a general market equilibrium among all the other modules (integrating module). Figure 2 depicts the high-level structure of NEMS.

Because energy markets are heterogeneous, a single methodology does not adequately represent all supply, conversion, and end-use demand sectors. The modularity of the NEMS design provides the flexibility for each component of the U.S. energy system to use the methodology and coverage that is most appropriate. Furthermore, modularity provides the capability to execute the modules individually or in collections of modules, which facilitates the development and analysis of the separate component modules. The interactions among these modules are controlled by the integrating module.

The NEMS global data structure is used to coordinate and communicate the flow of information among the modules. These data are passed through common interfaces via the integrating module. The global data structure includes energy market prices and consumption; macroeconomic variables; energy production, transportation, and conversion information; and centralized model control variables, parameters, and assumptions. The global data structure excludes variables that are defined locally within the modules and are not communicated to other modules.

A key subset of the variables in the global data structure is the end-use prices and quantities of fuels which are used to equilibrate the NEMS energy balance in the convergence algorithm. These delivered prices of energy and the quantities demanded are defined by product, region, and sector. The delivered prices of fuel encompass all the activities necessary to produce, import, and transport fuels to the end user. The regions for the price and quantity variables in the global data structure are the nine Census divisions. The four Census regions (shown in Figure 1 by breaks between State groups) and nine Census divisions are a common, mainstream level of regionality widely used by EIA and other organizations for data collection and analysis.

Figure 1. Census Divisions



Division 1

New England

Connecticut
Maine
Massachusetts
New Hampshire
Rhode Island
Vermont

Division 2

Middle Atlantic

New Jersey
New York
Pennsylvania

Division 3

East North Central

Illinois
Indiana
Michigan
Ohio
Wisconsin

Division 4

West North Central

Iowa
Kansas
Minnesota
Missouri
Nebraska
North Dakota
South Dakota

Division 5

South Atlantic

Delaware
District of Columbia
Florida
Georgia
Maryland
North Carolina
South Carolina
Virginia
West Virginia

Division 6

East South Central

Alabama
Kentucky
Mississippi
Tennessee

Division 7

West South Central

Arkansas
Louisiana
Oklahoma
Texas

Division 8

Mountain

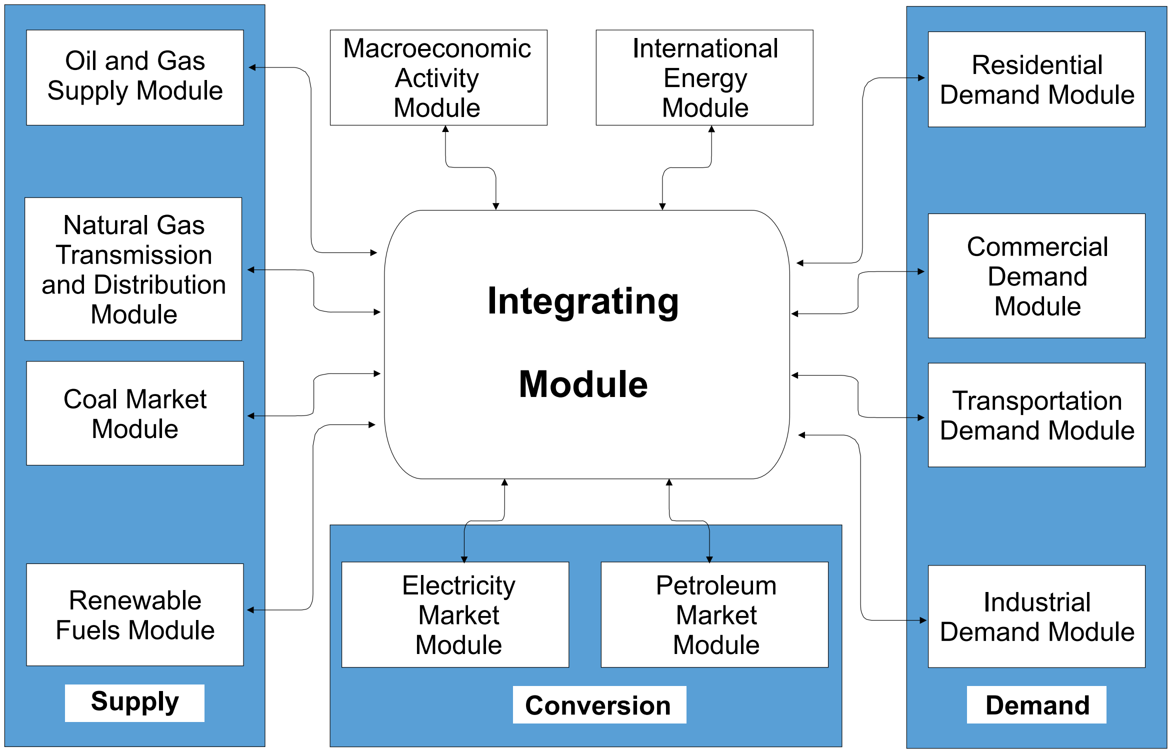
Arizona
Colorado
Idaho
Montana
Nevada
New Mexico
Utah
Wyoming

Division 9

Pacific

Alaska
California
Hawaii
Oregon
Washington

Figure 2. National Energy Modeling System



Integrating Module

The NEMS integrating module controls the entire NEMS solution process as it iterates to determine a general market equilibrium across all the NEMS modules. It has the following functions:

- Manages the NEMS global data structure
- Executes all or any of the user-selected modules in an iterative convergence algorithm
- Checks for convergence, while reporting variables that remain out of convergence
- Implements price relaxation between iterations to accelerate convergence
- Updates expected values of the key NEMS variables.

The integrating module executes the demand, conversion, and supply modules iteratively until it achieves an economic equilibrium of supply and demand in all the consuming and producing sectors. Each module is called in sequence and solved, assuming that all other variables in the energy markets are fixed. The modules are called iteratively until the end-use prices and quantities remain constant within a specified tolerance—a condition defined as convergence. Equilibration is achieved annually throughout the midterm period, currently 2020, for each of the nine Census divisions.

In addition, the macroeconomic and international modules are executed iteratively to incorporate the feedback on the economy and international markets from changes in the domestic energy markets. The convergence tests check the stability of a set of key macroeconomic and international trade variables in response to interaction with the domestic energy system.

The NEMS algorithm executes the system of modules until convergence is reached. The solution procedure for one iteration involves the execution of all the component modules, as well as the updating of expectation variables (related to foresight assumptions) for use in the next iteration. The system is executed sequentially for each year in the forecast period. During each iteration within a year, each of the modules is executed in turn, with intervening convergence checks that isolate specific modules that are not converging. A convergence check is made for each price and quantity variable to see whether the percentage change in the variable is within the assumed tolerance. To avoid unnecessary iterations for changes in insignificant values, the quantity convergence check is omitted for quantities less than a user-specified minimum level. The order of execution of the modules may affect the rate of convergence but will generally not prevent convergence to an equilibrium solution or significantly alter the results. An optional relaxation routine can be executed to dampen swings in solution values between iterations. With this option, the current iteration values are reset partway between solution values from the current and previous iterations.

Because of the modular structure of NEMS and the iterative solution algorithm, any single module or subset of modules can be executed independently. Modules not executed are bypassed in the calling sequence, and the values they would calculate and provide to the other modules are held fixed at the values in the global data structure, which are the solution values from a previous run of NEMS. This flexibility is an aid to independent development, debugging, and analysis.

Page Intentionally Left Blank

A part of the integrating module, the carbon emissions submodule (CEM), computes the carbon emissions from the combustion of energy. The coefficients for carbon emissions are derived from Energy Information Administration, *Emissions of Greenhouse Gases in the United States 1998,*[15] published in October 1999. The coefficients account for the fact that some fossil fuels are used for nonfuel purposes, such as feedstocks, and thus the carbon in the fuel is sequestered in the end product.

CEM also allows for several carbon policy evaluation options to be analyzed within NEMS. Although these policy options are not assumed in the *Annual Energy Outlook 2000,* the options have been used in special analyses to simulate potential market-based approaches to meet national carbon emission objectives. The policy options implemented in CEM are as follows:

- *Carbon Tax*. A tax on carbon emissions from fossil fuels is added to raise delivered fossil fuel prices. The resulting higher prices then induce changes in fossil fuel use and carbon emissions, as well as changes in some long-term decision making, such as generating capacity decisions in the electricity market module.

- *Auction of Permits*. This option simulates an auction on carbon emissions permits to meet an overall cap on emissions. A carbon permit price is computed that clears the auction market. The permit fee is treated as a carbon tax and used as an adjustment to the fossil fuel prices. A new price is set each NEMS iteration until the emissions reach the goal. The revenue generated from the auction is calculated assuming there is no initial allocation of emission permits.

- *Market for Permits (Cap and Trade)*. A market for tradable carbon emissions permits is simulated assuming that an initial distribution of marketable permits to emission sources takes place. The permits are transferable but are not banked between years. As with the carbon tax and auction options, the full market price of the permits is added to the energy prices. The system of marketable permits is implemented in the same way as the permit auction, with the exception of the calculation of revenues from permit sales. Similar treatment is warranted because the marginal cost of a "free" permit is equivalent to one purchased at auction, given the opportunity cost of holding the distributed permit.

  In an open, competitive permit market, the permit will tend to be priced at the marginal cost of reducing carbon emissions, regardless of the initial distribution of permits. If permits are purchased by suppliers and passed through to the fuel price, the marginal cost of the carbon emissions by a particular sector in a region will be reflected in the individual end-use fuel cost for that sector.

The use of any of these emission policy options in NEMS requires a macroeconomic analysis to assess the fiscal and monetary issues, as well as possible international trade effects. The analysis depends on such factors as how revenues generated from the policy would be used, how monetary authorities would react to the fiscal policy changes, and how international agreements to reduce carbon would be implemented.

[15] Energy Information Administration, *Emissions of Greenhouse Gases in the United States 1998,* DOE/EIA-0573(98) (Washington, DC, October 1999).

Page Intentionally Left Blank

MACROECONOMIC ACTIVITY MODULE

Macroeconomic assessment at EIA involves several modes of analysis. The first type of analysis, used in forecasting the *Annual Energy Outlook* where energy prices change, uses kernel regression and response surface techniques to mimic the response of larger macroeconomic and industrial models. This mode of analysis requires a given economic baseline and then calculates the economic impacts of changing energy prices, calculated from the chosen growth path. The economic growth cases are derived from the larger core models and can reflect either high, low, or reference case growth assumptions. Analyzing economic impacts from energy price changes uses the macroeconomic activity module (MAM) within NEMS and provides a subset of the macroeconomic variables available in the larger core models. The composition of the subset is determined by the other energy modules in NEMS, as they use various macroeconomic concepts as assumptions to their particular energy model.

The other type of macroeconomic analysis requires the use of the underlying core macroeconomic models separately. There are four core models, estimated by Standard and Poor's/DRI (DRI), that serve as the basis for EIA's macroeconomic assessment. These include: the U.S. Quarterly Model of the Economy, Personal Computer Model of Industrial Output, an Employment Model by Industry, and a Regional Model. All of these models are linked by crucial assumptions that are provided by one of the other three models. Using the core models in a standalone fashion requires that the energy market concepts contained in the core models show NEMS-like behavior. To accomplish the goal of duplicating NEMS-like behavior, all energy market concepts in the core models show the same percentage change from base of the corresponding NEMS energy market concepts.

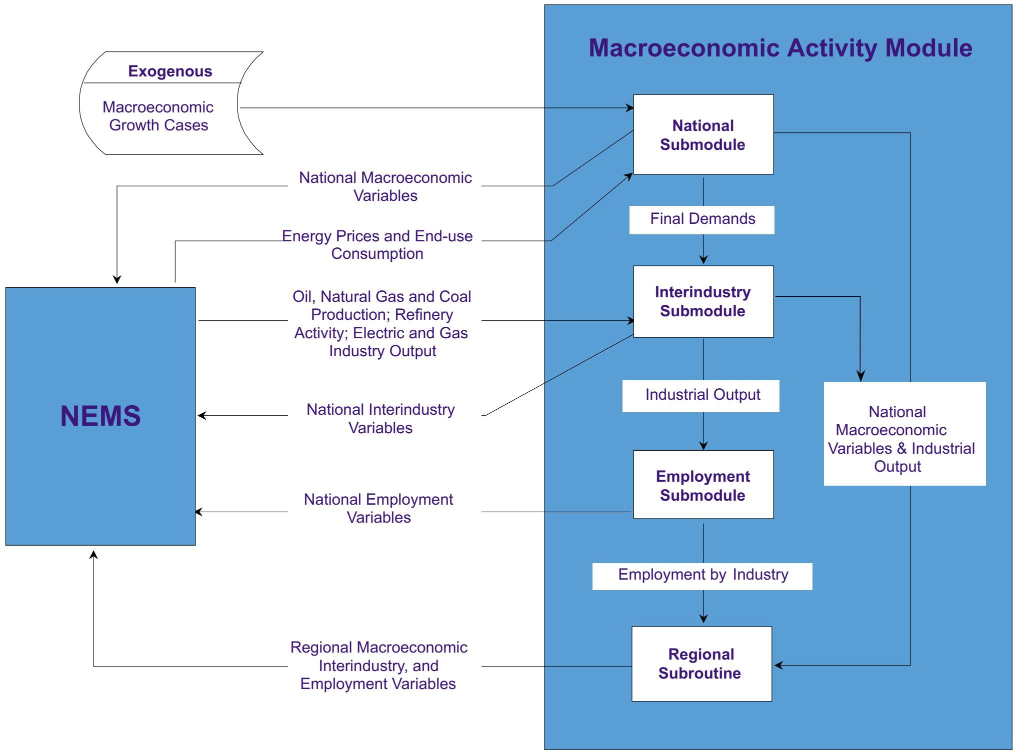
MAM provides forecasts of economic variables to the energy modules within NEMS and forecasts the impacts on the aggregate economy of changes in energy market conditions. MAM consists of three submodules (the national, interindustry, and employment submodules) and a subroutine (the regional subroutine), which are run in sequence. The national submodule provides forecasts of a wide range of economic variables at the national level. In particular, it provides variables that drive other parts of NEMS, including interest rates, final demands for goods and services, and disposable income. The interindustry submodule calculates the industrial output needed to satisfy the final demands from the national submodule. The levels of industrial output are used by the industrial and transportation demand modules in NEMS to calculate energy consumption in those sectors. The employment submodule calculates the levels of employment necessary to produce the output by industry. Finally, the regional subroutine of MAM takes national variable values from the national and interindustry submodules and transforms them into appropriate regional values. The overall interrelationships are shown in Figure 3.

The sequence of interactions in MAM begins with the energy supply and demand modules of NEMS, which determine the reaction of energy markets. These energy market effects are passed to the national submodule, and the economy is projected to react to the altered energy markets. The altered macroeconomic final demands are in turn passed to the interindustry submodule, which calculates their effect on interindustry activity. The altered interindustry projections are then used to determine employment levels.

Macroeconomic concepts, industry gross output, and employment levels are passed back to the other

MAM Outputs	Inputs from NEMS	Exogenous Inputs
Gross domestic product Other economic activity measures, including housing starts, commercial floorspace growth, vehicle sales, population Price indices and deflators Production rates for manufacturing Production rates for nonmanufacturing Interest rates	Petroleum, natural gas, coal, and electricity prices Oil, natural gas, and coal production Electric and gas industry output Refinery output End-use energy consumption by fuel	Macroeconomic variables defining alternative economic growth cases

Figure 3. Macroeconomic Activity Module Structure



NEMS modules, and the system iterates until convergence is achieved.

MAM outputs include measures of macroeconomic performance and manufacturing and nonmanufacturing sector production activities. Depending on the concept, these measures are provided nationally or at the geographic level of the nine Census divisions (see Figure 1).

National Submodule

The national submodule of MAM is a kernel regression representation of the DRI U.S. Quarterly Model. The kernel regression approach relies upon databases containing simulation results of the DRI U.S. Quarterly Macroeconomic Model. The simulations represent different assumptions about the price of crude oil and about policy instruments. The databases are linked so that the input variables (i.e. tax collections and energy prices and quantities) from each simulation are associated with their respective output variables (i.e. macroeconomic concepts.) The kernel regression representation simulates the reaction to changing energy markets of the larger version of the DRI U.S. Quarterly Model. The growth potential of the economy is essentially grounded in the growth of the factors of production—labor, capital, and energy—and the aggregate productivity of these factors. The user can select three different macroeconomic growth cases before executing MAM, and MAM will estimate how the economy changes in response to changing energy markets. These growth cases are initially derived from simulations of the DRI U.S. Quarterly Model and are used as the starting point to examine energy/economic impacts. Approximately 100 economic variables from the DRI simulations are used by NEMS to define an economic growth case.

Interindustry Submodule

The interindustry submodule provides industrial output projections to the regional MAM subroutine and the energy modules. It also calculates interindustry impacts associated with changes in national economic activity resulting from energy market changes. A response surface version of the DRI Input-Output Model for the Personal Computer (PCIO) constitutes the core interindustry segment of this submodule, which is fully linked to other NEMS components.

The interindustry submodule calculates deviations from a given baseline interindustry projection whenever macroeconomic final demands change. Because of the top-down structure of input-output modeling, the interindustry and national submodules do not iterate directly with each other. However, through their joint effect on the projections of the energy supply and demand modules, which in turn alter the macroeconomic outlook, changes in interindustry projections affect the results of the national submodule.

Employment Submodule

The employment submodule provides employment projections to the regional MAM subroutine and the energy modules. It also calculates employment impacts associated with changes in national industrial output resulting from energy price changes. A response surface version of the DRI Employment Model by Industry constitutes the core employment segment of the submodule, which is fully linked to other NEMS components.

Regional Subroutine

The initial implementation of the regional subroutine is a set of equations that share national economic and industrial output data to specific regions. The sharing equations are derived from the Regional Macroeconomic Model developed by DRI. The regional subroutine disaggregates national economic variables such as disposable income, industrial production, and consumer prices into appropriate regional values.

Use of the Underlying Core Models

MAM estimates macroeconomic impacts of energy market changes. In order to estimate these energy market impacts, an underlying baseline has to be provided. As the NEMS energy inputs change, MAM estimates the resulting changes to the macroeconomic variables provided in the baseline. The underlying core models are used in two ways: to provide economic baselines upon which percentage change impacts are calculated and to provide kernel regression and response surface representations which mimic the behavior of the larger scale structural models. The core models are provided by DRI and include their U.S. Quarterly Model of the Economy, PCIO Industrial Output Model, an Employment Model by Industry, and a Regional Economic Model. All four of these models are used in order to provide the macroeconomic growth cases (the high economic growth, reference case, and low economic growth).

Page Intentionally Left Blank

INTERNATIONAL ENERGY MODULE

The international energy module (IEM) consists of four submodules (Figure 4) that perform the following functions:

- world oil market submodule—calculates the average annual world oil price (imported refiner acquisition cost) that is consistent with worldwide petroleum demand and supply availability
- crude oil supply submodule—provides imported crude oil supply curves for five crude oil quality classes
- petroleum products supply submodule—provides imported refined product supply curves for eleven types of refined products
- oxygenates supply submodule—provides imported oxygenates supply curves for methyl tertiary butyl ether (MTBE) and methanol.

The world oil price that is generated by the world oil market submodule is used by all the modules of NEMS as well as the other submodules of IEM. The import supply curves for crude oils, refined products, and oxygenates are used by the petroleum market module.

World Oil Market Submodule

In NEMS, the U.S. oil market is modeled in considerable detail, while foreign markets retain a less-detailed formulation. EIA's modeling of the near- to mid-term world oil market depends on two key assumptions: (1) oil is the marginal fuel and (2) the Organization of Petroleum Exporting Countries (OPEC) is the marginal supplier of oil. The first assumption implies that competition between oil and other fuels is not significant enough to impact the world oil price. In addition, prices remain sufficiently low such that the market penetration of new technologies that would reduce the demand for oil is inhibited. In the second assumption, OPEC producers are assumed to expand oil production capacity in order to meet the growth in worldwide oil demand.

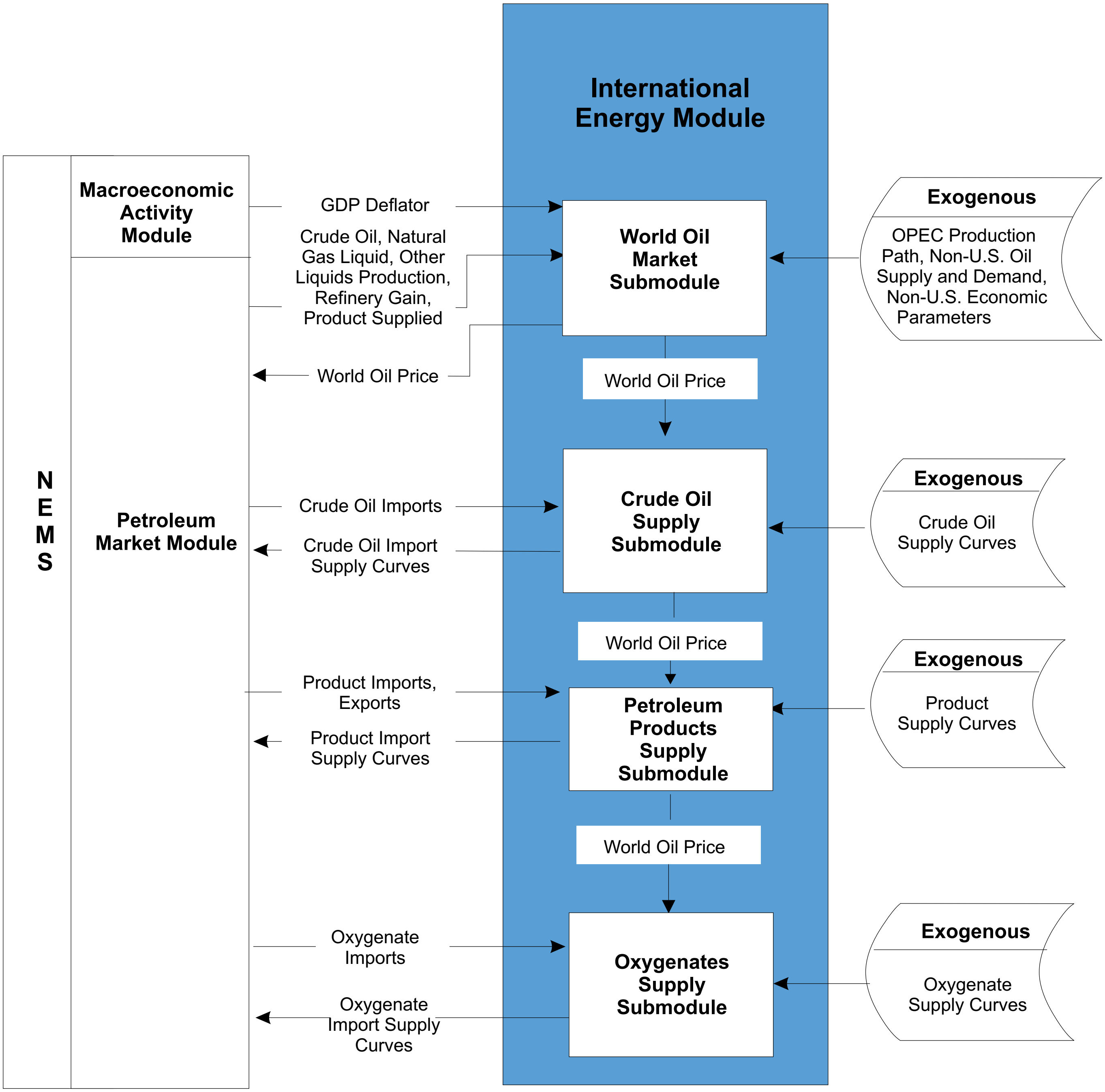
The various price cases examined by EIA differ in the magnitude to which OPEC producers expand their production capacity. Lower prices imply considerable capacity expansion activity with a probable assist from foreign investment interests. Higher prices imply an unwillingness on the part of OPEC producers to invite foreign investment participation. The world oil market submodule forecasts the world oil price and produces a regional world oil market supply/demand balance that is consistent with the forecasted price. The world oil price forecast is based upon a regression analysis of the price in the previous time period and the percent utilization of OPEC production capacity. IEM has either the capability to forecast world oil prices given OPEC production capacity estimates or the capability to forecast OPEC production given an exogenous world oil price path.

