Integrating Module of the
National Energy Modeling System:
Model Documentation 2001

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1. Introduction

The National Energy Modeling System (NEMS) is a computer-based, energy-economy modeling system of U.S. energy markets for the midterm period. NEMS projects the production, imports, conversion, consumption, and prices of energy, subject to a variety of assumptions. The assumptions encompass macroeconomic and finanacial factors, world energy markets, resource availability and costs, behavioral and technological choice criteria, technology characteristics, and demographics. NEMS produces a general equilibrium solution for energy supply and demand in the U.S. energy markets on an annual basis through 2020.

Baseline forecasts from NEMS are published in the *Annual Energy Outlook*. Analyses are also prepared in response to requests by the U.S. Congress, the DOE Office of Policy, and others. NEMS was first used for forecasts presented in the *Annual Energy Outlook 1994.*

Scope and Organization

Publication of this document is supported by Public Law 93-275, Federal Energy Administration Act of 1974, Section 57(B)(1) (as amended by Public Law 94-385, Energy Conservation and Production Act), which states in part

> *...that adequate documentation for all statistical and forecast reports prepared...is made available to the public at the time of publication of such reports.*

In particular, this report is designed to meet EIA's model documentation standards established in accordance with these laws.

For documentation purposes, the individual components of NEMS are considered distinct models and documented individually. While the NEMS integrating module is a distinct component of NEMS, the integrating module is not by itself, a model. Rather, it is a component of the overall NEMS model and implements specific aspects of the overall modeling methodology that are not documented elsewhere. The documentation is organized accordingly.

Because the Integrating Module controls the solution process for all of NEMS, the second chapter summarizes NEMS as a whole, including some of the design considerations for the system. Chapter 3 briefly describes the individual component modules of NEMS. Readers interested in a more comprehensive summary of NEMS should see *The National Energy Model System: An Overview 2000*, DOE/EIA-0581(2000), March, 2000.

Chapter 4 describes the NEMS global data structure, used for inter-module communication, solution initialization and storage, and certain database operations.

Chapter 5, Integrating Module Solution Methodology, provides the mathematical specification for the solution algorithm and describes the convergence techniques used. Chapter 5 also documents other modeling functions of the Integrating Module, include generation of foresight assumptions and carbon dioxide emission policy routines.

A bibliography is contained in Appendix A, and the model abstract is in Appendix B.

Model Archival Citation

This documentation refers to the NEMS Integrating Module as archived for the *Annual Energy Outlook 2001*.

2. Overview of the Structure of NEMS

NEMS is structured as a modular system. The modules include the Integrating Module and a series of relatively independent analytical modules that represent the domestic energy system, the international energy market, and the economy. The domestic energy system is decomposed into fuel supply markets, conversion activities, and end-use consumption sectors.

NEMS is a model of domestic energy markets. As such, the decisions to produce, convert, or consume energy products are presumed to serve the economic self-interest of those making the decisions. Many NEMS modules explicitly reproduce the economic decisionmaking involved in the portion of the energy system being modeled. In order to represent these decisions, NEMS is constructed in a reasonably fine detail of energy product categories and the regional locations of the sites of energy production and use. This detail is necessary since the economics of allocating energy products is strongly influenced by the product category at issue and regional differences in costs and other factors. **Table 1** provides a summary of NEMS product and regional detail.

Regional Detail

The Integrating Module of NEMS processes energy consumption and price information aggregated primarily at the Census division levels. The nine Census divisions are depicted in **Figure 1**. In addition, the integrating module processes some intermodule energy market data at regional levels tied to electricity supply regions. These alternative regional breakouts provide specific market feedbacks for consumption and prices of fuel used for electricity generation. While the NEMS modules use different regional structures as appropriate for their market segments, they aggregate (or disaggregate) their solutions to the Census Division structure for processing by the Integrating Module and by the reporting programs. Details of the conversion processes embedded in the modules are given in the individual *Model Documentation Reports* (see Appendix A, bibliography).

Time Horizon

The horizon for the midterm model is 2020, covering that time period in which the structure of the economy, the nature of energy markets, and regional demographics are sufficiently well understood in structural and regional detail. The majority of policies proposed today can be expected to have their greatest impacts during the midterm years.

Rather than trying to attain some planned state of energy markets, NEMS attempts to simulate where the present state of energy markets and planned policies would take us. Therefore it solves forward in time year-by-year.