Crude Oil Supply Submodule

The crude oil supply submodule consists of a set of import supply curves to all five Petroleum Administration for Defense Districts (PADDs) for each of five quality classes of crude oils and for each simulation year. The petroleum market module uses the supply curves to determine the quantities and prices of the crude oils to be imported. Because the petroleum market module is a linear programming formulation, the imported crude oil supply curves are formulated as 3-step, piecewise-linear functions. The five classes of imported crude oils categorized by sulfur content and American Petroleum Institute (API) gravity include: low-sulfur light, me-

IEM Outputs	Inputs from NEMS	Exogenous Inputs
World oil price	Domestic crude oil production	OPEC production path
Crude oil import supply curves	Domestic natural gas liquids production	Reference non-U.S. oil supply and demand
Refined product import supply curves	Domestic other liquids production	Non-U.S. economic parameters
Oxygenate import supply curves	Domestic refinery gain	Base import supply curves for crude oils, refined products, and oxygenates
	Domestic product supplied	
	GDP price deflators	
	Domestic crude oil imports	
	Domestic refined product imports	
	Domestic oxygenate imports	

Figure 4. International Energy Module Structure



dium-sulfur heavy, high-sulfur light, high-sulfur heavy, high-sulfur very heavy.

The imported crude oil supply curves are developed exogenous to NEMS using a large-scale linear programming formulation of international refining and transportation. This formulation, known as the World Oil Refining, Logistics, and Demand (WORLD) model, is run repetitively, parameterizing on the import levels of the five crude oil classes into each PADD. From these runs, base price/quantity relationships for imported crude oils are established. Within NEMS, these base relationships are shifted as a function of the world oil price and presented to the petroleum market module as a flexible set of crude oil import alternatives. By observing which import supply curves are selected by the petroleum market module, it becomes possible to map these selections back into the WORLD model in order to provide estimates of future sources of crude oil imports into the United States.

Petroleum Products Supply Submodule

The petroleum products supply submodule consists of a set of import supply curves to all five PADDs for each of ten refined product types and for each simulation year. The petroleum market module uses the supply curves to determine the quantities and prices of refined products to be imported. Because the petroleum market module is a linear programming formulation, the imported refined product supply curves are formulated as 3-step, piecewise-linear functions. The ten types of imported refined products include: traditional gasoline (including aviation), reformulated gasoline, reformulated gasoline blending stocks for oxygenated blending (RBOB), No. 2 heating oil, low-sulfur distillate fuel, high- and low-sulfur residual fuel, jet fuel (including naphtha jet), liquefied petroleum gas, petrochemical feedstocks, and other petroleum products.

Similar to the imported crude oil supply curves, the imported refined product supply curves are also developed exogenous to NEMS using the WORLD model. By observing which import supply curves are selected by the petroleum market module, it becomes possible to map these selections back into the WORLD model in order to provide estimates of future sources of refined product imports into the United States.

Oxygenates Supply Submodule

The oxygenates supply submodule consists of a set of import supply curves to all five PADDs for the oxygenates MTBE and methanol and for each simulation year. The petroleum market module uses the supply curves to determine the quantities and prices of oxygenates to be imported. Because the petroleum market module is a linear programming formulation, the imported oxygenate supply curves are formulated as 3-step, piecewise-linear functions. Similar to the imported crude oil supply curves, the imported oxygenate supply curves are developed exogenous to NEMS using the WORLD model. By observing which import supply curves are selected by the petroleum market module, it becomes possible to map these selections back into the WORLD model in order to provide estimates of future sources of oxygenate imports into the United States.

Because of the potential expansion of the U.S. ethanol industry and the lack of commercial markets for other oxygenates, it is assumed that ethanol, ethyl tertiary butyl ether (ETBE), tertiary amyl methyl ether (TAME), and tertiary butyl alcohol (TBA) are all supplied from domestic sources. Therefore, IEM does not provide import supply curves for these oxygenates.

By presenting NEMS with a flexible array of import choices, valuable insights can be gained on such issues as the future crude oil/refined product import composition, potential U.S. refinery expansion (both distillation capacity and downstream capacity), and future sources of petroleum imports (including Persian Gulf import dependence).

Page Intentionally Left Blank

RESIDENTIAL DEMAND MODULE

The residential demand module (RDM) forecasts energy consumption by Census division for seven marketed energy sources plus solar and geothermal energy. RDM is a structural model and its forecasts are built up from projections of the residential housing stock and of the energy-consuming equipment contained therein. The components of RDM and its interactions with the NEMS system are shown in Figure 5. NEMS provides forecasts of residential energy prices, population, and housing starts, which are used by RDM to develop forecasts of energy consumption by fuel and Census division.

RDM incorporates the effects of four broadly-defined determinants of energy consumption: economic and demographic effects, structural effects, technology turnover and advancement effects, and energy market effects. Economic and demographic effects include the number, dwelling type (single-family, multi-family or mobile homes), occupants per household, and location of housing units. Structural effects include increasing average dwelling size and changes in the mix of desired end-use services provided by energy (new end uses and/or increasing penetration of current end uses, such as the increasing popularity of electronic equipment and computers). Technology effects include changes in the stock of installed equipment caused by normal turnover of old, worn out equipment with newer versions which tend to be more energy efficient, the integrated effects of equipment and building shell (insulation level) in new construction, and in the projected availability of even more energy-efficient equipment in the future. Energy market effects include the short-run effects of energy prices on energy demands, the longer-run effects of energy prices on the efficiency of purchased equipment and the efficiency of building shells, and limitations on minimum levels of efficiency imposed by legislated efficiency standards.

Housing Stock Submodule

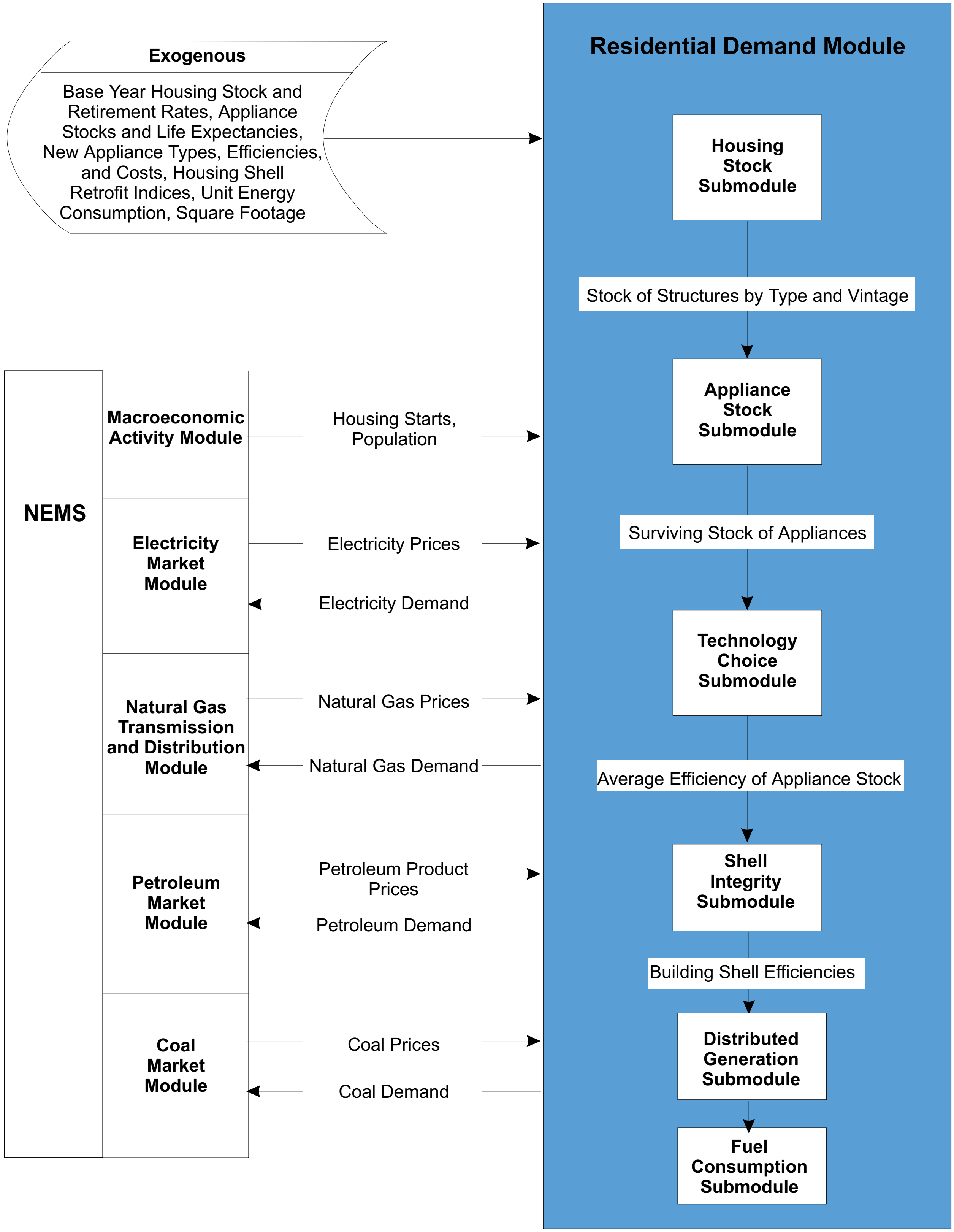
The base housing stock by Census division and dwelling type is derived from EIA's 1997 Residential Energy Consumption Survey (RECS). Each element of the base stock is retired on the basis of a constant rate of decay for each dwelling type. RDM receives as an input from the macroeconomic activity module forecasts of housing additions by type and Census division. RDM supplements the surviving stocks from the previous year with the forecast additions by dwelling type and Census division. The average square footage of new construction is based on recent upward trends developed from the 1997 RECS.

Appliance Stock Submodule

The installed stock of appliances is also taken from the 1997 RECS. The efficiency of the appliance stock is derived from historical shipments by efficiency level over a many-year interval for the following equipment: heat pumps, gas furnaces, central air conditioners, room air conditioners, water heaters, refrigerators, freezers, stoves, dishwashers, clothes washers, and clothes dryers. A linear retirement function with both minimum and maximum equipment lives is used to retire equipment in surviving housing units. For equipment where shipment data are available, the efficiency of the retiring equipment varies over the projection. In early years, the retiring efficiency tends to be lower as the older, less efficient equipment in the stock turns over first. Also, as housing units retire, the associated appliances are removed from the base appliance stock as well. Additions to the base stock are tracked separately for housing units existing in 1997 and for cumulative new construction. As appliances are removed from the stock, they are replaced by new appliances with generally higher efficiencies due to technology improvements, equipment standards, and market forces. Appliances added into new construction are accumulated and retired parallel to appliances in the existing stock. Appliance stocks are

RDM Outputs	Inputs from NEMS	Exogenous Inputs
Energy product demand Changes in housing and appliance stocks Appliance stock efficiency	Energy product prices Housing starts Population	Current housing stocks and retirement rates Current appliance stocks and life expectancy New appliance types, efficiencies, and costs Housing shell retrofit indices Unit energy consumption Square footage

Figure 5. Residential Demand Module Structure



Space Heating Equipment: electric furnace, electric air-source heat pump, natural gas furnace, natural gas hydronic, kerosene furnace, liquefied petroleum gas, distillate furnace, distillate hydronic, wood stove, ground-source heat pump, natural gas heat pump.
Space Cooling Equipment: room air conditioner, central air conditioner, electric air-source heat pump, ground-source heat pump, natural gas heat pump.
Water Heaters: solar, natural gas, electric, oil, liquefied petroleum gas.
Refrigerators: 18 cubic foot top-mounted freezer, 25 cubic foot side-by-side with through-the-door features.
Freezers: chest - manual defrost, upright - manual defrost
Lighting: incandescent, compact fluorescent, mercury vapor
Clothes Dryers: natural gas, electric
Cooking: natural gas, electric, liquefied petroleum gas.
Dishwashers
Clothes Washers
Fuel Cells
Solar Photovoltaic

maintained by fuel, end use, and technology as shown in the above table.

Technology Choice Submodule

Fuel-specific equipment choices are made for both new construction and replacement purchases. For new construction, initial heating system shares (provided by the most recently available Census Bureau survey data covering new construction, currently 1997) are adjusted based on relative life cycle costs for all competing technology and fuel combinations. Once new home heating system shares are established, the fuel choices for other services, such as water heating and cooking, are determined based on the fuel chosen for space heating. For replacement purchases, fuel switching is allowed for an assumed percentage of all replacements but is dependent on the estimated costs of fuel-switching (switching from electricity to gas heating is assumed to involve the costs of running a new gas line).

For both replacement equipment and new construction, a "second-stage" of the equipment choice decision requires selecting from several projected available efficiency levels. The projected efficiency range of available equipment represents a "menu" of efficiency levels and installed cost combinations projected to be available at the time the choice is being made. Costs and efficiencies for selected appliances are shown in the table on page 27, derived from the report *Assumptions to the Annual Energy Outlook 2000*.[16] At the low end of the efficiency range are the minimum levels required by legislated standards. In any given year, higher efficiency levels are associated with higher installed costs. Thus, purchasing higher than the minimum efficiency involves a trade-off between higher installation costs and future savings in energy expenditures. In RDM, these trade-offs are calibrated to recent shipment, cost, and efficiency data. Changes in projected purchases by efficiency level are based on changes in either the installed capital costs or changes in the first-year operating costs across the available efficiency levels. As energy prices increase, the incentive of greater energy expenditures savings will promote increased purchases of higher-efficiency equipment. In some cases, due to government programs or general projections of technology improvements, projected increases in efficiency or decreases in the installed costs of higher-efficiency equipment will also promote purchases of higher-efficiency equipment.

Shell Integrity Submodule

Shell integrity is also tracked separately for the existing housing stock and the stock of cumulative new construction. Shell integrity for existing construction is assumed to respond to increases in real energy prices by becoming more efficient. There is no change in existing shell integrity when real energy prices decline. New shell efficiencies are projected to increase, based on recent trends in shell efficiency measures and building codes. All shell efficiencies are subject to a maximum shell efficiency based on studies of currently available residential construction methods.

Distributed Generation Submodule

Distributed generation equipment with explicit technology characterizations is also modeled for residential customers. Currently, two technologies are characterized, photovoltaics and fuel cells. The submodule incorporates historical estimates of

[16] Energy Information Administration, *Assumptions to the Annual Energy Outlook 2000*, http://www.eia.doe.gov/oiaf/aeo/assumption/pdf/0554(2000).pdf (Washington, DC, January 2000).

jected increases in efficiency or decreases in the installed costs of higher-efficiency equipment will also promote purchases of higher-efficiency equipment.

Shell Integrity Submodule

Shell integrity is also tracked separately for the existing housing stock and the stock of cumulative new construction. Shell integrity for existing construction is assumed to respond to increases in real energy prices by becoming more efficient. There is no change in existing shell integrity when real energy prices decline. New shell efficiencies are projected to increase, based on recent trends in shell efficiency measures and building codes. All shell efficiencies are subject to a maximum shell efficiency based on studies of currently available residential construction methods.

Distributed Generation Submodule

Distributed generation equipment with explicit technology characterizations is also modeled for residential customers. Currently, two technologies are characterized, photovoltaics and fuel cells. The submodule incorporates historical estimates of photovoltaics (residential-sized fuel cells are not expected to be commercialized until after 2001) from its technology characterization and exogenous penetration input file. Program-based photovoltaic estimates for the Department of Energy's Million Solar Roofs program are also input to the submodule from the exogenous penetration portion of the input file. Endogenous, economic purchases are based on a penetration function driven by a cash flow model which simulates the costs and benefits of distributed generation purchases. The cash flow calculations are developed from NEMS projected energy prices coupled with the technology characterizations provided from the input file.

Potential economic purchases are modeled by Census division and technology for all years subsequent to the base year. The cash flow model develops a 30-year cost-benefit horizon for each potential investment. It includes considerations of annual costs (down payments, loan payments, maintenance costs and, for fuel cells, gas costs) and annual benefits (interest tax deductions, any applicable tax credits, electricity cost savings, and water heating savings for fuel cells) over the entire 30-year period. Penetration for a potential investment in either photovoltaics or fuel cells is a function of whether it achieves a cumulative positive cash flow, and if so, how many years it takes to achieve it.

Once the cumulative stock of distributed equipment is projected, reduced residential purchases of electricity are provided to NEMS. For fuel cells, increased residential natural gas consumption is also provided to NEMS based on the calculated energy input requirements of the fuel cells, partially offset by natural gas water heating savings from the use of waste heat from the fuel cell.

Fuel Consumption Submodule

The fuel consumption submodule modifies base year energy consumption intensities in each forecast year. Base year energy consumption for each end use is derived from energy intensity estimates from the 1997 RECS. The base year energy intensities are modified for the following effects: (1) increases in efficiency, based on a comparison of the projected appliance stock serving this end use relative to the base year stock, (2) changes in shell integrity for space heating and cooling end uses, (3) changes in real fuel prices—short-run price elasticity effects, (4) changes in square footage, (5) changes in the number of occupants per household, (6) changes in weather relative to the base year, (7) adjustments in utilization rates caused by efficiency increases (efficiency "rebound" effects), and (8) reductions in purchased electricity and increases in natural gas consumption from distributed generation. Once these modifications are made, total energy use is computed across end uses and housing types and then summed by fuel for each Census division.

Characteristics of Selected Equipment

Equipment Type	Relative Performance[1]	1998 Installed Cost (1998 dollars)	Efficiency[2]	2015 Installed Cost (1998 dollars)	Efficiency[2]	Approximate Discount Rate
Electric Heat Pump	Minimum	$4,100	10.0	$4,100	10.0	38%
	Best	$5,555	17.7	$5,200	18.0	
Natural Gas Furnace	Minimum	$1,300	0.78	$1,300	0.78	15%
	Best	$2,700	0.96	$1,600	0.96	
Room Air Conditioner	Minimum	$450	8.7	$450	9.7	140%
	Best	$760	11.7	$760	12.0	
Central Air Conditioner	Minimum	$2,500	10.0	$2,500	10.0	36%
	Best	$3,600	18.0	$3,200	18.0	
Refrigerator (18 cubic ft)	Minimum	$530	690	$530	478	19%
	Best	$850	518	$700	400	
Electric Water Heater	Minimum	$350	0.86	$350	0.86	83%
	Best	$1,025	2.60	$800	2.20	
Solar Water Heater	N/A	$2,600	2.0	$2,600	2.0	83%

[1] Minimum performance refers to the lowest efficiency equipment available. Best refers to the highest efficiency equipment available.

[2] Efficiency measurements vary by equipment type. Electric heat pumps and central air conditioners are rated for cooling performance using the Seasonal Energy Efficiency Ratio (SEER); natural gas furnaces are based on Annual Fuel Utilization Efficiency; room air conditioners are based on Energy Efficiency Ratio (EER); refrigerators are based on kilowatt-hours per year; and water heaters are based on Energy Factor (delivered Btu divided by input Btu).

Page Intentionally Left Blank

The commercial demand module (CDM) forecasts energy consumption by Census division for eight marketed energy sources plus solar and geothermal energy. For the three major commercial sector fuels, electricity, natural gas and distillate oil, CDM is a "structural" model and its forecasts are built up from projections of the commercial floorspace stock and of the energy-consuming equipment contained therein. For the remaining five marketed "minor fuels," simple econometric projections are made.

The commercial sector encompasses business establishments that are not engaged in industrial or transportation activities. Commercial sector energy is consumed mainly in buildings, except for a relatively small amount for services such as street lights and water supply. CDM incorporates the effects of four broadly-defined determinants of energy consumption: economic and demographic effects, structural effects, technology turnover and change effects, and energy market effects. Demographic effects include total floorspace, building type and location. Structural effects include changes in the mix of desired end-use services provided by energy (such as the penetration of telecommunications equipment, personal computers and other office equipment). Technology effects include changes in the stock of installed equipment caused by normal turnover of old, worn out equipment to newer versions which tend to be more energy efficient, the integrated effects of equipment and building shell (insulation level) in new construction, and the projected availability of equipment with even greater energy-efficiency. Energy market effects include the short-run effects of energy prices on energy demands, the longer-run effects of energy prices on the efficiency of purchased equipment, and limitations on minimum levels of efficiency imposed by legislated efficiency standards.

The model structure carries out a sequence of five basic steps, as shown in Figure 6. The first step is to forecast commercial sector floorspace. The second step is to forecast the energy services (space heating, lighting, etc.) required by the projected floorspace. The third step is to project the electricity generation and water and space heating supplied by distributed generation and cogeneration technologies. The fourth step is to select specific technologies (natural gas furnaces, fluorescent lights, etc.) to meet the demand for energy services. The last step is to determine how much energy will be consumed by the equipment chosen to meet the demand for energy services.