Figure 1. Census Divisions
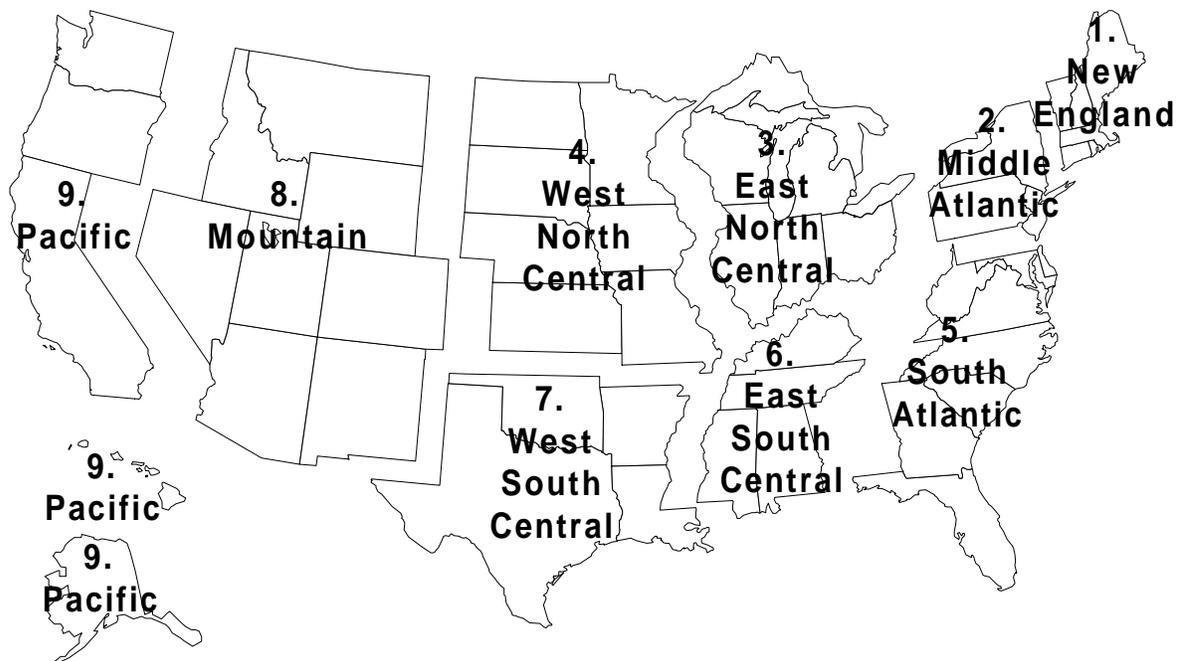
Table 1. Summary of NEMS Modeling Detail

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-fueled 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

Major Assumptions

Each module within NEMS embodies the many assumptions necessary to characterize the future production, conversion, and consumption of energy products in the United States. The NEMS Integrating Module assumes that the individual modules can be integrated to provide a convergent process for the system as a whole. It makes use of the Gauss-Seidel algorithm for blocked non-linear simultaneous equations, interpreted for the characteristics of the national energy marketplace simulated here. Chapter 4 describes this approach in detail.

Experience has shown that this approach occasionally has difficulty converging on a final solution, due to two broad classes of discontinuities in the component modules: the linear programming solution methods used by some modules jump from one vertex to another of their polygonal solution space; and other modules use tabulated functions evaluated either as step functions or by linear interpolation. These issues are handled in NEMS by ensuring that the spacings between the modules' steps are reasonably small. Convergence issues are discussed in more detail in Chapter 5.

NEMS Modular Structure

As shown in **Figure** 2, 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 demand modules (residential, commercial, transportation and industrial sectors), one module to simulate energy/economy interactions (macroeconomic activity), one to simulate world energy/domestic energy interactions (international energy activity), and one module to provide the mechanism that achieves a general market equilibrium among all the modules (the Integrating Module). The last of these is the focus of this document.

Model modularity implies a system of self-contained units, each performing a specific, well-defined function. This concept is generally consistent with the economic structure of energy markets, which can be represented by various supply, conversion, and demand components that are largely separable. Due to the heterogenous nature of energy markets, a single methodology cannot adequately represent all fuel supply, energy conversion, and end-use demand sectors. Modularity allows the flexibility to use the methodology and coverage that is most appropriate for each module. Furthermore, modularity provides the capability to execute the modules individually or to easily substitute alternative modules to represent a specific function, so long as the required interfaces are satisfied. The interactions among these modules are controlled by the integrating mechanism. The information flows to and from the modules of NEMS are summarized in **Table 2.**