Floorspace Submodule

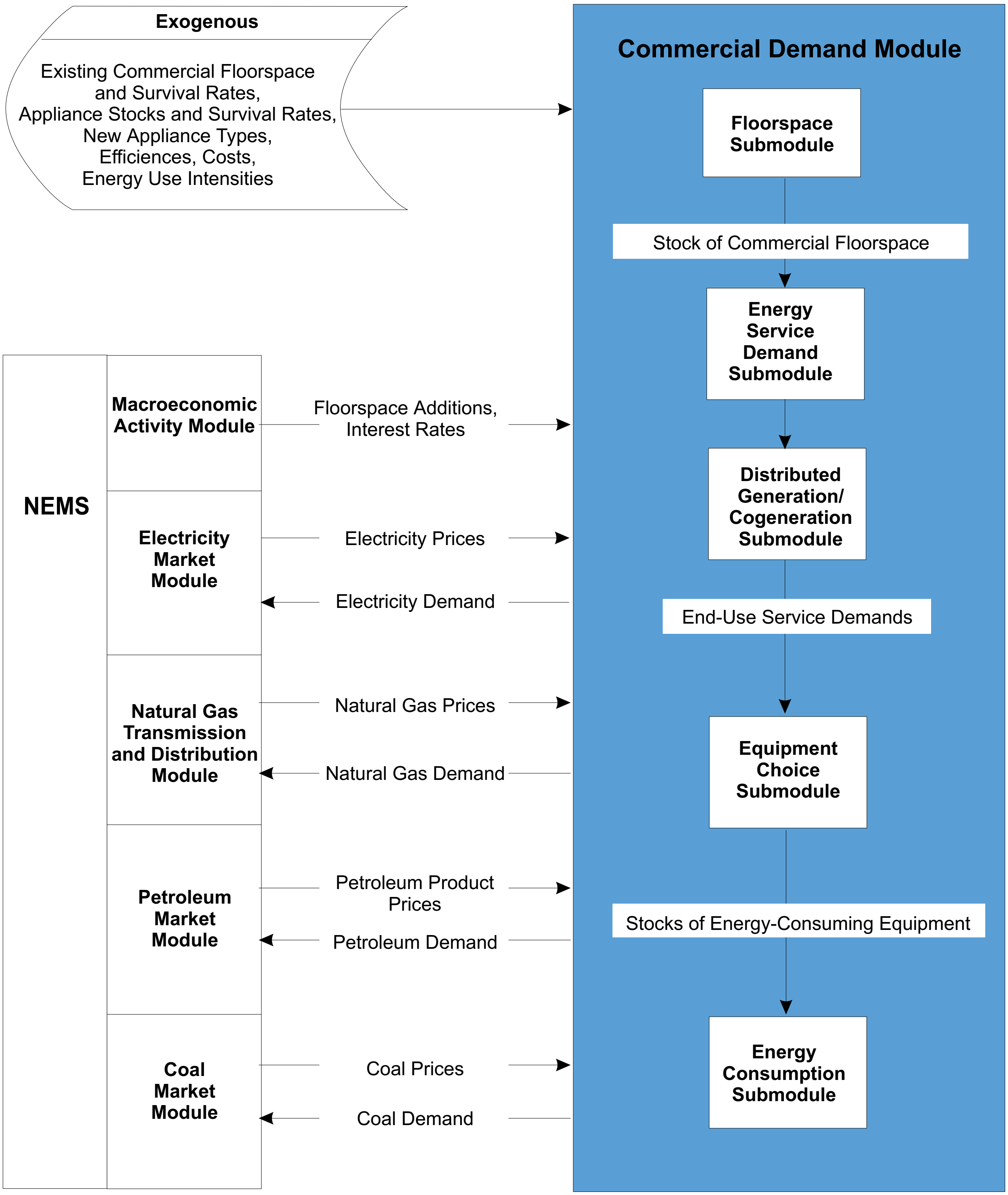
The base stock of commercial floorspace by Census division and building type is derived from EIA's 1995 Commercial Buildings Energy Consumption Survey (CBECS). CDM receives forecasts of total floorspace by building type and Census division from the macroeconomic activity module (MAM) based on DRI-Dodge definitions of the commercial sector. These forecasts embody both economic and demographic effects on commercial floorspace. Since the definition of commercial floorspace from DRI-Dodge is not calibrated to CBECS, CDM estimates the surviving floorspace from the previous year and then calibrates its new construction so that growth in total floorspace matches that from MAM by building type and Census division. CDM models commercial floorspace for the following 11 building types:

- Assembly
- Education
- Food sales
- Food service
- Health care
- Lodging
- Office-large
- Office-small
- Mercantile and service
- Warehouse
- Other

Energy Service Demand Submodule

CDM Outputs	Inputs from NEMS	Exogenous Inputs
Energy product demands Changes in floorspace and appliance stocks	Energy product prices Interest rates Floorspace growth	Existing commercial floorspace Floorspace survival rates Appliance stocks and survival rates New appliance types, efficiencies, costs Energy use intensities

Figure 6. Commercial Demand Module Structure



Energy consumption is derived from the demand for energy services. So the next step is to forecast energy service demands for the projected floorspace. CDM models service demands for the following ten end-use services:

- Heating
- Cooling
- Ventilation
- Water heating
- Lighting
- Cooking
- Refrigeration
- Office equipment personal computer (PC)
- Office equipment other
- Other end uses.

Different building types require unique combinations of energy services. A hospital must have more light than a warehouse. An office building in the Northeast requires more heating than one in the South. Total service demand for any service depends on the floorspace, type, and location of buildings. Base service demand by end use by building type and Census division is derived from estimates developed from CBECS energy consumption. Projected service demands are adjusted for trends in new construction based on CBECS data concerning recent construction.

Distributed Generation and Cogeneration Submodule

Commercial consumers may decide to purchase equipment to generate electricity (and perhaps provide heat as well) rather than depend on purchased electricity to fulfill all of their electric power requirements. The third basic step of the commercial module structure projects electricity generation, fuel consumption, water heating, and space heating supplied by ten distributed generation and cogeneration technologies. The characterized technologies include: photovoltaic solar systems; natural gas fuel cells, reciprocating engines, turbines and microturbines; diesel engines; coal-fired cogeneration; and municipal solid waste, wood, and hydroelectric generators.

Existing electricity cogeneration is derived from historical data contained in the most recent year's version of Form EIA-860B, "Annual Electric Generator Report-Nonutility," formerly Form EIA-867, "Annual Nonutility Power Producer Report." The estimated units form the installed base of cogeneration equipment that is carried forward into future years and supplemented with any projected additions. Program driven installations of solar photovoltaic systems and fuel cells are also included based on information from the Departments of Energy and Defense. For years following the base year, an endogenous forecast of distributed generation and cogeneration of electricity is developed based on the economic returns projected for distributed generation technologies. A detailed cash-flow approach is used to estimate the number of years required to achieve a positive cumulative cash flow. The calculations include the annual costs (down payments, loan payments, maintenance costs, and fuel costs) and returns (tax deductions, tax credits, and energy cost savings) from the investment covering a 30-year period from the time of the investment decision. Penetration of these technologies is a function of how quickly an investment in a technology is estimated to recoup its flow of costs. In terms of NEMS projections, investments in distributed generation reduce purchases of electricity. Fuel consuming technologies also generate waste heat which is assumed to be partially captured and used to offset commercial water heating and space heating energy use.

Equipment Choice Submodule

Once service demands are projected, the next step is to project the type and efficiency of equipment that will be used to satisfy the demands. The bulk of equipment required to meet service demand will carry over from the equipment stock of the previous model year. However, equipment must always be purchased to satisfy service demand for new construction. It must also be purchased for equipment which has either worn out (replacement equipment) or reached the end of its economically useful life (retrofit equipment). For required equipment replacements, CDM uses a constant decay rate based on equipment life. A technology will be "retrofitted" only if the combined annual operating and maintenance costs plus annualized capital costs of a potential technology are lower than the annual operating and maintenance costs of an existing technology.

Equipment choices are made based on a comparison of annualized capital and operating and maintenance costs across all allowable equipment for a particular end-use service. In order to add "inertia" to the equipment choices, only subsets of the total menu of potentially available equipment may be allowed for defined market segments. For example, for replacement space heating equipment in large office buildings, 8 percent of floor space is free to consider all available equipment using any fuel or technology. A second segment of 33 percent must select from technologies using the same fuel as already installed. A third segment, the remaining 59 percent of floorspace, is constrained to consider only different efficiency levels of the same fuel and technology already installed. For lighting, all choices are limited to the same technology, where technologies are broadly defined to encompass principal competing technologies (outdoor lighting types do not compete for indoor lighting service demand).

When computing annualized costs for determining equipment choices, commercial floorspace is segmented by what are referred to as "implicit discount rates" (to distinguish them from the generally lower and more common notion of financial discount rates). Seven segments are used to simulate consumer behavior when purchasing commercial equipment. The segments range from rates as low as the 10-year Treasury bond rate, to rates high enough to guarantee that only equipment with the lowest capital cost (and least efficiency) is chosen. As real energy prices increase (decrease) there is an incentive for all but the highest implicit discount rate segments to purchase increased (decreased) levels of efficiency.

The equipment choice submodule is designed to choose among a discrete set of technologies that are characterized by a "menu" which defines availability, capital costs, maintenance costs, efficiencies, and equipment life. Technology characteristics for selected space heating equipment are shown in the table on page 33, derived from the report *Assumptions to the Annual Energy Outlook 2000*.[17] This menu of projected equipment models projects technological innovation, market developments, and policy interventions. For *Annual Energy Outlook 2000*, the technology types that are included for seven of the ten service demand categories are listed in the table on page 34.

The remaining three end-use services (PC-related office equipment, other office equipment, and other end uses) are considered "minor services" and are forecast using exogenous equipment efficiency and market penetration trends.

Energy Consumption Submodule

Once the required equipment choices have been made, the total stock and efficiency of equipment for a particular end use are determined. Energy consumption by fuel can be calculated from the amount of service demand satisfied by each technology and the corresponding efficiency of the technology. At this stage, adjustments to energy consumption are also made.

These include adjustments for changes in real energy prices (short-run price elasticity effects), adjustments in utilization rates caused by efficiency increases (efficiency "rebound" effects), and changes for weather relative to the CBECS survey year. Once these modifications are made, total energy use is computed across end uses and building types for the three major fuels, for each Census division. Combining these projections with the econometric/trend projections for the five minor fuels yields total projected commercial energy consumption.

[17] Energy Information Administration, *Assumptions to the Annual Energy Outlook 2000*, http://www.eia.doe.gov/oiaf/aeo/assumption/pdf/0554(2000).pdf (Washington, DC, January 2000).

Characteristics of Selected Space Heating Equipment

Equipment Type	Vintage	Efficiency[1]	Capital Cost (1987 dollars per thousand Btu per hour)	Maintenance Cost (1987 dollars per thousand Btu per hour)	Service Life (years)
Electric Heat Pump	Current Standard	6.8	$71.92	$2.10	12
	1998- typical	7.5	$77.18	$2.10	12
	1998- high efficiency	9.4	$96.47	$2.10	12
	2005- typical	8.0	$77.18	$2.10	12
	2005- high efficiency	9.5	$94.72	$2.10	12
	2015 - typical	8.5	$73.67	$2.10	12
	2015 - high efficiency	10.0	$91.21	$2.10	12
Ground-Source Heat Pump	1998- typical	3.4	$166.67	$1.35	20
	1998- high efficiency	4.0	$250.00	$1.35	20
	2005- typical	3.4	$145.83	$1.35	20
	2005- high efficiency	4.1	$225.00	$1.35	20
	2015- typical	3.8	$135.42	$1.35	20
	2015 -high efficiency	4.2	$197.92	$1.35	20
Electric Boiler	Current Standard	0.98	$16.48	$0.09	21
Packaged Electric	1995	0.93	$18.63	$3.29	18
Natural Gas Furnace	Current Standard	0.80	$9.21	$0.69	20
	1998- high efficiency	0.92	$11.12	$0.67	20
	2015 - typical	0.81	$9.21	$0.68	20
Natural Gas Boiler	Current Standard	0.80	$7.95	$0.26	25
	1998 - high efficiency	0.90	$11.49	$0.35	25
	2005- typical	0.81	$7.76	$0.26	25
	2005- high efficiency	0.90	$9.49	$0.30	25
Natural Gas Heat Pump	1998- engine driven	4.1	$229.17	$4.69	13
	2005- engine driven	4.1	$166.67	$3.65	13
	2005- absorption	1.4	$173.61	$4.17	15
Distillate Oil Furnace	Current Standard	0.81	$10.58	$0.69	15
	1998	0.83	$16.06	$0.69	15
	2000	0.86	$16.26	$0.69	15
	2010	0.89	$16.81	$0.69	15
Distillate Oil Boiler	Current Standard	0.83	$12.28	$0.06	20
	1998- high efficiency	0.87	$17.19	$0.06	20
	2005- typical	0.83	$12.16	$0.06	20
	2005- high efficiency	0.87	$16.45	$0.06	20

[1]Efficiency measurements vary by equipment type. Electric air-source and natural gas heat pumps are rated for heating performance using the Heating Seasonal Performance Factor (HSPF); natural gas and distillate furnaces are based on Annual Fuel Utilization Efficiency; ground-source heat pumps are rated on coefficient of performance; and boilers are based on combustion efficiency.

Commercial End-Use Technology Types

End-Use Service by Fuel	Technology Types
Electric Space Heating:	air-source heat pump, ground-source heat pump, boiler, packaged space heating
Natural Gas Space Heating:	boiler, furnace, engine-driven heat pump, absorption heat pump
Fuel Oil Space Heating:	boiler, furnace
Electric Space Cooling:	air-source heat pump, ground-source heat pump, reciprocating chiller, centrifugal chiller, rooftop air conditioner, residential style central air conditioner, window unit
Natural Gas Space Cooling:	absorption chiller, engine-driven chiller, rooftop air conditioner, engine-driven heat pump, absorption heat pump
Electric Water Heating:	electric resistance, heat pump water heater, tankless water heater
Natural Gas Water Heating:	natural gas water heater, tankless water heater
Fuel Oil Water Heating:	fuel oil water heater
Ventilation:	small Constant Air Volume (CAV) system, large CAV system, small Variable Air Volume (VAV) system, large VAV system, fan coil unit, multi-zone CAV system
Electric Cooking:	range, convection oven, deck oven, fryer, griddle, other electric
Natural Gas Cooking:	range, range w/power burner, deck oven, fryer, infrared fryer, griddle, infrared griddle, other
Incandescent Style Lighting:	incandescent, compact fluorescent, halogen, halogen-infrared, coated filament, hafnium carbide
Four-foot Fluorescent Lighting:	magnetic ballast, electronic ballast, electronic w/controls, electronic w/reflectors, scotopic, electrodeless
Eight-foot Fluorescent Lighting:	magnetic ballast, electronic ballast, magnetic-high output, electronic-high output, scotopic, electrodeless
High Intensity Discharge Lighting:	metal halide, mercury vapor, high pressure sodium, sulfur
Medium Temperature Refrigeration:	strip curtain, open case, glass door, mechanical sub-cooling, non-CFC 2-stage R-22 system
Refrigeration:	centralized refrigeration system, walk-in cooler, walk-in freezer, reach-in refrigerator, reach-in freezer, ice machine, refrigerated vending machine
Low Temperature Refrigeration:	open case, glass door, time control, high efficiency motor, non-CFC 2-stage R-22 system
Very Low Temperature Refrigeration:	open case, glass door, hot glass defrost, high efficiency motor, non-CFC 2-stage R-22 system

The industrial demand module (IDM) forecasts energy consumption for fuels and feedstocks for nine manufacturing industries and six nonmanufacturing industries, subject to delivered prices of energy and macroeconomic variables representing the value of output for each industry. The module includes industrial cogeneration of electricity that is either used in the industrial sector or sold to the electricity grid. The IDM structure is shown in Figure 7.

Industrial energy demand is projected as a combination of "bottom up" characterizations of the energy-using technology and "top down" econometric estimates of behavior. The influence of energy prices on industrial energy consumption is modeled in terms of the efficiency of use of existing capital, the efficiency of new capital acquisitions, and the mix of fuels utilized, given existing capital stocks. Energy conservation from technological change is represented over time by trend-based "technology possibility curves." These curves represent the aggregate efficiency of all new technologies that are likely to penetrate the future markets as well as the aggregate improvement in efficiency of 1994 technology.

IDM incorporates three major industry categories: energy-intensive manufacturing industries, nonenergy-intensive manufacturing industries, and nonmanufacturing industries. The level and type of modeling and the attention to detail is different for each. Manufacturing disaggregation is at the 2-digit Standard Industrial Classification (SIC) level, with some further disaggregation of more energy-intensive or large energy-consuming industries. Industries treated in more detail include food, paper, chemicals, glass, cement, steel, and aluminum. Energy product demands are calculated independently for each industry.

Each industry is modeled (where appropriate) as three interrelated components: buildings (BLD), boilers/ steam/cogeneration (BSC), and process/ assembly (PA) activities. Buildings are estimated to account for 6 percent of energy consumption in manufacturing industries (in nonmanufacturing industries, building energy consumption is assumed to be negligible).

Consequently, IDM uses a simple modeling approach for the BLD component. Energy consumption

Energy-Intensive Manufacturing

- Food and Kindred Products (SIC 2)
- Paper and Allied Products (SIC 26)
- Bulk Chemicals (SIC 281, 282, 286, 287)
- Glass and Glass Products (SIC 321, 322, 323)
- Hydraulic Cement (SIC 324)
- Blast Furnaces and Basic Steel (SIC 331, 322)
- Primary Aluminum (SIC 3334)

Nonenergy-Intensive Manufacturing

- Metals-Based Durables (SIC 34, 35, 36, 37, 38)
- Other Manufacturing (all remaining manufacturing SICs)

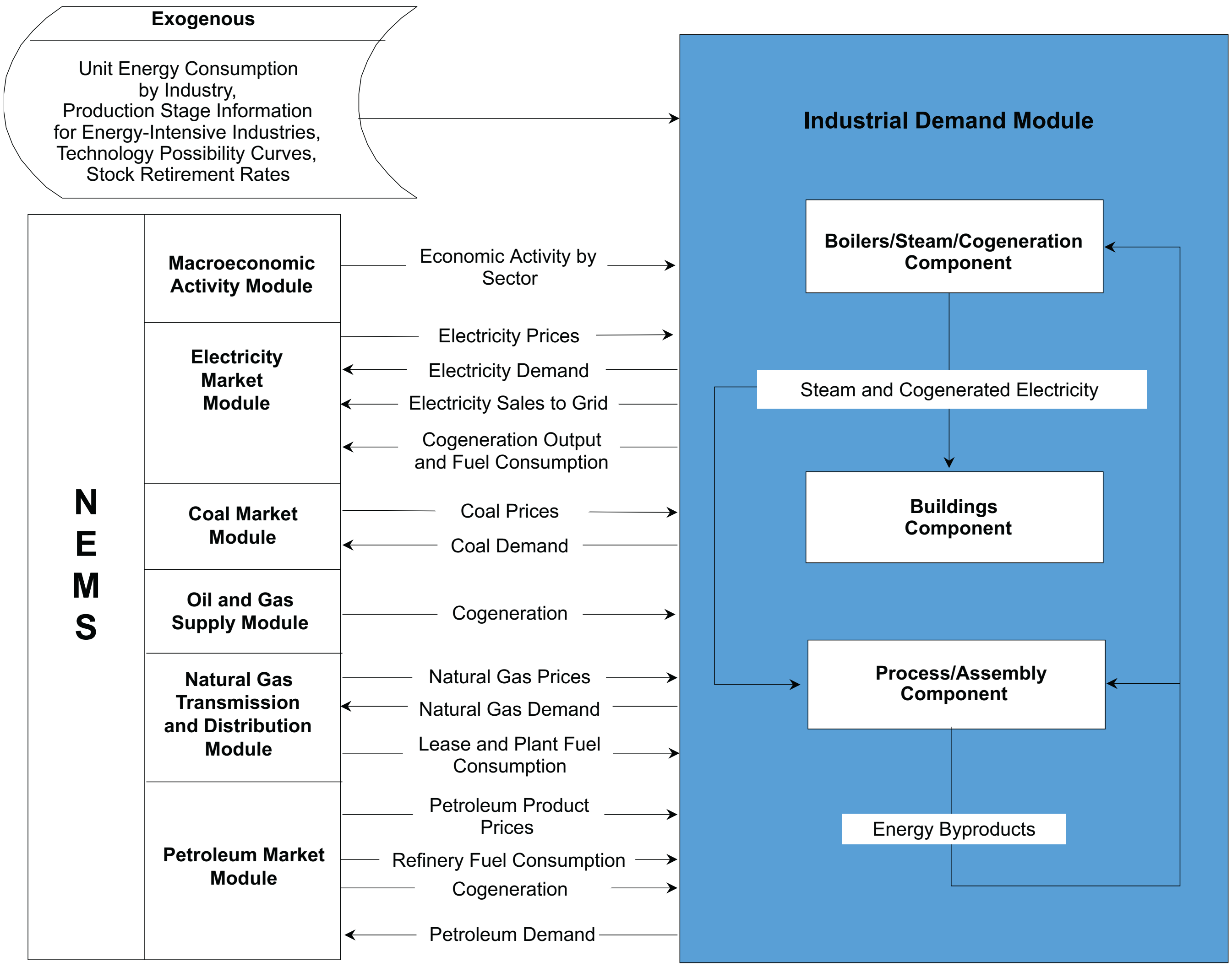
Nonmanufacturing Industries

- Agricultural Production - Crops (SIC 01)
- Other Agriculture including Livestock (SIC 02, 07, 08, 09)
- Coal Mining (SIC 12)
- Oil and Gas Mining (SIC 13)
- Metal and Other Nonmetallic Mining (SIC 10, 14)
- Construction (SIC 15, 16, 17)

SIC = Standard Industrial Classification

IDM Outputs	Inputs from NEMS	Exogenous Inputs
Energy product demand Electricity sales to grid Cogeneration output and fuel consumption	Energy product prices Economic output by industry Refinery fuel consumption Lease and plant fuel consumption Cogeneration from refineries and oil and gas production	Production stages in energy-intensive industries Technology possibility curves Unit energy consumption Stock retirement rates

Figure 7. Industrial Demand Module Structure



in industrial buildings is assumed to grow at the same rate as the average growth rate of employment and output in that industry. The BSC component consumes energy to meet the steam demands from the other two components and to provide internally generated electricity to the BLD and PA components. The boiler component consumes fossil fuels to produce steam, which is passed to the PA component.

IDM models "traditional" cogeneration based on steam demand from the BLD and the PA components. The "nontraditional" cogeneration units are represented in the electricity market module since these units are mainly grid-serving, electricity-price-driven entities.

Cogeneration capacity, generation, and fuel use are calculated from exogenous data on existing and planned capacity additions and new additions determined from an engineering and economic evaluation. Existing cogeneration capacity and planned additions are derived from Form EIA-860B, "Annual Electric Generator Report-Nonutility," formerly Form EIA-867, "Annual Nonutility Power Producer Report." Existing cogeneration capacity is assumed to remain in service throughout the forecast or, equivalently, to be refurbished or replaced with similar units of equal capacity.

Calculation of unplanned cogeneration capacity additions begins in 2001, based on the assumption that additions through 2000 would be planned units un-

End Use Characterization

Food: direct fuel, hot water/steam, refrigeration, and other electric.

Bulk Chemicals: direct fuel, hot water/steam, electrolytic, and other electric.

Process Step Characterization

Pulp and Paper: wood preparation, waste pulping, mechanical pulping, semi-chemical pulping, Kraft pulping, bleaching, and papermaking.

Glass: batch preparation, melting/refining, and forming.

Cement: dry process clinker, wet process clinker, and finish grinding.

Steel: coke oven, open hearth steel making, basic oxygen furnace steel making, electric arc furnace steel making, ingot casting, continuous casting, hot rolling, and cold rolling.

Aluminum: only primary aluminum smelting is explicitly included.

der construction. Modeling of unplanned capacity additions is done in two parts: biomass-fueled and fossil-fueled. Biomass cogeneration capacity is assumed to be added to the extent possible as additional biomass waste products are produced, primarily in the pulp and paper industry. The amount of biomass cogeneration capacity added is equal to the quantity of new biomass available (in Btu), divided by the total heat rate from biomass steam turbine cogeneration.

Additions to fossil-fueled cogeneration capacity are limited to gas turbine plants. It is assumed that the technical potential for traditional cogeneration is based primarily on supplying thermal requirements. First, the model assesses the amount of capacity that could be added to generate the industrial steam requirements not met by existing cogeneration. The second step is an economic evaluation of gas turbine prototypes for each steam load segment. Finally, cogeneration additions are projected based on a range of acceptable payback periods.

The PA component accounts for the largest share of direct energy consumption for heat and power, 55 percent. For the seven most energy-intensive industries, process steps or end uses are modeled using engineering concepts. The production process is decomposed into the major steps, and the energy relationships among the steps are specified.

The energy intensities of the process steps or end uses vary over time, both for existing technology and for technologies expected to be adopted in the future. In IDM, this variation is based on engineering judgment and is reflected in the parameters of technology possibility curves, which show the declining energy intensity of existing and new capital relative to the 1994 stock.

IDM uses "technology bundles" to characterize technological change in the energy-intensive industries. These bundles are defined for each production process step for five of the industries and for end use in two of the industries. The process step industries are pulp and paper, glass, cement, steel, and aluminum. The end-use industries are food and bulk chemicals.

The unit energy consumption is defined as the energy use per ton of throughput at a process step or as energy use per dollar of output for the end use industries. The "Existing UEC" is the current average installed intensity as of 1994. The "New 1994 UEC" is the intensity expected to prevail for a new installation in 1991. Similarly, the "New 2020 UEC" is the intensity expected to prevail for a new installation in 2020. For intervening years, the intensity is interpolated.

The rate at which the average intensity declines is determined by the rate and timing of new additions to capacity. In IDM, the rate and timing of new additions are functions of retirement rates and industry growth rates.

IDM uses a vintaged capital stock accounting framework that models energy use in new additions to the stock and in the existing stock. This capital stock is represented as the aggregate vintage of all plants built within an industry and does not imply the inclusion of specific technologies or capital equipment.

The capital stock is grouped into three vintages: old, middle, and new. The old vintage consists of capital in production prior to 1995, which is assumed to retire at a fixed rate each year. Middle-vintage capital is that added after 1994, excluding the year of the forecast. New production capacity is built in the forecast years when the capacity of the existing stock of capital in IDM cannot produce the output forecasted by the NEMS regional submodule of the macroeconomic activity module. Capital additions during the forecast horizon are retired in subsequent years at the same rate as the pre-1995 capital stock.

The energy-intensive and/or large energy-consuming industries are modeled with a structure that explicitly describes the major process flows or "stages of production" in the industry (some industries have major consuming uses).

Technology penetration at the level of major processes in each industry is based on a technology penetration curve relationship. A second relationship can provide additional energy conservation resulting from increases in relative energy prices. Major process choices (where applicable) are determined by industry production, specific process flows, and exogenous assumptions.

IDM achieves fuel switching by application of a logit function methodology for estimating fuel shares in the boilers/steam/cogeneration component. A small amount of additional fuel switching capability takes place within the PA component.

Recycling, waste products, and byproduct consumption are modeled using parameters based on off-line analysis and assumptions about the manufacturing processes or technologies applied within industry. These analyses and assumptions are mainly based upon environmental regulations such as government requirements about the share of recycled paper used in offices. IDM also accounts for trends within industry toward the production of more specialized products such as specialized steel which can be produced using scrap material versus raw iron ore.

The transportation demand module (TRAN) forecasts the consumption of transportation sector fuels by transportation mode, including the use of renewables and alternative fuels, subject to delivered prices of energy fuels and macroeconomic variables, including disposable personal income, gross domestic product, level of imports and exports, industrial output, new car and light truck sales, and population. The structure of the module is shown in Figure 8.

NEMS projections of future fuel prices influence the fuel efficiency, vehicle-miles traveled, and alternative-fuel vehicle (AFV) market penetration for the current fleet of vehicles. Alternative-fuel shares are projected on the basis of a multinomial logit vehicle attribute model, subject to State and Federal government mandates.

Fuel Economy Submodule

This submodule projects new light-duty vehicle fuel efficiency by 12 U.S. Environmental Protection Agency (EPA) vehicle size classes and 15 engine technologies (gasoline, diesel, and 13 AFV technologies) as a function of energy prices and income-related variables. There are 59 fuel-saving technologies which vary in cost and marginal fuel savings by size class. Characteristics of a sample of these technologies are shown on page 42, derived from *Assumptions to the Annual Energy Outlook 2000*.[18] Technologies penetrate the market based on a cost-effectiveness algorithm which compares the technology cost to the discounted stream of fuel savings and the value of performance to the consumer. In general, higher fuel prices lead to higher fuel efficiency estimates within each size class, a shift to a more fuel-efficient size class mix, and an increase in the rate at which alternative-fuel vehicles enter the marketplace.

Regional Sales Submodule

Vehicle sales from the macroeconomic activity module are divided into car and light truck sales based on demographic analysis. The remainder of the submodule is a simple accounting mechanism that uses endogenous estimates of new car and light truck sales and the historical regional vehicle sales adjusted for regional population trends to produce estimates of regional sales, which are subsequently passed to the alternative-fuel vehicle and the light-duty vehicle stock submodules.

Alternative-Fuel Vehicle Submodule

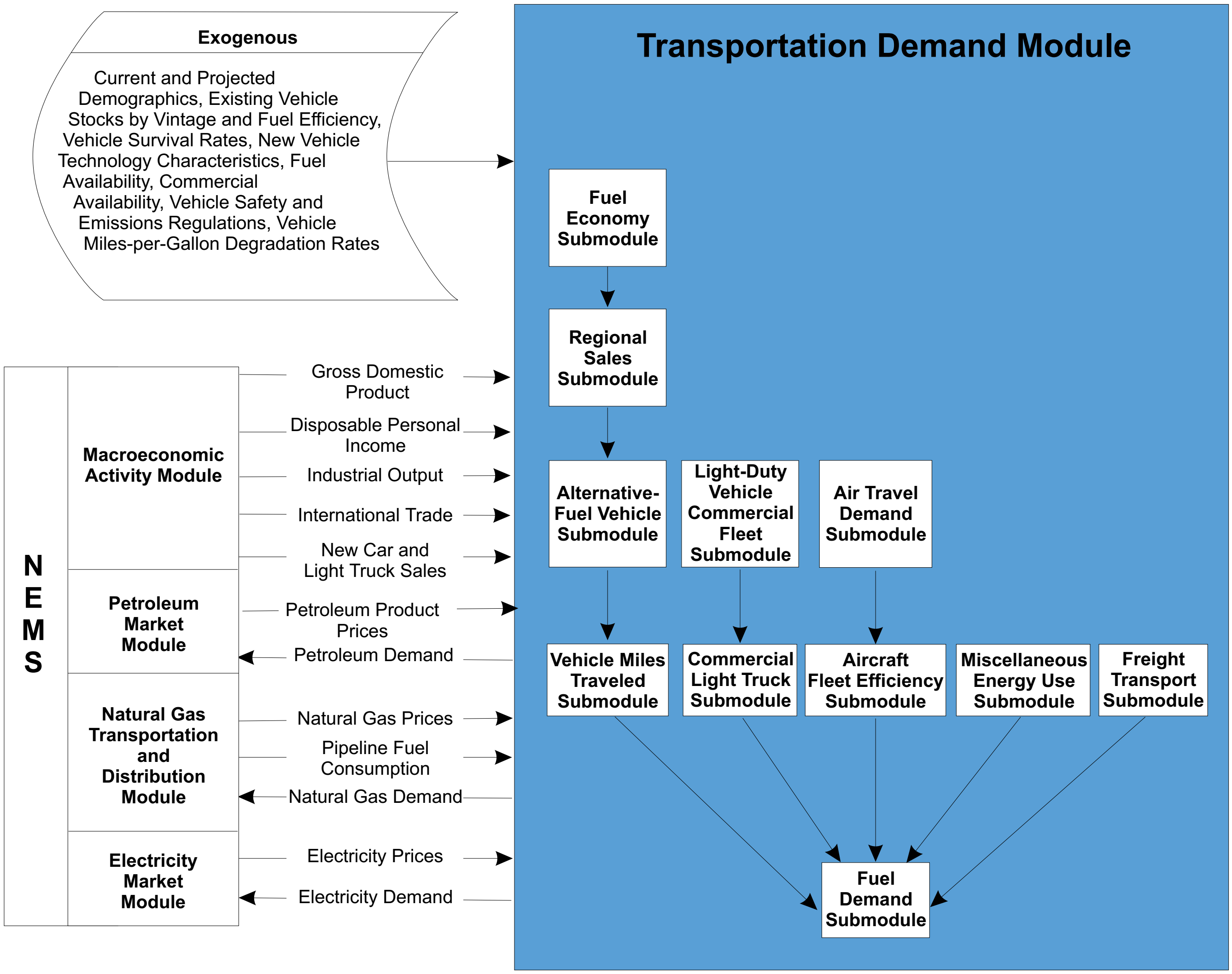
This submodule projects the sales shares of alternative-fuel technologies as a function of time, technology attributes, costs, and fuel prices. The alternative-fuel technologies are listed on the next page. Vehicle attributes are shown on page 42, derived from *Assumptions to the Annual Energy Outlook 2000.* Both conventional and new technology vehicles are considered. The alternative-fuel vehicle submodule receives regional new car and light truck sales by size class from the regional sales submodule.

The forecast of vehicle sales by technology requires a two-stage nested decision process. The first stage consists of endogenously calculating the sales shares between conventional, diesel, and total alternative fuel vehicles on a regional level, based on the follow-

TRAN Outputs	Inputs from NEMS	Exogenous Inputs
Fuel demand by mode Sales, stocks and characteristics of vehicle types by size class Vehicle-miles traveled Fuel efficiencies by technology type Alternative-fuel vehicle sales by technology type Light-duty commercial fleet vehicle characteristics	Energy product prices Gross domestic product Disposable personal income Industrial output Vehicle sales International trade Natural gas pipeline consumption	Current and projected demographics Existing vehicle stocks by vintage and fuel efficiency Vehicle survival rates New vehicle technology characteristics Fuel availability Commercial availability Vehicle safety and emissions regulations Vehicle miles-per-gallon degradation rates

[18] Energy Information Administration, *Assumptions to the Annual Energy Outlook 2000*, http:/www.eia.doe.gov/oiaf/aeo/assumption/pdf/0554(2000).pdf (Washngton, DC, January 2000).

Figure 8. Transportation Demand Module Structure



Methanol flex-fueled
Methanol neat (85 percent methanol)
Ethanol flex-fueled
Ethanol neat (85 percent ethanol)
Compressed natural gas (CNG)
CNG bi-fuel
Liquefied petroleum gas (LPG)
LPG bi-fuel
Electric
Diesel-electric hybrid
Fuel cell gasoline
Fuel cell hydrogen
Fuel cell methanol

ing factors: regional fuel operating costs per mile (fuel price divided by fuel efficiency), vehicle price, range, regional fuel availability, commercial availability, and regional regulatory constraints.

The second stage estimates shares among the alternative-fuel vehicle technologies within each region, based on the same regional factors and methodology used in the prior step to calculate the shares of conventional, diesel, and total alternative-fuel vehicle sales.

Light-Duty Vehicle Stock Submodule

This submodule specifies the inventory of light-duty vehicles from year to year. Survival rates are applied to each vintage, and new vehicle sales are introduced into the vehicle stock through an accounting framework. The fleet of vehicles and their fuel efficiency characteristics are important to the translation of transportation services demand into fuel demand.

TRAN maintains a level of detail that includes twenty vintage classifications and six passenger car and six light truck size classes corresponding to EPA interior volume classifications for all vehicles less than 8,500 pounds, as follows:

Cars:
- Mini-compact - less than 85 cubic feet
- Subcompact - between 85 and 99 cubic feet
- Compact - between 100 and 109 cubic feet
- Mid-size - between 110 and 119 cubic feet
- Large - 120 or more cubic feet, including all station wagons (small, mid-size, and large)
- Two-seater - designed to seat two adults

Trucks:
- Passenger vans
- Cargo vans
- Small pickups - trucks with gross vehicle weight rating (GVWR) less than 4,500 pounds
- Large pickups - trucks with GVWR 4,500 to 8,500 pounds
- Small utility
- Large utility

Vehicle-Miles Traveled (VMT) Submodule

This submodule projects travel demand for automobiles and light trucks. VMT per capita estimates are based on the fuel cost of driving per mile, per capita disposable personal income, an index that reflects the aging of the population, and an adjustment for female-to-male driving ratios. Total VMT is calculated by multiplying VMT per capita by the driving age population.

Light-Duty Vehicle Commercial Fleet Submodule

This submodule generates estimates of the stock of cars and trucks used in business, government, and utility fleets. It also estimates travel demand, fuel efficiency, and energy consumption for the fleet vehicles prior to their transition to the private sector at predetermined vintages.

Commercial Light Truck Submodule

The commercial light truck submodule estimates sales, stocks, fuel efficiencies, travel, and fuel demand for all trucks greater than 8,500 pounds and less than 10,000 pounds.

Air Travel Demand Submodule

This submodule estimates the demand for both passenger and freight air travel. Passenger travel is forecasted by domestic travel, which is disaggregated between business and personal travel, and international travel. Dedicated air freight travel is disaggregated between the total air freight demand and air freight carried in the lower hull of commercial passenger aircraft. In each of the market segments, the demand for air travel is estimated as a function of the cost of air travel (including fuel costs) and economic growth (GDP, disposable income, and merchandise exports).

Aircraft Fleet Efficiency Submodule

This submodule forecasts the total stock and the average fleet efficiency of narrow body and wide body aircraft required to meet the projected travel demand. The stock estimation is based on the growth of travel demand and a logistic function that calculates the survival of the older planes. The overall fleet efficiency is determined by the weighted average of the surviving aircraft efficiency (including retrofits) and the efficiencies of the newly acquired aircraft. The efficiency improvements of the new aircraft are determined by technology choice which depends on the trigger fuel price, the time in which the technology has been commercially viable, and by the expected efficiency gains of aircraft incorporating those technologies. Technology characteristics are shown on page 43.

Freight Transport Submodule

This submodule translates NEMS estimates of industrial production into ton-miles traveled requirements for rail and ship travel, and into vehicle-miles traveled for trucks, then into fuel demand by mode of freight travel. The freight truck stock is subdivided into medium and heavy-duty trucks. VMT freight estimates by truck size class and technology are based on matching freight needs, as measured by the growth in industrial output by Standard Industrial Classification (SIC) code, to VMT levels associated with truck stocks and new vehicles. Rail and shipping ton-miles traveled are also estimated as a function of growth in industrial output.

Freight truck fuel efficiency growth rates relative to fuel prices are tied to historical growth rates by size class and are also dependent on the maximum penetration, introduction year, fuel trigger price (based on cost-effectiveness), and fuel economy improvement of the technologies including alternative-fuel technologies. Technology characteristics are shown on page 43. In the rail and shipping modes, energy efficiency estimates are structured to evaluate the potential of both technology trends and efficiency improvements related to energy prices.

Miscellaneous Energy Use Submodule

This submodule projects the use of energy in military operations, mass transit vehicles, recreational boats, and automotive lubricants, based on endogenous variables within NEMS (e.g., vehicle fuel efficiencies) and exogenous variables (e.g., the military budget).

Selected Technology Characteristics for Automobiles

	Fractional Fuel Efficiency Change	First Year Introduced	Fractional Horsepower Change
Front Wheel Drive	0.060	1980	0
4-Speed Automatic	0.045	1980	0.05
5-Speed Automatic	0.065	1995	0.07
6-Speed Manual	0.020	1991	0.05
Electronic Transmission I	0.005	1988	0
Electronic Transmission II	0.015	1998	0
Emissions Tier I	-0.010	1994	0
Emissions Tier II	-0.010	2003	0
Side Impact	-0.005	1996	0

Examples of Domestic Midsize Automobile Attributes

	Year	Gasoline	Ethanol Flex	Methanol Flex	LPG	Electric-Diesel Hybrid	Fuel Cell Methanol
Vehicle Price (thousand 1990 dollars)	1998	18.7	18.8	19.1	22.5	52.1	N/A
	2020	20.0	20.4	20.1	23.9	32.4	35.5
Vehicle Miles per Gallon	1998	27.13	28.17	28.44	28.95	48.10	48.00
	2020	29.97	30.80	31.08	31.47	50.05	44.21
Vehicle Range (100 miles)	1998	4.58	3.36	2.63	3.92	5.99	4.61
	2020	5.07	3.69	2.88	4.29	6.56	5.05
Fuel Availability Relative to Gasoline	1998	1.00	1.00	1.00	0.02	1.00	0.02
	2020	1.00	1.00	1.00	0.10	1.00	0.10
Commercial Availability Relative to Gasoline	1998	1.00	0.269	0.269	0.018	0.000	0.000
	2020	1.00	1.00	1.00	0.999	0.993	0.993

Aircraft Technology Characteristics

Technology	Introduction Year	Jet Fuel Prices Necessary for Cost-Effectiveness (1997 dollars per gallon)	Seat-Miles per Gallon Gain Over 1990 (percent)	
			Narrow Body	Wide Body
Engines				
Ultra-high Bypass	1995	0.69	10	10
Propfan	2000	1.36	23	0
Thermodynamics	2010	1.22	20	20
Aerodynamics				
Hybrid Laminar Flow	2020	1.53	15	15
Advanced Aerodynamics	2000	1.70	18	18
Other				
Weight Reducing Materials	2000	-	15	15

Freight Truck Technology Characteristics

	Fuel Economy Improvement (percent)		Maximum Penetration (percent)		Introduction Year		Capital Cost (1998 dollars)	
	Medium	Large	Medium	Large	Medium	Large	Medium	Large
Existing Technologies								
Advanced Tires: Radials	2	2	70	70	N/A	N/A	$150	$450
Drag Reduction	3	5	65	65	N/A	N/A	$500	$1,000
New Technologies								
Advanced Transmission	2	1	40	40	2001	2001	$2,500	$2,500
Lightweight Materials	1	1	30	30	2002	2002	$3,000	$3,000
Synthetic Gear Lube	2	2	60	60	2001	2001	$40	$60
Advanced Tires: Low Resistance	4	4	70	70	2001	2001	$300	$900
Advanced Drag Reduction	4	7	65	65	2001	2002	$600	$1,200
Electronic Engine Control	4	4	95	95	2001	2001	$1,000	$1,000
Advanced Engine	9	9	90	90	2009	2009	$1,000	$1,000
Turbocompounding	0	5	0	90	N/A	2001	N/A	$2,000
Hybrid Powertrain	54	0	20	0	2006	N/A	$6,000	N/A
Port-injection	0	1	0	100	N/A	2001	N/A	$300

Page Intentionally Left Blank

The electricity market module (EMM) represents the generation, transmission, and pricing of electricity, subject to: delivered prices for coal, petroleum products, and natural gas; the cost of centralized generation from renewable fuels; macroeconomic variables for costs of capital and domestic investment; and electricity load shapes and demand. The submodules consist of capacity planning, fuel dispatching, finance and pricing, and load and demand-side management (Figure 9). In addition, nonutility supply and electricity trade are represented in the fuel dispatching and capacity planning submodules. Nonutility generation from cogenerators and other facilities whose primary business is not electricity generation is represented in the demand and fuel supply modules. All other nonutility generation is represented in EMM. The generation of electricity is accounted for in 15 supply regions (Figure 10), and fuel consumption is allocated to the 9 Census divisions.

Operating (dispatch) decisions are provided by the cost-minimizing mix of fuel and variable operating and maintenance (O&M) costs, subject to environmental costs. Capacity expansion is determined by the least-cost mix of all costs, including capital, O&M, and fuel. Construction of generating plants with long lead times is selected with planning horizons up to six periods into the future; the planning horizon can change with respect to the generating technology being considered. Electricity demand is represented by load curves, which vary by region, season, and time of day.

The solution to the submodules of EMM is simultaneous in that, directly or indirectly, the solution for each submodule depends on the solution to every other submodule. A solution sequence through the submodules can be viewed as follows:

- The load and demand-side management submodule processes electricity demand to construct load curves
- The electricity capacity planning submodule projects the construction of new utility and nonutility plants, the level of firm power trades, and the addition of scrubbers for environmental compliance
- The electricity fuel dispatch submodule dispatches the available generating units, both utility and nonutility, allowing surplus capacity in select regions to be dispatched for another region's needs (economy trade)
- The electricity finance and pricing submodule calculates total revenue requirements for each operation and computes average and marginal-cost based electricity prices.

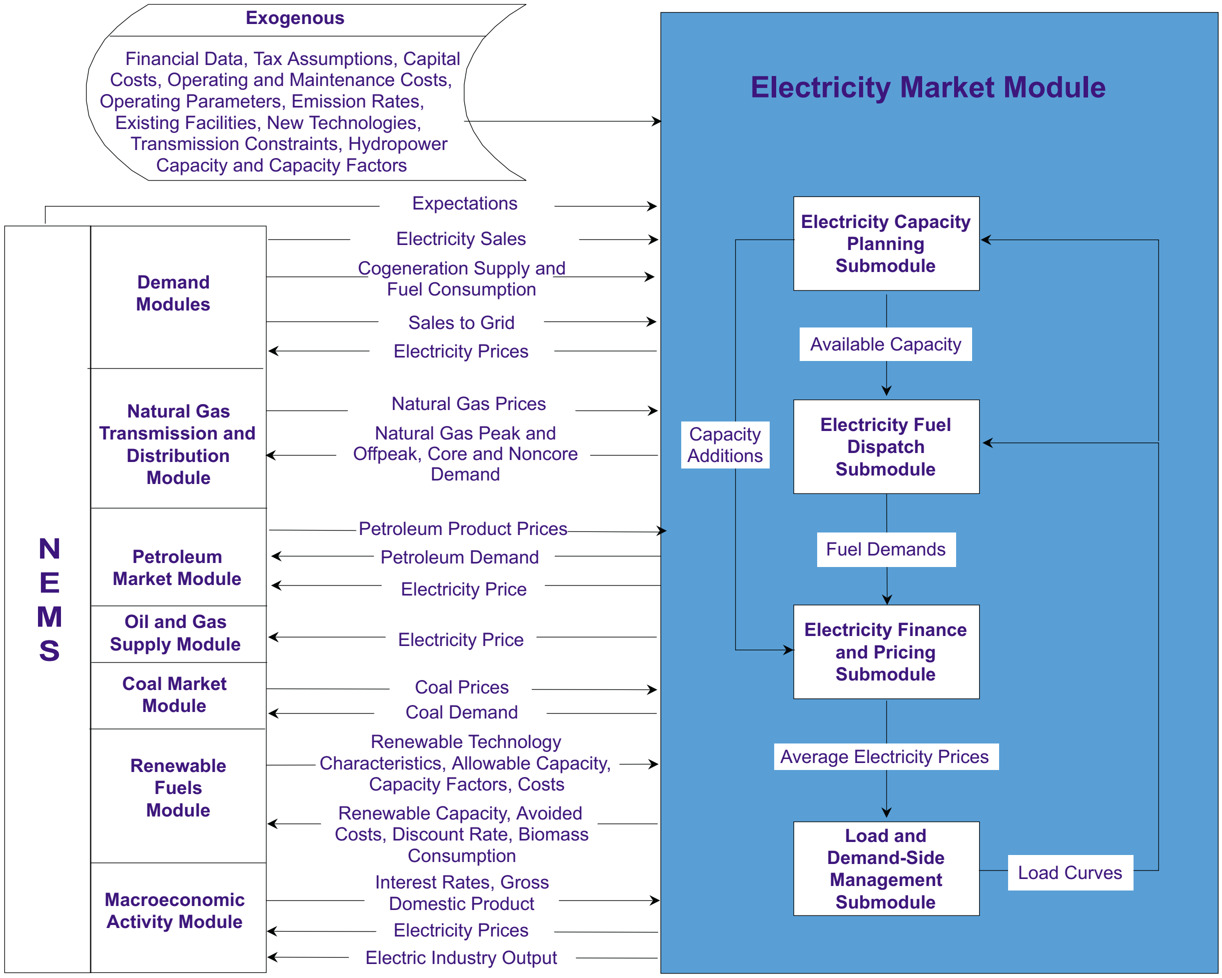
Electricity Capacity Planning Submodule

The electricity capacity planning (ECP) submodule determines how best to meet expected growth in electricity demand, given available resources, expected load shapes, expected demands and fuel prices, environmental constraints, and costs for utility and nonutility technologies. When new capacity is required to meet electricity demand, then the timing of the demand increase, the expected utilization of the new capacity, the operating efficiencies and the construction and operating costs of available technologies determine what technology is chosen.