Figure 2. Basic NEMS Structure
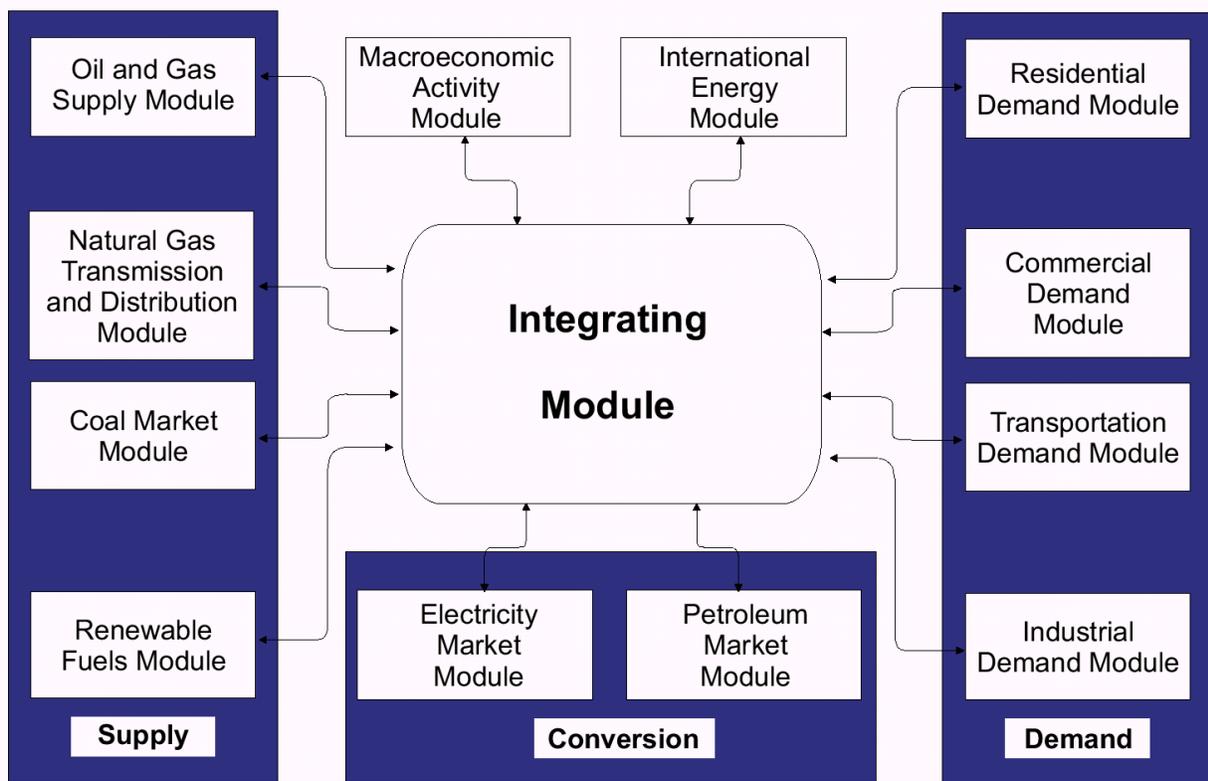
Table 2. NEMS Module Information Flows

Module	Outputs	Inputs from NEMS	Exogenous Inputs
Oil and Gas Supply	Crude oil production Domestic and Canadian natural gas supply curves Mexican and liquefied natural gas imports and exports Cogeneration from oil and gas production Reserves and reserve additions Drilling levels Associated-Dissolved gas production	Domestic and Canadian natural gas production and wellhead prices Crude oil demand World oil price Electricity Price	Resource levels Initial finding rate parameters and costs Production profiles Tax parameters Mexican and liquefied natural gas imports and exports
Natural Gas Transmission and Distribution	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 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
Petroleum Market	Petroleum product prices Crude oil imports and exports Crude oil demand Petroleum product imports and exports Refinery activity and fuel use Ethanol demand and price Cogeneration Natural gas plant liquids production Processing gain Capacity additions Capital expenditures Revenues	Petroleum product demand by sector Domestic crude oil production World oil price International crude oil supply curves International product supply curves International oxygenates supply curves Natural gas prices Electricity prices Natural gas production Macroeconomic variables Biomass supply curves	Processing unit operating parameters Processing unit capacities Product specifications Operating costs Capital costs Transmission and distribution costs Federal and State taxes Agricultural feedstock quantities and costs Cogeneration unit operating parameters Cogeneration unit capacities
Coal Market	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 Demand for U.S. coal imports
Renewable Fuels	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

Table 2. NEMS Module Information Flows (Continued)