The expected utilization of the capacity is important in the decision making process. A technology with relatively high capital costs but comparatively low operating costs (primarily fuel costs) may be the appropriate choice if the capacity is expected to operate

EMM Outputs	Inputs from NEMS	Exogenous Inputs
Electricity prices and price components	Electricity sales	Financial data
Fuel demands	Fuel prices	Tax assumptions
Capacity additions	Cogeneration supply and fuel consumption	Capital costs
Capital requirements	Electricity sales to the grid	Operation and maintenance costs
Emissions	Renewable technology characteristics, allowable capacity, and costs	Operating parameters
Renewable capacity	Renewable capacity factors	Emissions rates
Avoided costs	Gross domestic product	New technologies
	Interest rates	Existing facilities
		Transmission constraints
		Hydropower capacity and capacity factors

Figure 9. Electricity Market Module Structure



continuously (base load). However, a plant type with high operating costs but low capital costs may be the most economical selection to serve the peak load (i.e., the highest demands on the system), which occurs infrequently. Intermediate or cycling load occupies a middle ground between base and peak load and is best served by plants that are cheaper to build than baseload plants and cheaper to operate than peak load plants.

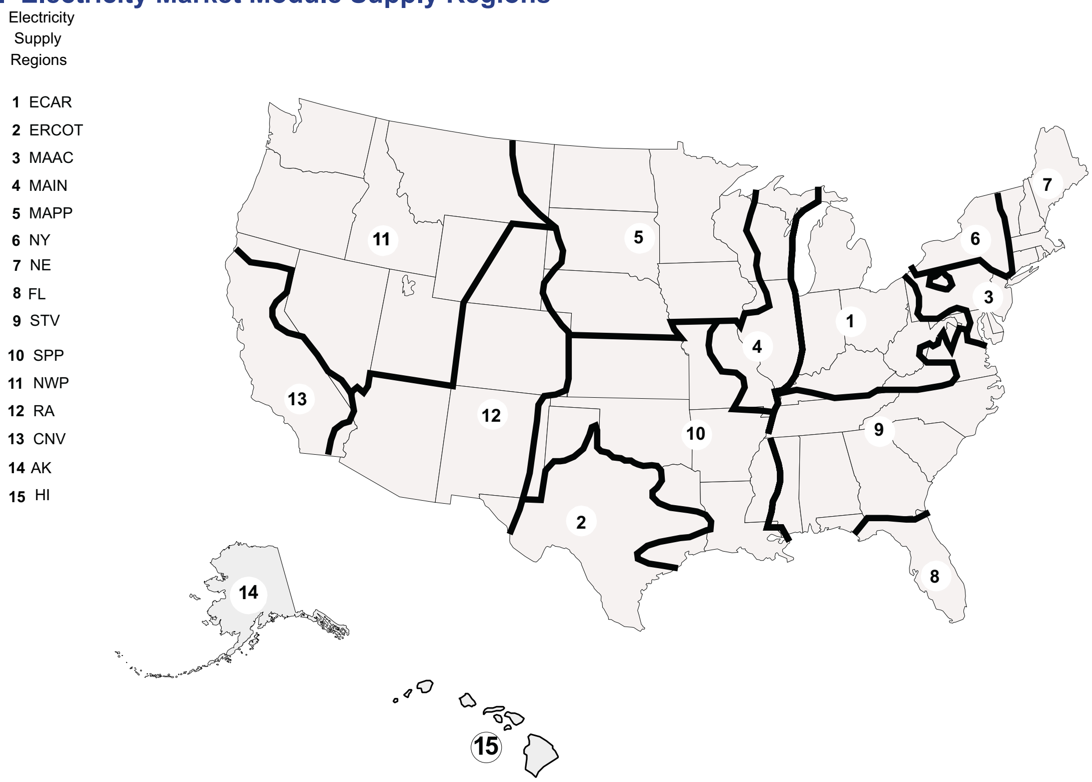
Technologies are compared on the basis of total capital and operating costs incurred over a 20-year period. As new technologies become available, they are competed against conventional plant types. Fossil-fuel, nuclear, and renewable generating technologies are represented, as listed on page 48.

The timing of the demand increase is important because the construction lead times of technologies differ. The ECP submodule looks up to six periods into the future when identifying new capacity needs. A multiperiod optimization is performed, whereby capacity choices in each year are made by looking at several years in the future rather than a single year.

Construction lead times also contribute to uncertainty about investment decisions. Technologies with long lead times are subject to greater financial risk. Compared to plants with shorter lead times, they are more sensitive to market changes in interest and inflation rates and are more vulnerable to uncertain demand projections that determine the need for new capacity. To capture these factors, the discount rate for each technology is adjusted using risk premiums based on the construction lead time. The risk-adjusted discount rate results in the perception that a technology with a long lead time is less economically attractive than another technology with similar costs, but a shorter lead time.

Uncertainty about investment costs for new technologies is captured in ECP using technological optimism and learning factors. The technological optimism factor reflects the inherent tendency to under-

Figure 10. Electricity Market Module Supply Regions



estimate costs for new technologies. The degree of technological optimism depends on the complexity of the engineering design and the stage of development. As development proceeds and more data become available, cost estimates become more accurate and the technological optimism factor declines. Learning factors represent reductions in capital costs due to "learning-by-doing." For new technologies, cost reductions due to learning also account for international experience in building generating capacity.

The decrease in overnight capital costs due to learning depends on the stage of technological development. The cost for a "revolutionary" technology is assumed to decrease by 10 percent for the first three doublings of capacity, 5 percent for the next five doublings, and 1 percent for every doubling thereafter. The cost for an "evolutionary" technology is assumed to decrease by 5 percent for the first five doublings and 1 percent for every doubling thereafter. The cost for a "conventional" technology is assumed to decrease by 1 percent for every doubling of capacity.

Capital costs for all new electricity generating technologies (fossil, nuclear, and renewable) decrease in response to foreign and domestic experience. Foreign units of new technologies are assumed to contribute to reductions in capital costs for units that are installed in the United States to the extent that (1) the technology characteristics are similar to those used in U.S. markets, (2) the design and construction firms and key personnel compete in the U.S. market, (3) the owning and operating firm competes actively in the United States, and (4) there exists relatively complete information about the status of the associated facility. If the new foreign units do not satisfy one or more of these requirements, they are given a reduced weight or not included in the learning effects calculation. Capital costs from the *Annual Energy Outlook 2000* reference case are shown on page 49. For renewable technologies, the capital costs are for California, which is representative of the United States.

Initially, investment decisions are determined in ECP using cost and performance characteristics that are represented as single point estimates corresponding to the average (expected) cost. However, these parameters are also subject to uncertainty and are better represented by distributions. If the distributions of two or more options overlap, the option with the lowest average cost is not likely to capture the entire market. Therefore, ECP uses a market-sharing algorithm to adjust the initial solution and reallocate some of the capacity expansion decisions to technologies that are “competitive” but do not have the lowest average cost.

Fossil-fired steam plant retirements are calculated endogenously within the model. Fossil plants are retired if the market price of electricity is not sufficient to support continued operation. The expected revenues from these plants are compared to the annual going-forward costs, which are mainly fuel and operations and maintenance costs. A plant is retired if these costs exceed the revenues and the overall cost of electricity can be reduced by building replacement capacity.

Retirement decisions for nuclear capacity are also determined by the model. Four options for the operating license are considered. A unit can be retired early (10 years prior to the end of the operation license), retired when the license expires, or operated an additional 10 or 20 years by renewing the license. At each stage, the assumed aging-related expenditures due to capital additions, increased maintenance, and/or performance declines are compared to the cost of replacement capacity. A unit is retired if the aging costs, which are recovered over ten years, exceed the cost of building new capacity.

The ECP submodule also determines whether to contract for unplanned firm power imports from Canada and from neighboring electricity supply regions. Imports from Canada are competed using supply curves developed from cost estimates for potential hydroelectric projects in Canada. Imports from neighboring electricity supply regions are competed in ECP based on the cost of the unit in the exporting region plus the additional cost of transmitting the power. Transmission costs are computed as a fraction of revenue.

After building new capacity, the submodule passes total available capacity to the electricity fuel dispatch submodule and new capacity expenses to the electricity finance and pricing submodule.

Fossil
Coal without FGD pre-1965
Coal without FGD post-1965
Coal with FGD
New pulverized coal with FGD
Advanced clean coal technology
Gas/oil steam
Conventional gas/oil combined cycle
Advanced combined cycle
Conventional combustion turbine
Advanced combustion turbine
Fuel cells
Nuclear
Conventional nuclear
Advanced nuclear
Renewables
Conventional hydropower
Geothermal
Solar-thermal
Solar-photovoltaic
Wind
Wood
Municipal solid waste
FGD = flue gas desulfurization

Electricity Fuel Dispatch Submodule

Given available capacity, firm purchased-power agreements, fuel prices, and load curves, the electricity fuel dispatch (EFD) submodule minimizes variable costs as it solves for generation facility utilization and economy power exchanges to satisfy demand in each time period and region. The submodule uses merit order dispatching; that is, utility, independent power producer, and small power producer plants are dispatched until demand is met in a sequence based on their operating costs, with least-cost plants being operated first. Limits on emissions of sulfur dioxide from generating units and the engineering characteristics of units serve as constraints. Coal-fired capacity can cofire with biomass in order to lower operating costs and/or emissions. During off-peak periods, the submodule institutes load following, which is the practice of running plants near their minimum operating levels rather than shutting them down and incurring shutoff and startup costs. In addition, to account for scheduled and unscheduled maintenance, the capacity of each plant is derated (lowered) to the expected availability level. Finally, the operation of utility and nonutility plants for each region is simulated over six seasons to reflect the seasonal variation in electricity demand.

Interregional economy trade is also represented in the EFD submodule by allowing surplus generation in one region to satisfy electricity demand in an importing region, resulting in a cost savings. Economy trade with Canada is determined in a similar manner as interregional economy trade. Surplus Canadian energy is allowed to displace energy in an importing region if it results in a cost savings. After dispatching, fuel use is reported back to the fuel supply modules and operating expenses and revenues from trade are reported to the electricity finance and pricing submodule.

Electricity Finance and Pricing Submodule

The costs of building capacity, buying power, and generating electricity are tallied in the electricity finance and pricing (EFP) submodule, which simulates the cost-of-service method often used by State regulators to determine the price of electricity. Using historical costs for existing plants (derived from various sources such as Federal Energy Regulatory Commission (FERC) Form 1, "Annual Report of Major Electric Utilities, Licensees and Others," and Form EIA-412, "Annual Report of Public Electric Utilities"), cost estimates for new plants, fuel prices from the NEMS fuel supply modules, unit operating levels, plant decommissioning costs, plant phase-in costs, and purchased power costs, the EFP submodule calculates total revenue requirements for each area of operation—generation, transmission, and distribution. Revenue requirements shared over sales by customer class yield the price of electricity for each class. Electricity prices are returned to the demand modules. In addition, the submodule generates detailed financial statements.

EFP also determines "competitive" prices for electricity generation. Unlike cost-of-service prices, which are based on average costs, competitive prices are based on marginal costs. Marginal costs are primarily the operating costs of the most expensive plant required to meet demand. The competitive price also includes a "reliability price adjustment," which represents the value consumers place on reliability of service when demands are high and available capacity is limited. Prices for transmission and distribution are assumed to remain regulated, so the delivered electricity price under competition is the sum of the marginal price of generation and the average price of transmission and distribution.

Load and Demand-Side Management Submodule

The load and demand-side management (LDSM) submodule generates load curves representing the demand for electricity. The demand for electricity varies over the course of a day. Many different technologies and end uses, each requiring a different level of capacity for different lengths of time, are powered by electricity. For operational and planning analysis, an annual load duration curve, which represents the aggregated hourly demands, is constructed. Because demand varies by geographic area and time of year, the LDSM submodule generates load curves for each region and season.

Emissions

EMM tracks emission levels for sulfur dioxide (SO_2) and nitrogen oxides (NO_x). Facility development,

Current Overnight Capital Costs by Technology for the Reference Case
(1998 dollars per kilowatt of capacity)

Technology Type	Capital Costs
Advanced Combustion Turbine	465
Conventional Combustion Turbine	332
Advanced Gas/Oil Combined Cycle	580
Conventional Gas/Oil Combined Cycle	449
Gas/Oil Steam Turbine	1,012
Scrubbed Coal New	1,102
Integrated Gas Combined Cycle	1,315
Fuel Cells	2,163
Advanced Nuclear	2,390
Biomass	1,877
Solar Thermal	3,059
Solar Photovoltaic	4,836
Wind	1,086

retrofitting, and dispatch are constrained to comply with the pollution constraints of the Clean Air Act Amendments of 1990 (CAAA90) and other pollution constraints. An innovative feature of this legislation is a system of trading emissions allowances. The trading system allows a utility with a relatively low cost of compliance to sell its excess compliance (i.e., the degree to which its emissions per unit of power generated are below maximum allowable levels) to utilities with a relatively high cost of compliance. The trading of emissions allowances does not change the national aggregate emissions level set by CAAA90, but it does tend to minimize the overall cost of compliance.

The renewable fuels module (RFM) consists of five submodules that represent the various types of renewable energy technologies used for grid-connected U.S. electricity supply (Figure 11). Since most renewables (wind, solar, and geothermal) are used to generate electricity, the interaction with the electricity market module (EMM) is important for modeling grid-connected renewable-electric applications. The penetration of grid-connected generation technologies, with the exception of municipal solid waste, is determined by EMM. Hydropower is included in EMM directly.

Each submodule of RFM is solved independently of the rest. Because variable operation and maintenance costs for renewable technologies are lower than for any other major generating technology and they produce almost no air pollution, all available renewable generating capacity is dispatched first by EMM.

Costs for renewable energy technologies increase if supply expands rapidly—greater than 25 percent a year nationally. Wind or biomass technology capital costs also increase when the degree of technology use necessitates using higher cost resources; costs increase because of natural resource degradation, costs of upgrading the existing transmission or distribution network, or competition for use of the resources.

Wind-Electric Submodule

The wind-electric submodule projects the availability of wind resources as well as the cost and performance of wind turbine generators. This information is passed to EMM so that wind turbines can be built and dispatched in competition with other electricity generating technologies. The wind turbine data are expressed in the form of energy supply curves that provide the maximum amount of turbine generating capacity that could be installed, given the available land area, wind speed, and capacity factor.

Geothermal-Electric Submodule

The geothermal-electric submodule provides EMM with the amounts of new geothermal capacity that can be built at 51 individual sites, along with related cost and performance data. The information is expressed in the form of a supply curve that represents the aggregate amount of new capacity and associated costs that can be offered in each year. The factors determining the offered amounts of capacity include total reservoir heat, temperature, and the history of previously installed capacities.

Geothermal resource data are based on Sandia National Laboratory's 1991 geothermal resource assessment. Only hydrothermal (hot water and steam) resources are considered. Hot dry rock resources are not included, because they are not expected to be exploited during the NEMS forecast horizon.

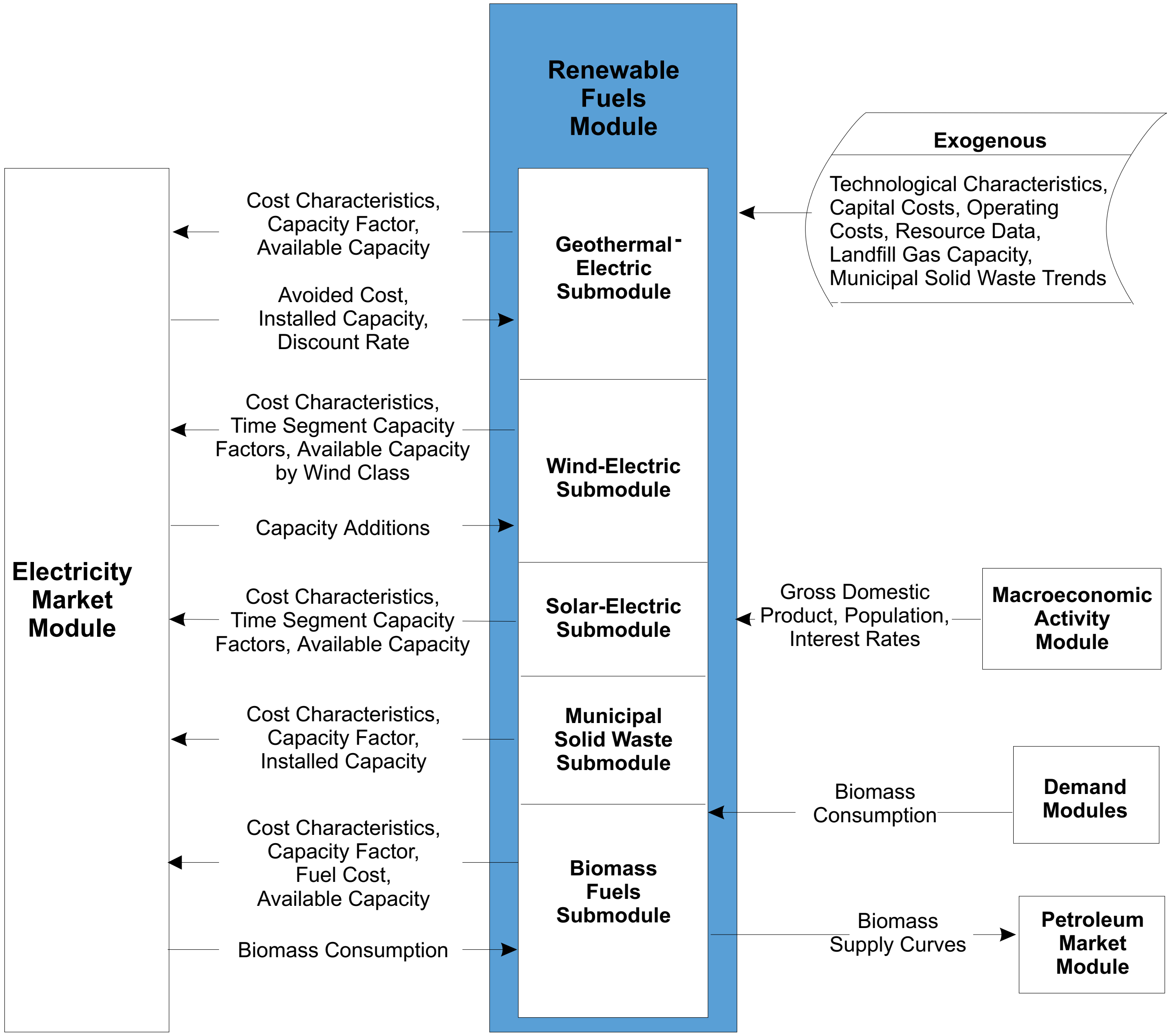
Capital and operating costs are estimated separately, and life-cycle costs are calculated according to standardized NEMS assumptions. The costing methodology includes ways to analyze effects of Federal and State energy tax construction and production incentives (if any). Individual reservoirs and their sizes and locations are mapped and matched to the NEMS electricity supply regions (see Figure 10).

Solar-Electric Submodule

The solar-electric submodule models both solar-photovoltaic and thermal-electric installations. Only central station grid-connected applications constructed by a utility or independent power producer are considered as generators. Grid-connected solar facilities can be utility or nonutility, a distinction

RFM Outputs	Inputs from NEMS	Exogenous Inputs
Energy production capacities Capital costs Operating costs (including wood supply prices for the wood submodule) Capacity factors Available capacity Biomass fuel costs Biomass supply curves	Installed energy production capacity Gross domestic product Population Interest rates Avoided cost of electricity Discount rate Capacity additions Biomass consumption	Site-specific geothermal resource quality data Site-specific wind resource quality data Plant utilization (capacity factor) Technology cost and performance parameters Landfill gas capacity Municipal solid waste management trends and regionality

Figure 11. Renewable Fuels Module Structure



that is internal to EMM. The required input information is identical.

Capacity projections are developed endogenously by competing them against other generating technologies on the basis of capital costs, capacity factors, and fixed and variable operation and maintenance costs. Solar energy is a form of renewable energy that requires a more detailed characterization to represent its regionality and intermittent nature. This is dealt with by the regional load shapes used by EMM and different seasonal and daily time periods to represent intermittency.

Biomass Fuels Submodule

The biomass fuels submodule provides biomass-fired plant technology characterizations (capital costs, operating costs, capacity factors, etc.) and fuel information for EMM, thereby allowing biomass-fueled power plants to compete with other electricity generating technologies.

Biomass fuel prices are represented by a supply curve constructed according to the accessibility of wood resources to the electricity generation sector. The supply curve employs resource inventory and cost data for four categories of biomass fuel - urban wood waste and mill residues, forest residues, energy crops, and agricultural residues.[19] Fuel distribution and preparation cost data are built into these curves. The supply schedule of biomass fuel prices are combined with other variable operating costs associated with burning biomass. The aggregate variable cost is then passed to EMM.

Municipal Solid Waste Submodule

The municipal solid waste (MSW) submodule provides annual projections of energy produced from the incineration of MSW. It uses the quantity of MSW produced (derived from an econometric equation that uses gross domestic product and population as the forecast drivers), the heating value of a pound of MSW, and shares of MSW combusted for energy recovery. In addition, the submodule supplies EMM with capital and operating cost information, which is used only for calculations of electricity prices. MSW energy production does not compete with other electricity generating technologies, because MSW is viewed as a byproduct of a community's waste disposal activities rather than a competitive alternative to other fuels.

An exogenous projection of landfill gas-fueled generating capacity is added to the total projection of MSW before it is passed to EMM. This projection uses the same MSW forecast as combustion units. EIA assumes that a constant share of waste is combusted, but that increasing recycling results in a decline in the share of MSW landfilled. Calculations applying a landfill gas production profile to quantities landfilled yield total annual methane emissions. This total is then combined with an assumed increasing percent of emissions captured for energy conversion, and the resulting energy is converted to equivalent generating capacity.

[19] Urban Wood Waste and Mill Residues: Antares Group, Inc; Forest and Crop Residues: Oak Ridge National Laboratory; Energy Crops: Oak Ridge Energy Crop County Level Database (December 20, 1996); and Agricultural Residues: Oak Ridge National Laoboratory.

Page Intentionally Left Blank

The oil and gas supply module (OGSM) consists of a series of process submodules that project the availability of:

- Domestic crude oil production and dry natural gas production from onshore, offshore, and Alaskan reservoirs
- Imported pipeline-quality gas from Mexico and Canada
- Imported liquefied natural gas.

The OGSM regions are shown in Figure 12.

The driving assumption of OGSM is that domestic oil and gas exploration and development are undertaken if the discounted present value of the recovered resources at least covers the present value of taxes and the cost of capital, exploration, development, and production. In contrast, international gas trade is determined in part by scenario-dependent, noneconomic factors. Crude oil is transported to refineries, which are simulated in the petroleum market module, for conversion and blending into refined petroleum products. The individual submodules of the oil and gas supply module are solved independently, with feedbacks achieved through NEMS solution iterations (Figure 13).

Technological progress is represented in OGSM through annual increases in the finding rates and success rates, as well as annual decreases in costs. For conventional onshore and shallow offshore, this is accomplished in several ways. While the OGSM methodology assumes that increases in cumulative drilling lower the finding rate, the methodology permits this decline to be partially, fully, or more than fully offset by improvements in technology. This “technological stretch” effect is represented by an assumed upwards shift in the finding rate function at the end of each forecast year. Another representation of technology is in the success rates for exploratory wells, which are assumed to increase annually by a given constant percentage due to technological progress. Technology is further represented in this part of the model on the cost side by the existence of time-trend proxy coefficients in the cost equations. These coefficients are intended to capture the beneficial (cost-reducing) effects of technology by putting downward pressure on the drilling, lease equipment, and operating cost projections. For unconventional gas, a series of eleven different “technology groups” are represented by time-dependent adjustments to factors which influence finding rates, success rates, and costs.

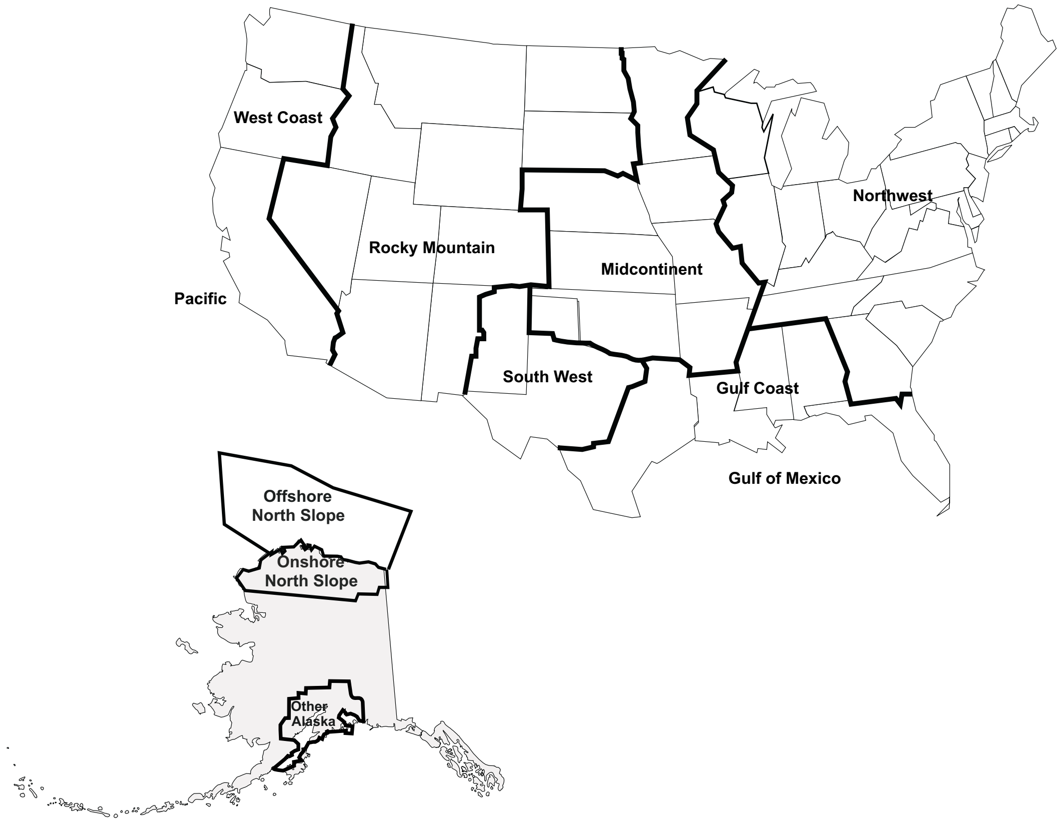
Lower 48 Onshore and Shallow Offshore Supply Submodule

The lower 48 supply submodule projects oil and gas production by conventional recovery methods in onshore and shallow offshore regions and unconventional gas recovery in onshore regions. Unconventional gas is defined as gas produced from nonconventional geologic formations, as opposed to conventional (sandstones) and carbonate rock formations. The three nonconventional geologic formations considered are low-permeability or tight sandstones, gas shales, and coalbed methane. Enhanced oil recovery from onshore regions is handled separately. The lower 48 submodule actually consists of three separate components: onshore lower 48 conventional oil and gas supply, offshore oil and gas supply, and unconventional gas recovery supply.

The lower 48 submodule accounts for drilling, reserves estimates, and production capacity—computed independently (for the most part) for each region (6 onshore and 3 offshore) by well class (exploratory and developmental) and fuel category (conventional oil, conventional shallow gas, conventional deep gas, and unconventional gas).

OGSM Outputs	Inputs from NEMS	Exogenous Inputs
Crude oil production	Domestic and Canadian natural gas production and wellhead prices	Resource levels
Domestic and Canadian natural gas supply curves	Crude oil demand	Initial finding rate parameters and costs
Mexican and liquefied natural gas imports and exports	World oil price	Production profiles
Cogeneration from oil and gas production	Electricity price	Tax parameters
Reserves and reserve additions		Mexican and liquefied natural gas imports and exports
Drilling levels		
Associated-dissolved gas production		

Figure 12. Oil and Gas Supply Module Regions



For conventional onshore and shallow offshore, the procedure is as follows:

- First, the prospective costs of a representative drilling project for a given fuel category and well class within a given region are computed. Costs are a function of national levels of drilling activity and the effects of technological progress.

- Second, the present value of the discounted cash flows (DCF) associated with the representative project is computed. These cash flows include both the capital and operating costs of the project, including royalties and taxes, and the revenues derived from a declining well production profile, computed after taking into account the progressive effects of resource depletion and valued at constant real prices as of the year of initial valuation.

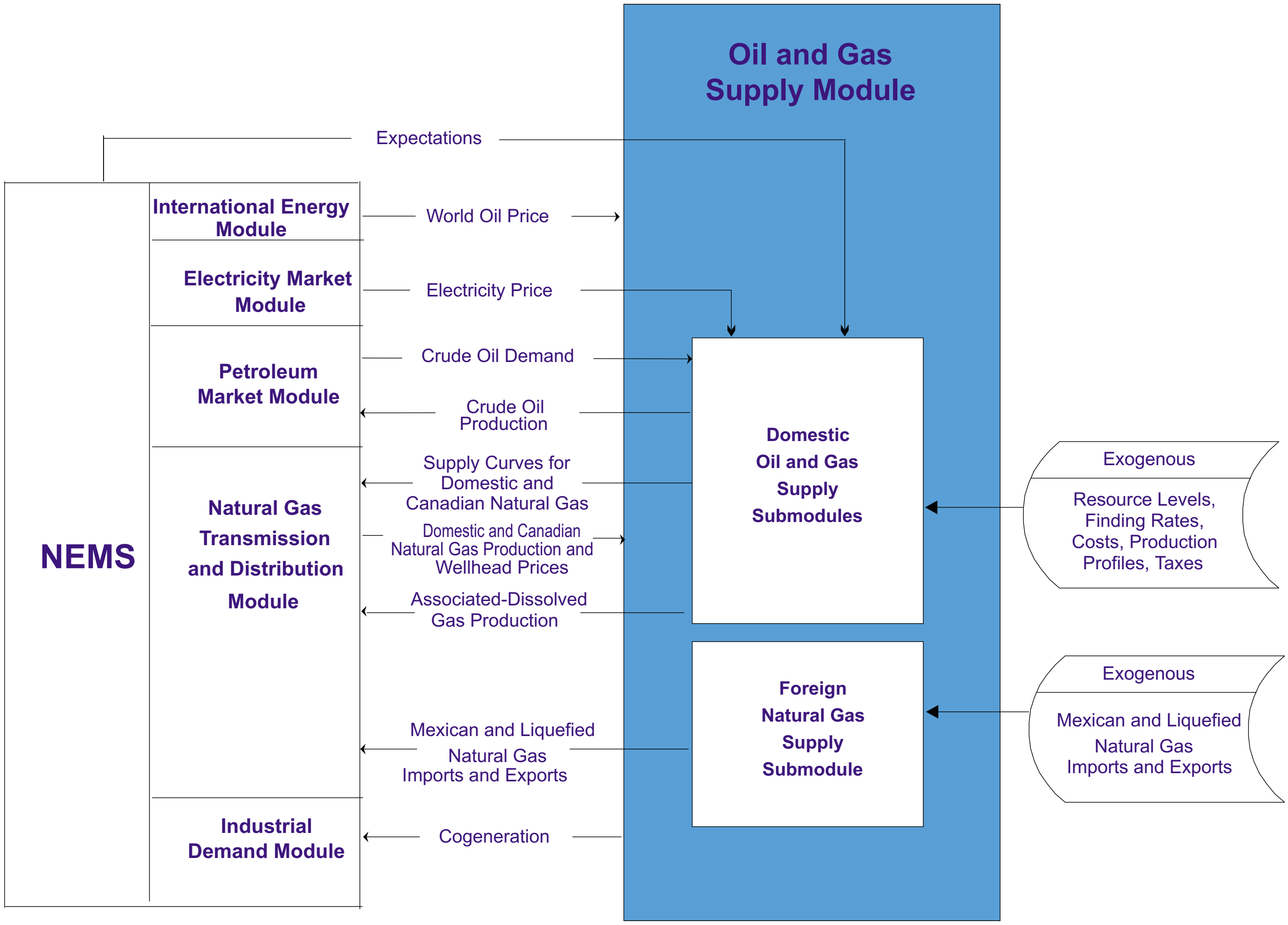
- Third, drilling levels are calculated as a function of projected profitability as measured by the projected DCF levels for each project.

- Fourth, regional finding rate equations are used to forecast new field discoveries from new field wildcats, new pools and extensions from other exploratory drilling, and reserve revisions from development drilling.

- Fifth, production is determined on the basis of reserves, including new reserve additions, previous productive capacity, flow from new wells, and, in the case of natural gas, fuel demands. This occurs within the market equilibration of the natural gas transmission and distribution module (NGTDM) for natural gas and within OGSM for oil.

For unconventional gas, a play-level model calculates the economic feasibility of individual plays based on locally specific wellhead prices and costs, resource quantity and quality, and the various effects of technology on both resources and costs. In each year, an initial resource characterization determines the expected ultimate recovery (EUR) for the wells drilled in a particular play. Resource profiles are adjusted to reflect assumed technological impacts on the size, availability, and industry knowl-

Figure 13. Oil and Gas Supply Module Structure



edge of the resources in the play. Subsequently, prices received from NGTDM and endogenously determined costs adjusted to reflect technological progress are utilized to calculate the economic profitability (or lack thereof) for the play. If the play is profitable, drilling occurs according to an assumed schedule, which is adjusted annually to account for technological improvements, as well as varying economic conditions. This drilling results in reserve additions, the quantities of which are directly related to the EURs for the wells in that play. Given these reserve additions, reserve levels and "expected" production-to-reserves (P/R) ratios are recalculated at both the OGSM and the NGTDM region level. The resultant values are aggregated with similar values from the conventional onshore and shallow offshore submodule. The aggregate P/R ratios and reserve levels are then passed to NGTDM, which determines the prices and production for the following year through market equilibration.

Deep Water Offshore Supply Submodule

This submodule uses a field-based engineering and economic analysis approach to project reserve additions and production from resources in the deep water offshore Gulf of Mexico Outer Continental Shelf subregion. Two structural components make up the deep water offshore supply submodule, an exogenous price/ supply data generation routine and a endogenous reserves and production timing algorithm.

The price/supply data generation methodology employs a rigorous field-based DCF approach. This offline model utilizes key field properties data, algorithms to determine key technology components, and algorithms to determine the exploration, development and production costs, and computes a minimum acceptable supply price (MASP) at which the discounted net present value of an individual prospect equals zero. The MASP and the recoverable resources for the different fields are aggregated by planning region and by resource type to generate resource-specific price-supply curves. In addition to the overall supply price and reserves, costs components for exploration, development drilling, production platform, and operating expenses, as well as exploration and development well requirements, are also carried over to the endogenous component.

After the exogenous price/supply curves have been developed, they are transmitted to an endogenous algorithm. This algorithm makes choices for field exploration and development based on relative economics of the project profitability compared with the equilibrium crude oil and natural gas prices determined by the petroleum market module and natural gas transmission and distribution module. Development of economically recoverable resources into proved reserves is constrained by drilling activity. Proved reserves are translated into production based on a P/R ratio. The drilling activity and the P/R ratio are both determined by extrapolating the historical information.

Alaska Oil and Gas Submodule

This submodule projects the crude oil and natural gas produced in Alaska. The Alaska oil and gas submodule is divided into three sections: new field discoveries, development projects, and producing fields. Oil and gas transportation costs to lower 48 facilities are used in conjunction with the relevant market price of oil or gas to calculate the estimated net price received at the wellhead, sometimes called the "netback price." A discounted cash flow method is used to determine the economic viability of each project at the netback price.

Alaskan oil and gas supplies are modeled on the basis of discrete projects, in contrast to the onshore lower 48 conventional oil and gas supplies, which are modeled on an aggregate level. The continuation of the exploration and development of multiyear projects, as well as the discovery of new fields, is dependent on profitability. Production is determined on the basis of assumed drilling schedules and production profiles for new fields and developmental projects, historical production patterns, and announced plans for currently producing fields.

Enhanced Oil Recovery (EOR) Supply Submodule

The enhanced oil recovery supply submodule (EORSS) is designed to project regional oil production in the onshore lower 48 States extracted by use of advanced tertiary recovery techniques, in excess of the oil recovered by primary and secondary techniques. The model represents the two principal technologies separately — thermal methods and miscible/immiscible (or gas) methods. EORSS employs a reservoir-based, field-level engineering, rather than statistical, computational methodology. However, the basic process for both EOR and the other sources of crude oil and natural gas consists of essentially the same stages. The physical stages of the supply process involve the conversion of unproven resources into proved reserves, and then the proved reserves are extracted as flows of production. The significant differences between the methodology of EORSS and the other submodules of OGSM concern the conversion of unproven resources to proved reserves, the extraction of proved reserves for production, and the determination of supply activities.

EORSS uses discovery factors that convert a specified fraction of unproven resources into proved reserves. These factors depend on the expected profitability of EOR investment opportunities. Greater expected financial returns motivate the conversion of larger fractions of the resource base into proved reserves. This is consistent with the principle that funds are directed toward projects with relatively higher returns. Given the role of the discovery factors in the supply process, the implicit working assumption is that EOR investment opportunities with positive expected profit will attract sufficient financial development capital. The exploitation of economic EOR resources without an explicit budget constraint is consistent with the view that EOR investment does not compete directly with other oil and gas opportunities. This assumption is considered acceptable because EOR extraction is unlike the other oil and gas production processes, and its product differs sufficiently from the less heavy oil most often yielded by conventional projects.

For each forecast year, the remaining EOR proved reserves that continue to be economic are determined for each OGSM region. Production from a given stock of proved reserves is determined by the application of an assumed production-to-reserves ratio. The methodology used for determining end-of-year proved reserves for thermal production in the West Coast OGSM region is more detailed than that used for the thermal and gas EOR in the other OGSM regions because it is a much larger EOR producing region, with more extensive field-specific data available.

Figure 14. Foreign Natural Gas Trade via Pipeline and Liquefied Natural Gas Terminals

Key: Solid arrows: Pipeline entry/exit points.
Open arrows: Liquefied natural gas terminals.

Foreign Natural Gas Supply Submodule

The foreign natural gas supply submodule establishes proved reserves in the Western Canadian Sedimentary Basin (WCSB), natural gas trade via pipeline with Mexico, as well as liquefied natural gas (LNG) trade. The receiving regions for foreign gas supplies correspond to those of the natural gas integrating framework established for NGTDM. Within NGTDM, pipeline natural gas imports flow from two sources: Canada and Mexico. U.S. natural gas trade with Canada is represented by seven entry/exit points, and trade with Mexico is represented by three entry/exit points (Figure 14).

OGSM provides NGTDM with the beginning-of-year natural gas proved reserves from the WCSB and an associated expected production-to-reserve ratio. NGTDM uses this information to establish a short-term supply curve for the region. Along with exogenously specified forecasts for exports of gas to Canada, other Canadian supplies, and Canadian consumption, this supply curve is used to determine the wellhead gas production and price in the WCSB and the level and price of imports from Canada at the seven border crossings. Based on the WCSB gas wellhead price, OGSM forecasts drilling activity in the WCSB using an econometrically derived equation, along with the associated reserve additions. The finding rate is set at an historical average level and assumed to decline throughout the forecast. The reserve additions are added to the beginning-of-year proved reserves from the current forecast year, after the forecasted production levels are subtracted, to establish the beginning-of-year proved reserves for the next forecast year.

Mexican gas trade is a highly complex issue. A range of noneconomic factors influences, if not determines, flows of gas between the United States and Mexico. The uncertainty is so great that not only is the magnitude of flow for any future year in doubt, but also the direction of flow. Reasonable scenarios have been developed and defended in which Mexico may be either a net importer or exporter of hundreds of billions of cubic feet of gas by 2020. The vast uncertainty and the importance of noneconomic factors in future Mexican gas trade with the United States suggest that these flows should be handled on a scenario basis. Such a scenario can be introduced into the Mexican gas submodule as a user-specified path of future Mexican imports and exports. Otherwise, the analysis uses a prespecified default outlook for Mexican trade, drawn from an assessment of current and expected industry and market circumstances, as indicated in industry announcements or articles and reports in relevant publications. The outlook, regardless of its source, is fixed and is not responsive to energy price changes.

The volume of LNG imports into the United States is projected at four LNG terminals. Imported LNG costs compete with the purchase price of gas prevailing in the vicinity of the import terminal. This is a significant element in evaluating the competitiveness of LNG supplies, since LNG terminals vary greatly in their proximity to domestic producing areas. Terminals close to major consuming markets and far from competing producing areas may provide a sufficient economic advantage to make LNG a competitive gas supply source in some markets.

In addition to costs, extensive operational assumptions are required to determine LNG imports. Dominant general factors affecting the outlook include expected developments with respect to the use of existing capacity, expansion at existing sites, and construction at additional locations. The LNG forecast also requires the specification of a combination of factors: available gasification capacity, schedules for and lags between constructing and opening a facility, tanker availability, expected utilization rates, and worldwide liquefaction capacity. For inactive terminals, it is necessary to determine the length of time required to restart operations, normally between 12 and 18 months. These considerations are taken into account when the economic viability of LNG supplies is determined. The model accounts for LNG exports to Japan from Alaska using an exogenously-specified forecast.

NATURAL GAS TRANSMISSION AND DISTRIBUTION MODULE

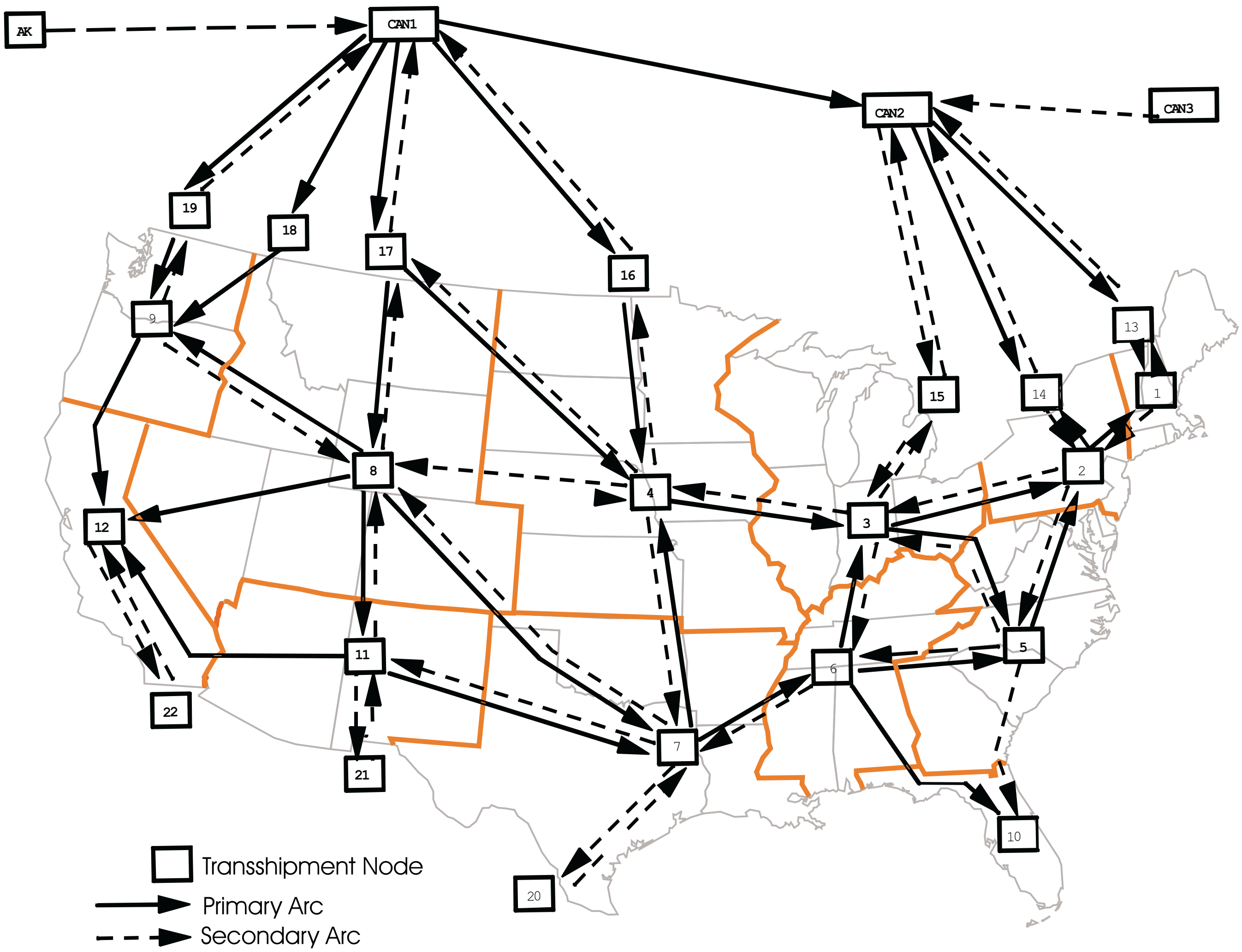
The natural gas transmission and distribution module (NGTDM) of NEMS represents the natural gas market and determines regional market-clearing prices for natural gas supplies and for end-use consumption, given the information passed from other NEMS modules. A transmission and distribution network (Figure 15), composed of nodes and arcs, is used to simulate the interregional flow and pricing of gas in the contiguous United States and Canada in both the peak (December through March) and offpeak (April through November) period. This network is a simplified representation of the physical natural gas pipeline system and establishes the possible interregional flows and associated prices as gas moves from supply sources to end users.

Flows are further represented by establishing arcs from transshipment nodes to each demand sector represented in an NGTDM region (residential, commercial, industrial, electric generators, and transportation). Mexican exports and net storage injections in the offpeak period are also represented as flow exiting a transshipment node. Similarly, arcs are also established from supply points into a transshipment node. Each transshipment node can have one or more entering arcs from each supply source represented: U.S. or Canadian onshore or U.S. offshore production, liquefied natural gas imports, supplemental gas production, gas produced in Alaska and transported via the Alaskan Natural Gas Transportation System, Mexican imports, or net storage withdrawals in the region in the peak period. Most of the types of supply listed above are set independently of current year prices and before NGTDM determines a market equilibrium solution. Only the onshore and offshore lower 48 U.S. and Western Canadian Sedimentary Basin production, along with net storage withdrawals, are represented by short-term supply curves and set dynamically during the NGTDM solution process. The flow of gas during the peak period is used to establish interregional pipeline and storage capacity requirements and the associated expansion. These capacity levels provide an upper limit for the flow during the offpeak period.

Arcs between transshipment nodes, from the transshipment nodes to end-use sectors, and from supply sources to transshipment nodes are assigned associated tariffs. The tariffs along interregional arcs reflect reservation (represented with volume dependent curves) and usage fees and are established in the pipeline tariff submodule. The tariffs on arcs to end-use sectors represent the interstate pipeline tariffs in the region, intrastate pipeline tariffs, and distributor markups set in the distributor tariff submodule. Tariffs on arcs from supply sources represent gathering charges or other differentials between the price at the supply source and the regional market “hub.” The tariff associated with injecting, storing, and withdrawing from storage is assigned to the arc representing net storage withdrawals in the peak period. During the primary solution process in the interstate transmission submodule, the tariffs along an interregional arc are added to the price at the source node to arrive at a price for the gas along the arc right before it reaches its destination node. Through an iterative process described below, the relative value of these prices for all of the arcs entering a node are used as the basis for evaluating the relative flow along each of the entering arcs and for setting the price at the destination node.

NGTDM Outputs	Inputs from NEMS	Exogenous Inputs
Natural gas end-use and electric generator prices Domestic and Canadian natural gas wellhead prices Domestic natural gas production Canadian natural gas imports and production Lease and plant fuel consumption Pipeline fuel use Pipeline and distribution tariffs Interregional natural gas flows Storage and pipeline capacity expansion Supplemental gas production	Natural gas demands Domestic and Canadian natural gas supply curves Mexican and liquefied natural gas imports and exports Macroeconomic variables Associated-dissolved natural gas production	Historical consumption patterns Historical flow patterns Rate design specifications Company-level financial data Pipeline and storage capacity and utilization data Historical end-use prices State and Federal tax parameters Pipeline and storage expansion cost data Supplemental gas production

Figure 15. Natural Gas Transmission and Distribution Module Network

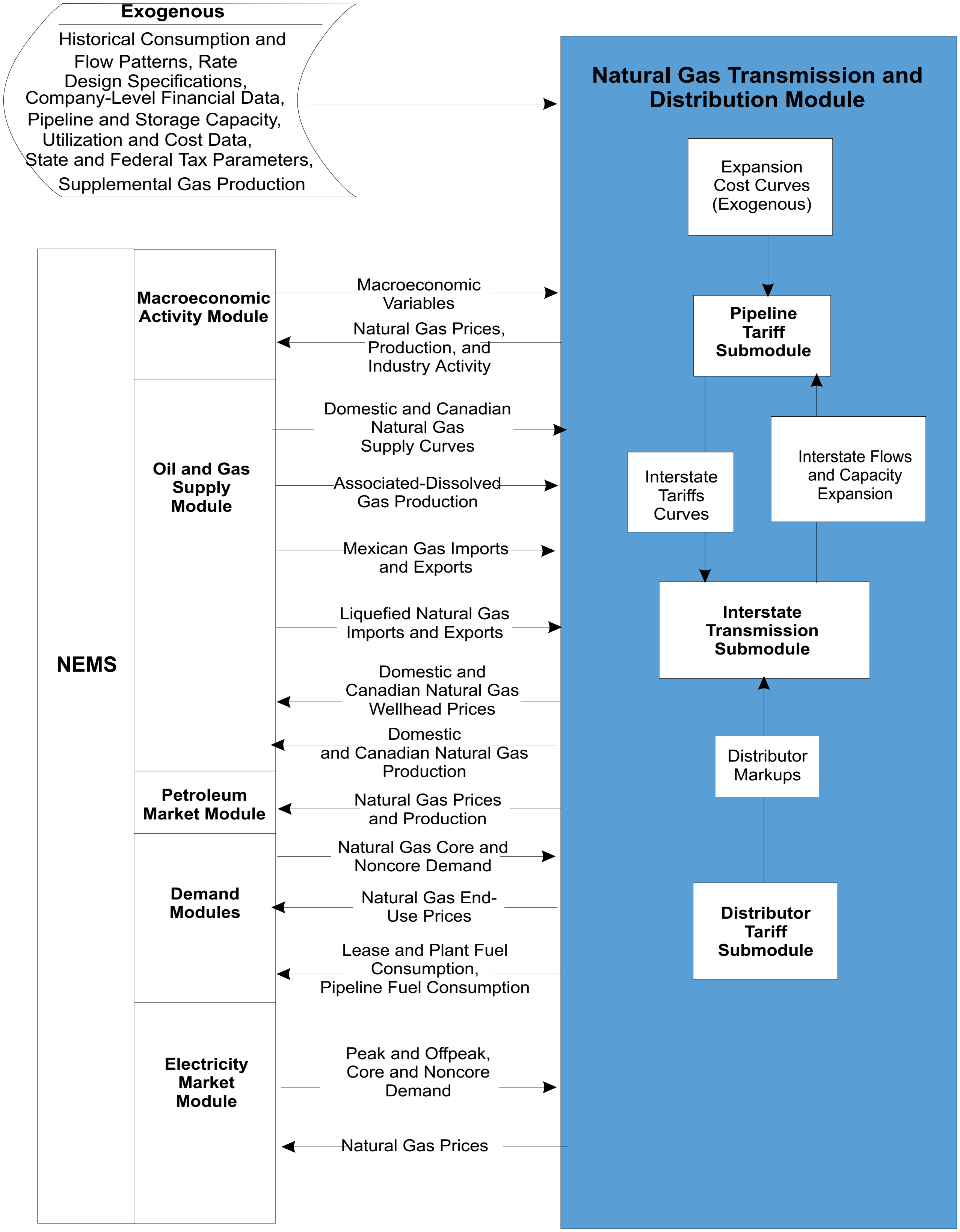


Interstate Transmission Submodule

The interstate transmission submodule (ITS) is the main integrating module of NGTDM. One of its major functions is to simulate the natural gas price determination process. ITS brings together the major economic factors that influence regional natural gas trade on a seasonal basis in the United States, the balancing of the demand for and the domestic supply of natural gas, including competition from imported natural gas. These are examined in combination with the relative prices associated with moving the gas from the producer to the end user where and when (peak versus offpeak) it is needed. In the process, ITS simulates the decision-making process for expanding pipeline and/or seasonal storage capacity in the U.S. gas market, determining the amount of pipeline and storage capacity to be added between or within regions in NGTDM. Storage serves as the primary link between the two seasonal periods represented.

ITS employs an iterative heuristic algorithm, along with an acyclic hierarchical representation of the primary arcs in the network, to establish a market equilibrium solution. Given the consumption levels from other NEMS modules, the basic process followed by ITS involves first establishing the backward flow of natural gas in each period from the consumers, through the network, to the producers, based primarily on the relative prices offered for the gas from the previous ITS iteration. This process is

Figure 16. Natural Gas Transmission and Distribution Module Structure



performed for the peak period first since the net withdrawals from storage during the peak period will establish the net injections during the offpeak period. Second, using the model's supply curves, wellhead prices are set corresponding to the desired production volumes. Also, using the pipeline and storage tariffs from the pipeline tariff submodule, pipeline and storage tariffs are set corresponding to the associated flow of gas, as determined in the first step. These prices are then translated from the producers, back through the network, to the city gate and the end users, by adding the appropriate tariffs along the way. A regional storage tariff is added to the price of gas injected into storage in the offpeak to arrive at the price of the gas when withdrawn in the peak period. This process is then repeated until the solution has converged. Finally, end-use prices are derived for residential, commercial, and transportation customers, as well as for both core and noncore industrial and electric generation sectors using the distributor tariffs provided by the distributor tariff submodule.

In the end, ITS derives average seasonal and ultimately annual natural gas wellhead, city gate, and end-use prices and the associated production and flows, reflecting an interregional market equilibrium among the competing participants in the market. In the process of determining interregional flows and storage injections/withdrawals, ITS also forecasts pipeline and storage capacity additions. In the next forecast year, the pipeline tariff submodule will adjust the revenue requirements to account for the associated expansion costs. Other primary outputs of the module include: lease, plant, and pipeline fuel use, Canadian import levels, and net storage withdrawals in the peak period.

Pipeline Tariff Submodule

The pipeline tariff submodule (PTS) provides usage fees and volume dependent curves for computing unitized reservation fees (or tariffs) for interstate transportation and storage services within ITS. These curves extend beyond current capacity levels and relate incremental pipeline or storage capacity expansion to corresponding estimated rates. The underlying basis for each tariff curve in the model is a forecast of the associated regulated revenue requirement. Econometrically estimated forecasting equations within a general accounting framework are used to track costs and compute revenue requirements associated with both reservation and usage fees under various rate design and regulatory scenarios. Other than an assortment of macroeconomic indicators, the primary input to PTS from other modules in NEMS is the level of pipeline and storage capacity expansions in the previous forecast year. Once an expansion is forecast to occur, PTS calculates the resulting impact on the revenue requirement. PTS currently assumes rolled-in (or average), not incremental, rates for new capacity. The pipeline tariff curves generated by PTS are used within ITS when determining the relative cost of purchasing and moving gas from one source versus another in the peak and offpeak seasons.

Distributor Tariff Submodule

The distributor tariff submodule (DTS) sets distributor markups charged by local distribution companies for the distribution of natural gas from the city gate to the end user. End-use distribution service is distinguished within DTS by sector (residential, commercial, industrial, electric generators, and transportation), season (peak and offpeak), and service type (core and noncore). DTS sets distribution tariffs by estimating or assuming the annual change in these tariffs, starting from base-year values that are established using historical data.

The annual change in distributor tariffs for residential, commercial, and industrial core customers depends on an assumed increase in operational efficiencies combined with a depreciation rate, as well as the annual change in natural gas consumption and in national average capital and employment costs. Distributor markups to the noncore customers are assumed not to change over time. Distributor markups to core electric generators are allowed to change in response to annual changes in consumption levels within the sector. The natural gas vehicle sector markups are calculated separately for fleet and personal vehicles. Markups for fleet vehicles are set and held constant at historical levels, with taxes added. Markups for personal vehicles are set at the industrial sector core price, plus taxes, plus an assumed distribution cost. This price is capped at the gasoline equivalent price, as long as minimum costs are covered.

PETROLEUM MARKET MODULE

The petroleum market module (PMM) represents domestic refinery operations and the marketing of petroleum products to consumption regions. PMM solves for petroleum product prices, crude oil and product import activity (in conjunction with the international energy module and the oil and gas supply module), and domestic refinery capacity expansion and fuel consumption. The solution is derived, satisfying the demand for petroleum products and incorporating the prices for raw material inputs and imported petroleum products, the costs of investment, and the domestic production of crude oil and natural gas liquids. The relationship of PMM to other NEMS modules is illustrated in Figure 17.

PMM is a regional, linear-programming representation of the U.S. petroleum market. Refining operations are represented by a three-region linear programming formulation of the five Petroleum Administration for Defense Districts (PADDs) (Figure 18). PADDs I and V are each treated as single regions, while PADDs II, III, and IV are aggregated into one region. Each region is considered as a single firm where more than 30 distinct refinery processes are modeled. Refining capacity is allowed to expand in each region, but the model does not distinguish between additions to existing refineries or the building of new facilities. Investment criteria are developed exogenously, although the decision to invest is endogenous.

PMM assumes that the petroleum refining and marketing industry is competitive. The market will move toward lower-cost refiners who have access to crude oil and markets. The selection of crude oils, refinery process utilization, and logistics (transportation) will adjust to minimize the overall cost of supplying the market with petroleum products.

Although the petroleum market responds to pressure, it rarely strays from the underlying refining costs and economics for long periods of time. If demand is unusually high in one region, the price will increase, driving down demand and providing economic incentives for bringing supplies in from other regions, thus restoring the supply/demand balance.

Existing regulations concerning product types and specifications, the cost of environmental compliance, and Federal and State taxes are also modeled. PMM incorporates taxes imposed by the 1993 Budget Reconciliation Act as well as costs resulting from the Clean Air Act Amendments of 1990 (CAAA90) and other environmental legislation. The costs of producing new formulations of gasoline and diesel fuel as a result of the CAAA90 are determined within the linear programming representation by incorporating specifications and demands for these fuels.

An important innovation in NEMS involves the relationship between the domestic and international markets. Whereas earlier models postulated entirely exogenous prices for oil on the international market (the world oil price), NEMS includes an international energy module that estimates supply curves for imported crude oils and products based on, among other factors, U.S. participation in international trade.

Regions

PMM models U.S. crude oil refining capabilities based on the five PADDs which were established during World War II and are still used by EIA for data collection and analysis. The use of PADD data permits PMM to take full advantage of EIA's historical database and allows analysis and forecasting

PMM Outputs	Inputs from NEMS	Exogenous Inputs
Petroleum product prices	Petroleum product demand by sector	Processing unit operating parameters
Crude oil imports and exports	Domestic crude oil production	Processing unit capacities
Crude oil demand	World oil price	Product specifications
Petroleum product imports and exports	International crude oil supply curves	Operating costs
Refinery activity and fuel use	International product supply curves	Capital costs
Ethanol demand and price	International oxygenates supply curves	Transmission and distribution costs
Cogeneration	Natural gas prices	Federal and State taxes
Natural gas plant liquids production	Electricity prices	Agricultural feedstock quantities and costs
Processing gain	Natural gas production	Cogeneration unit operating parameters
Capacity additions	Macroeconomic variables	Cogeneration unit capacities
Capital expenditures	Biomass supply curves	
Revenues		

Figure 17. Petroleum Market Module Structure

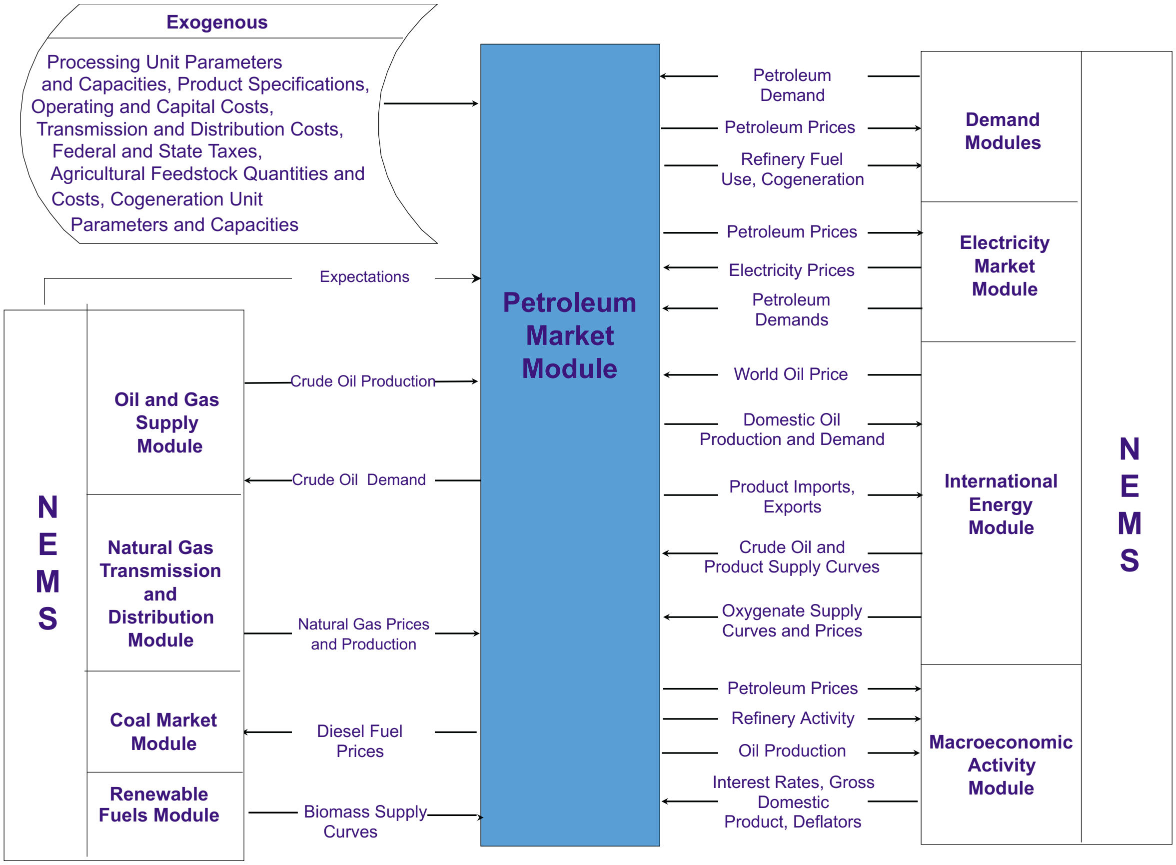
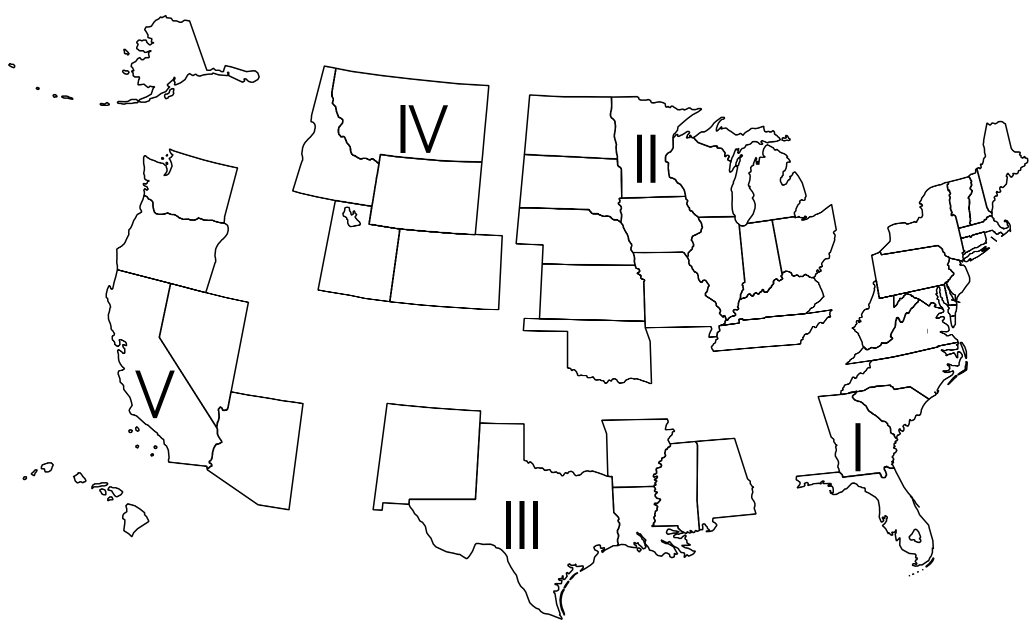


Figure 18. Petroleum Administration for Defense Districts



within the same framework as the petroleum industry uses.

Product Categories

Product categories, specifications, and recipe blends modeled in PMM include the following:

Motor gasoline: traditional unleaded, oxygenated (2.7%), Federal reformulated (2.0% oxygen), California reformulated (no oxygen).
Jet fuels: kerosene-based.
Distillates: kerosene, heating oil, highway diesel.
Residual fuels: low-sulfur, high-sulfur.
Liquefied petroleum gas (LPG): propane, LPG mixes.
Petrochemical feedstocks: petrochemical naphtha, petrochemical gas oil, propylene, aromatics.
Other: asphalt and road oil, still gas, petroleum coke, lubricating products and waxes, special naphthas.

Fuel Use

PMM determines refinery fuel use by refining region for purchased electricity, natural gas, distillate fuel, residual fuel, liquefied petroleum gas, and other petroleum. The fuels (natural gas, petroleum, other gaseous fuels, and other) consumed within the refinery to generate electricity from cogeneration facilities are also measured.

Crude Oil Categories

Both domestic and imported crude oil are aggregated into five categories, as defined by the following ranges of gravity and sulfur:

Category	Sulfur	Gravity
Low-sulfur light	0-0.5%	>24
Medium-sulfur heavy	0.35-1.1%	>24
High-sulfur light	>1.1%	>32
High-sulfur heavy	>1.1%	24-33
High-sulfur very heavy	>0.7%	<23

This aggregation of crude oil types allows PMM to account for changes in crude oil composition over time. A "composite" crude with the appropriate yields and qualities is developed for each category by averaging characteristics of specific crude oil streams that fall into each category. While the domestic and foreign categories are the same, the composites for each type may differ, because different crude oil streams make up the composites.

Refinery Processes

Not every refinery processing unit is represented in PMM. The refinery processes represented were chosen because they have the most significant impact on production. The following distinct processes are represented:

Atmospheric distillation, vacuum distillation
Delayed coker
Fluid coker-includes flexicoking mode
Fluid catalytic cracker (FCC)-includes distillate, vacuum gas oil, coker gas oil, atmospheric residual, unallowable feeds; conversion ranges 65 to 85 percent; ZSM catalyst mode, low severity mode
Gas oil hydrocracker
Residuum hydrocracker
Naphtha hydrotreater
Distillate desulfurization
FCC feed hydrofiner
Residuum desulfurizer
Lube and wax units
Module distillate deep hydrotreater
Solvent deasphalting
Catalytic reforming-separate units for semi-regenerative high-pressure, low-pressure cyclic; severity range as appropriate to the reactor; allow light straight run through heavy naphtha virgin streams, heavy naphthas from FCC, coker, and hydrocracker operations; allow new highly active catalyst operation
Naphtha splitter
FCC gasoline fractionation
FCC naphtha desulfurization
C2-C5 dehydrogenation
Butane splitter
Butane isomerization
Isomerization for pentanes, hexanes
Butylene isomerization
Alkylation
Aromatics recovery
MTBE, ETBE, and TAME production (captive and merchant)
Gas processing
Hydrogen generation
Steam generation
Power generation
Cogeneration
Sulfur plant
Fuel mixer
Methanol production

ETBE=Ethyl tertiary butyl ether. MTBE=Methyl tertiary butyl ether.
TAME= Tertiary amyl methyl ether.

Natural Gas Plants

The outputs of natural gas processing plants—ethane, propane, butane, isobutane, and natural gasoline—are modeled in PMM. These products move directly into the market to meet demand or are inputs to the refinery.

Ethanol

PMM contains an ethanol submodule which provides the PMM linear program with regional ethanol supplies and prices. Ethanol quantity/price curves are calculated in each Census division for both corn-derived and cellulose-derived ethanol, allowing PMM to forecast transportation ethanol demand. The supply curves take into account feedstock costs, feedstock conversion costs, and energy prices. Corn and corn co-product quantities and costs are provided exogenously from the *USDA Agricultural Baseline Projections to 2008*.[20] Cellulose feedstock supply/price curves are provided by the renewable fuels module of NEMS.

End-Use Markups

The linear programming portion of the model provides unit prices of products sold in the refinery regions (refinery gate) and in the demand regions (wholesale). End-use markups are added to produce a retail price for each of the Census divisions. The markups are based on an average of historical markups, defined as the difference between the end-use prices by sector and the corresponding wholesale price for that product. The average is calculated using data from 1989 to the present. Because of the lack of any consistent trend in the historical end-use markups, the markups remain at the historical average level over the forecast period.

State and Federal taxes are also added to transportation fuel prices to determine final end-use prices. Recent tax trend analysis indicated that State taxes increase at the rate of inflation, while Federal taxes do not. In PMM, therefore, State taxes are held constant in real terms throughout the forecast while Federal taxes are deflated at the rate of inflation.

Gasoline Types

Federal and State legislation have resulted in the production of several blends of gasoline. PMM categorizes these blends into four gasoline types: traditional gasoline, oxygenated gasoline, Federal reformulated gasoline, and California reformulated gasoline. The traditional category includes gasoline blended with 10 percent ethanol, also known as gasohol. Oxygenated gasoline is traditional gasoline containing a minimum of 2.7 percent oxygen by weight for use in specific regions of the United States during the winter months to reduce carbon monoxide.

Federal reformulated gasoline is blended according to U.S. Environmental Protection Agency Complex Model specifications with a minimum oxygen content of 2.0 percent by weight for use in ozone non-attainment areas. P.M. uses either ethanol or ethers (MTBE, ETBE, and other ethers) to obtain the 2.0 percent oxygen requirement. However, after 2002, the model uses only ethanol in Census division 9 to make Federal reformulated gasoline, because of California legislation which bans the use of MTBE in gasoline by the end of 2002. California reformulated gasoline is blended to the California Air Resources Board (CARB) specifications, which are more severe than the Federal reformulated standards, but have no minimum oxygen requirement. Because about two-thirds of California's gasoline consumption occurs within Federal ozone nonattainment areas, gasoline in these areas is also assumed to meet the Federal oxygen requirement of 2.0 percent. Although the reference case assumes current laws and regulations, additional product specifications can be modeled for policy analysis.

[20] U.S. Department of Agriculture, *USDA Agricultural Baseline Projections to 2008*, Staff Report WAOB-99-01 (Washington, DC, February 1999).

The coal market module (CMM) represents the mining, transportation, and pricing of coal, subject to end-use demand. Coal supplies are differentiated by heat and sulfur content. CMM also determines the minimum cost pattern of coal supply to meet exogenously defined U.S. coal export demands as a part of the world coal market. Coal supply is projected on a cost-minimizing basis, constrained by existing contracts. Twelve different coal types are differentiated with respect to thermal grade, sulfur content, and underground or surface mining. The domestic production and distribution of coal is forecast for 13 demand regions and 11 supply regions (Figures 19 and 20).

The solutions for the components of CMM are found simultaneously. The sequence of solution among components can be summarized as follows. Coal supply curves are produced by the coal production submodule and input to the coal distribution submodule. Given the coal supply curves, distribution costs, and coal demands, the coal distribution submodule projects delivered coal prices. The module is iterated to convergence with respect to equilibrium prices to all demand sectors. The structure of CMM is shown in Figure 21.

Coal Production Submodule

This submodule produces annual econometric coal supply curves, relating annual production to marginal prices. The supply curves are constructed from a regression analysis of production, prices, and costs. A separate supply curve is provided for surface and underground mining for all significant production by coal rank (bituminous, subbituminous and lignite), coal grade (steam or metallurgical), and sulfur level in each supply region. Constructing curves for the coal types available in each region yields a total of 34 curves that are used as inputs to the coal distribution submodule. A different set of supply curves is constructed for each year in the forecast period.

The factors accounted for in constructing the supply curves are labor productivity and the costs of factor inputs (mining equipment, mine labor, and fuel). Labor productivity projections are developed and applied to each supply curve, based on historical data. The projections incorporate an assumption that the rate of improvement will decline as the rate of technology penetration slows. Labor costs are tied to labor productivity and wage rates. It is assumed, in the reference case, that wage rates keep pace exactly with inflation.

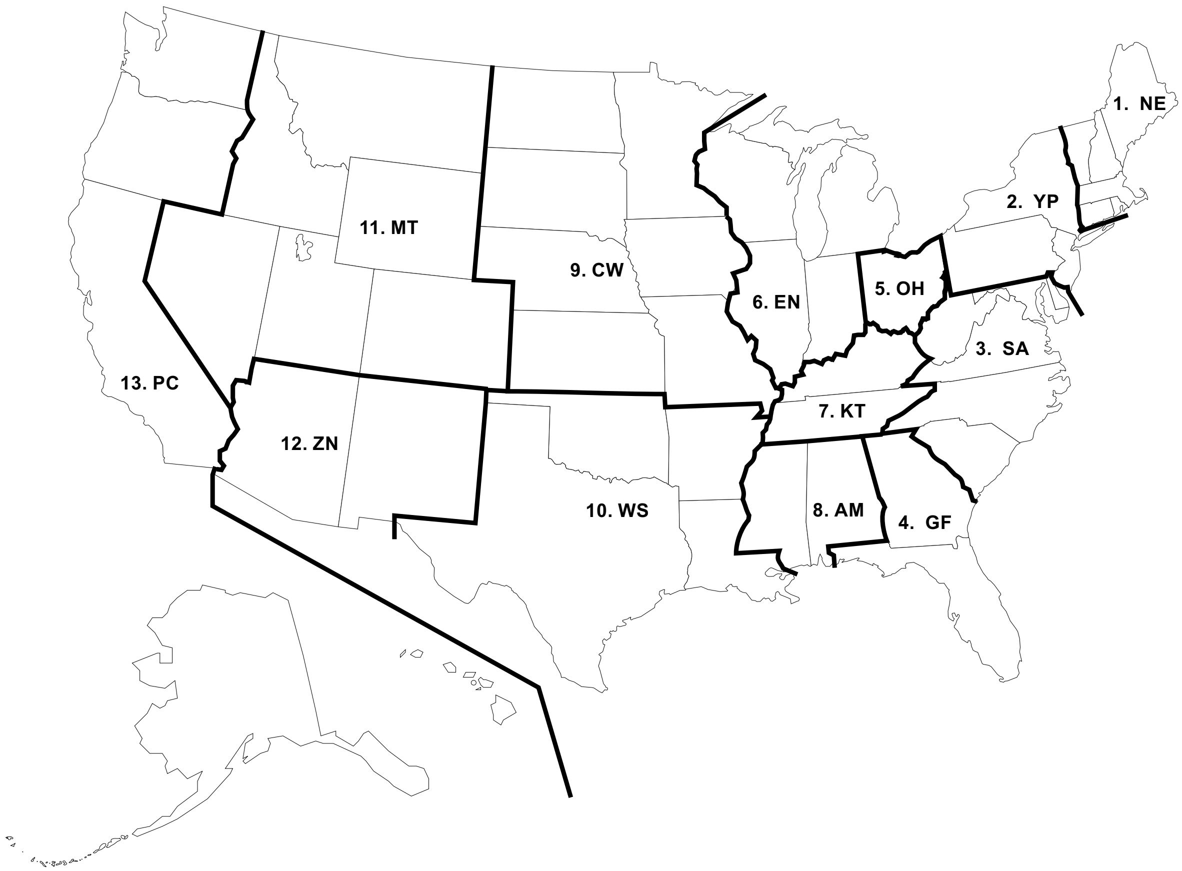
Coal Distribution Submodule

The coal distribution submodule is a linear program that determines the least-cost supplies of coal for a given set of coal demands by demand region and sector, accounting for transportation costs from the different supply curves, coal heat and sulfur content, existing coal supply contracts, technical limitations of older boiler types, and sulfur allowance costs under the Clean Air Act Amendments of 1990. Existing supply contracts between coal producers and utilities are incorporated in the model as minimum flows between specific supply curves and region-sulfur level combinations. The minimum flows are assumed to remain in effect for the duration of the contract and then be replaced by market-determined flows.

Coal transportation costs are simulated using interregional coal transportation costs derived by subtracting reported minemouth costs for each supply curve from reported delivered costs for each demand type in each demand region. Transportation rates are assumed to change in response to railroad labor productivity, diesel fuel costs, and equipment costs.

CMM Outputs	Inputs from NEMS	Exogenous Inputs
Coal production and distribution Minemouth coal prices End-use coal prices Coal exports Transportation rates Coal quality by source, destination, and end-use sector World coal flows	Coal demand Interest rates Price indices and deflators Diesel fuel prices	Base year production, prices, and coal quality parameters Contract quantities Labor productivity Labor costs Labor cost escalators Domestic transportation costs International transportation costs International supply curves International coal import demands Demand for U.S. coal imports

Figure 19. Coal Market Module Demand Regions



Region Code	Region Content
1	New England
2	Middle Atlantic
3	South Atlantic
4	Georgia and Florida
5	Ohio
6	East North Central
7	Kentucky and Tennessee

Region Code	Region Content
8	Alabama and Mississippi
9	West North Central
10	West South Central
11	Mountain
12	Arizona and New Mexico
13	Pacific

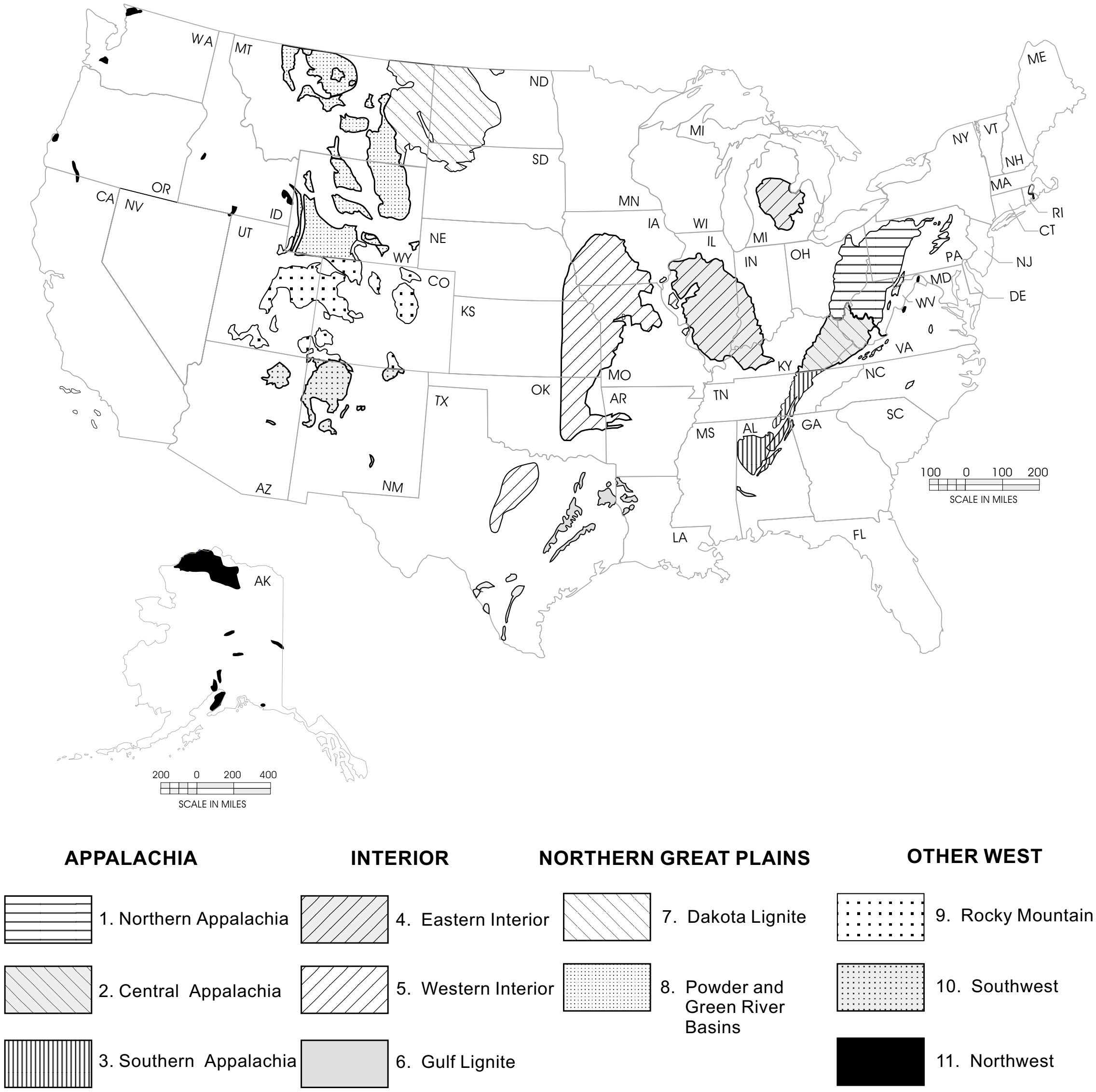
In recent years, railroad rates have declined because of operating efficiencies from such measures as improved scheduling and lower fuel cost per ton-mile that have resulted from low crude oil prices, more efficient diesel engines, and larger and lighter aluminum cars.

Coal Export Component

The coal export component of the coal distribution submodule projects quantities of coal imported and exported from the United States. The quantities are determined within a world trade context, based on user-provided characteristics of foreign coal supply and demand. The component disaggregates coal into 16 export regions and 20 import regions, as shown on the following page.

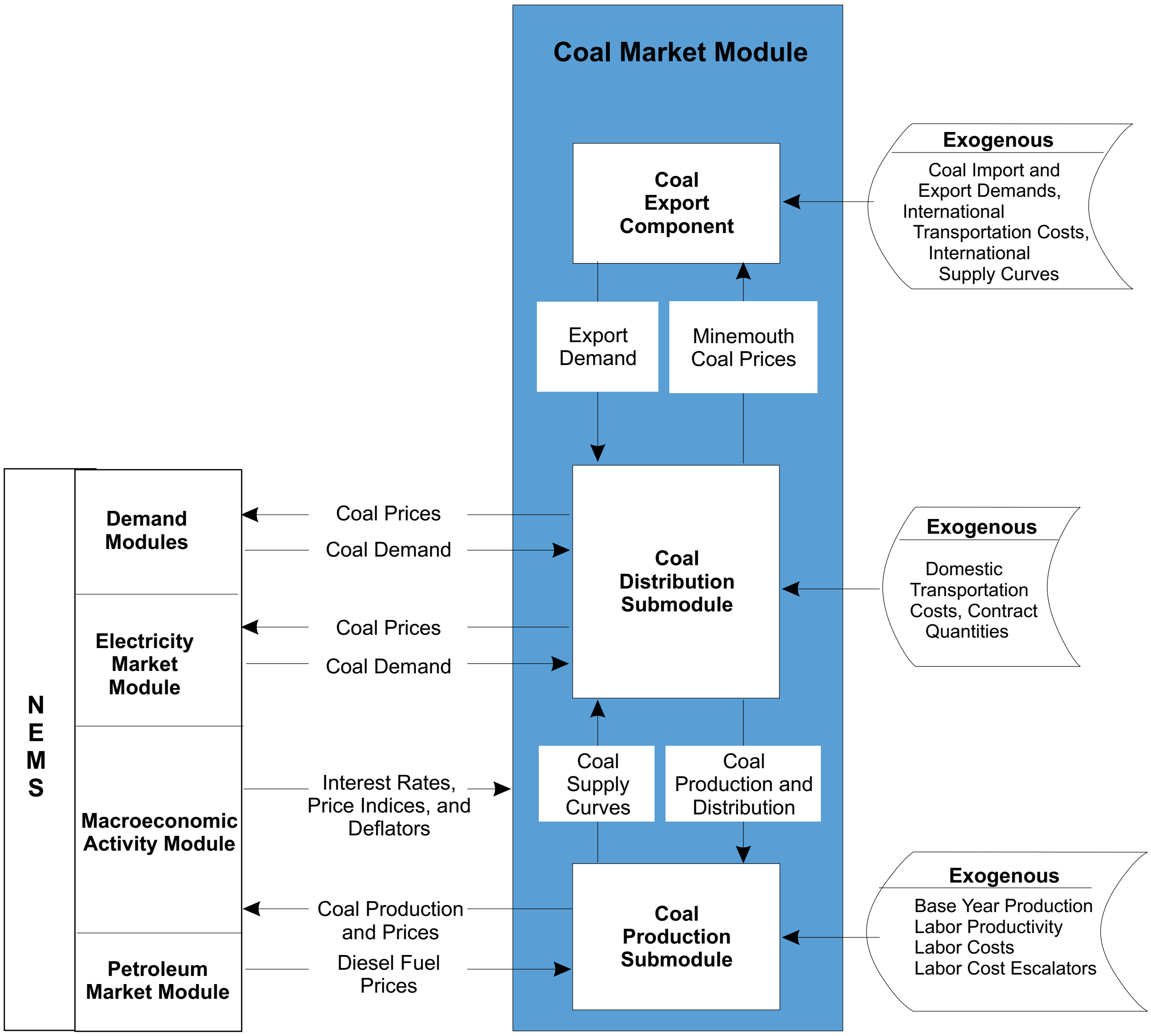
The export component is a part of the linear program that optimizes domestic coal supply. It determines world coal trade distribution by minimizing overall costs for coal, subject to U.S. coal supply prices and a number of constraints. Supply costs (mining and preparation plus transportation) for each coal export region, coal type, and end use compete in two demand sectors (coking and steam). The component also incorporates within the model structure supply diversity constraints that reflect the observed tendency of coal-importing countries to avoid excessive dependence upon one source of supply.

Figure 20. Coal Market Module Supply Regions



Coal Export Regions		Coal Import Regions	
U.S. East Coast	South Africa	U.S. East Coast	Iberia
U.S. Gulf Coast	Poland	U.S. Gulf Coast	Italy
U.S. Southwest and West	CIS (Europe)	U.S. Northern Interior	Mediterranean and Eastern Europe
U.S. Northern Interior	CIS (Asia)	U.S. Noncontiguous	Mexico
U.S. Noncontiguous	China	Eastern Canada	South America
Australia	Colombia	Interior Canada	Japan
Western Canada	Indonesia	Scandinavia	East Asia
Interior Canada	Venezuela	United Kingdom and Ireland	China and Hong Kong
		Germany	ASEAN (Association of South East Asia Nations)
		Other Northwestern Europe	India and South Asia

Figure 21. Coal Market Module Structure



BIBLIOGRAPHY

The National Energy Modeling System is documented in a series of model documentation reports, available on the EIA Web site at http://www.eia.doe.gov/bookshelf/docs.html or by contacting the National Energy Information Center (202/586-8800).

Energy Information Administration, *Integrating Module of the National Energy Modeling System: Model Documentation* DOE/EIA-M057(2000) (Washington, DC, December 1999).

Energy Information Administration, *Model Documentation Report: Macroeconomic Activity Module (MAM) of the National Energy Modeling System*, DOE/EIA-M065(2000) (Washington, DC, December 1999).

Energy Information Administration, *Documentation of the DRI Model of the U.S. Economy*, DOE/EIA-M061 (Washington, DC, December 1993).

Energy Information Administration, *NEMS International Energy Module: Model Documentation Report*, DOE/EIA-M071(99) (Washington, DC, February 1999).

Energy Information Administration, *EIA Model Documentation: World Oil Refining Logistics Demand Model, "World" Reference Manual*, DOE/EIA-M058 (Washington, DC, March 1994).

Energy Information Administration, *Model Documentation Report: Residential Sector Demand Module of the National Energy Modeling System,* DOE/EIA-M067(2000) (Washington, DC, December 1999).

Energy Information Administration, *Model Documentation Report: Commercial Sector Demand Module of the National Energy Modeling System*, DOE/EIA-M066(2000) (Washington, DC, December 1999).

Energy Information Administration, *Model Documentation Report: Industrial Sector Demand Module of the National Energy Modeling System*, DOE/EIA-M064(2000) (Washington, DC, January 2000).

Energy Information Administration, *Transportation Sector Model of the National Energy Modeling System: Model Documentation Report*, DOE/EIA-M070(2000) (Washington, DC, January 2000).

Energy Information Administration, *The Electricity Market Module of the National Energy Modeling System*: *Model Documentation Report,* DOE/EIA-M068(2000) (Washington, DC, January 2000).

Energy Information Administration, *Documentation of the Oil and Gas Supply Module (OGSM)*, DOE/EIA-M063(2000) (Washington, DC, January 2000).

Energy Information Administration, *Model Documentation: Natural Gas Transmission and Distribution Model of the National Energy Modeling System,* DOE/EIA-M062(2000) (Washington, DC, January 2000).

Energy Information Administration, *EIA Model Documentation: Petroleum Market Model of the National Energy Modeling System*, DOE/EIA-M059(2000) (Washington, DC, December 1999).

Energy Information Administration, *Model Documentation: Coal Market Module of the National Energy Modeling System*, DOE/EIA-M060(2000) (Washington, DC, January 2000).

Energy Information Administration, *Model Documentation: Renewable Fuels Module of the National Energy Modeling System*, DOE/EIA-M069(2000) (Washington, DC, January 2000).