Module	Outputs	Inputs from NEMS	Exogenous Inputs
Electricity Market	Electricity prices and price components Fuel demands Capacity additions Capital requirements Emissions Renewable capacity Avoided costs	Electricity sales Fuel prices Cogeneration supply and fuel consumption Electricity sales to the grid Renewable technology characteristics, allowable capacity, and costs Renewable capacity factors Gross domestic product Interest rates	Financial data Tax assumptions Capital costs Operation and maintenance costs Operating parameters Emissions rates New technologies Existing facilities Transmission constraints Hydropower capacity and capacity factors
Residential	Energy product demand Changes in housing and appliance stocks Appliance stock efficiency	Energy product prices Housing starts Population	Current housing stocks, retirement rates Current appliance stocks/life expectancy New appliance types, efficiencies, and costs Housing shell retrofit indices Unit energy consumption Square footage
Commercial	Energy product demand Changes in floorspace and appliance stocks	Energy product prices Interest rates Floorspace growth	Existing commercial floor space Floorspace survival rates Appliance stocks and survival rates New appliance types, efficiencies, costs Energy use intensities
Industrial	Energy product demand Electricity sales to the 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
Transportation	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 technologies characteristics Fuel availability Commercial availability Vehicle safety and emissions regulations Vehicle miles-per-gallon degradation rates
International Energy Activity	World oil price Crude oil import supply curves Refined product import supply curves Oxygenate import supply curves	Domestic crude oil production Domestic natural gas liquids production Domestic other liquids production Domestic refinery gain Domestic product supplied GDP price deflators Domestic crude oil imports Domestic refined product imports Domestic oxygenate imports	OPEC Production Path Reference non-U.S. oil supply and Demand Non-U.S. economic parameters Base import supply curves for crude oils, refined products, and oxygenates
Macroeconomic Activity Module	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
Macroeconomic Activity	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	Macroeconomic variables defining alternative economic growth cases

The data linkages between modules are implemented through the Integrating Module's Global Data Structure. The Global Data Structure (discussed in more detail in Chapter 4) is defined as the set of data communicated among any of the thirteen NEMS modules. The primary data flows among the modules are the delivered prices of energy and the quantities consumed by product, region, and sector. This subset of the Global Data Structure is used for equilibration and the NEMS energy balance. As shown in **Table 2**, the information flows are not limited to prices and quantities, but include other information such as economic activity, capital expenditures, and load curves.

3. Summary of the NEMS Component Modules

This chapter summarizes the components of NEMS, referred to as modules. For a more detailed description of the NEMS modules, the reader is referred to *The National Energy Modeling System: An Overview 2000*, DOE/EIA-0581(2000) and to the documentation reports for the individual NEMS modules, listed in the bibiliography (Appendix A.)

The inputs for and outputs from the following modules are summarized in **Table 2** (previous chapter).

Integrating Module

Figure 2 (previous chapter) depicts the relationship of the Integrating Module of NEMS with each of the component modules. The NEMS integrating module controls the NEMS solution process as it iterates to determine a general market equilibrium across all the NEMS modules.

The integrating module executes the system of 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 procedure continues until the specified convergence variables remain constant within a specified tolerance--a condition defined as convergence. Equilibration is achieved annually through 2020 for each of the nine Census divisions.

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 would be the solution values from a previous run of NEMS.

The integrating module also includes an emissions policy module to calculate carbon dioxide emissions and methane from energy use, and optionally, to impose carbon dioxide limits or emission fees on energy prices for potential policy analyses.

Macroeconomic Activity Module

The Macroeconomic Activity Module provides a set of essential macroeconomic drivers to the energy modules and a macroeconomic feedback mechanism within NEMS. Key macroeconomic variables include Gross Domestic Product (GDP), interest rates, disposable income, and employment. Industrial drivers are calculated for 35 industrial

sectors. This module is a kernal regression representation of the Standard and Poor's DRI Macroeconomic Model of the U.S. Economy.

International Module

The International Module represents the world oil markets, calculating the average world oil price and computing supply curves for five categories of imported crude oil for the Petroleum Market Module of NEMS, in response to changes in U.S. import requirements. International petroleum product supply curves, including curves for oxygenates, are also calculated.

Household Expenditures Module

The Household Expenditures Module provides estimates of average household direct expenditures for energy used in the home and in private motor vehicle transportation. The forecast of expenditures reflect the projections from NEMS for the residential and transportation sectors. The projected household energy expenditures incorporate the changes in residential energy prices and motor gasoline price determined in NEMS, as well as the changes in the efficiency of energy use for residential end-uses and in light-duty vehicle fuel efficiency. Average expenditures estimates are provided for households by income group and Census division.

Residential and Commercial Demand Modules

The Residential Demand Module forecasts consumption of residential sector energy by housing type and end use, subject to delivered energy prices, availability of renewable sources of energy, and housing starts. The Commercial Demand Module forecasts consumption of commercial sector energy by building types and nonbuilding uses of energy and by category of end use, subject to delivered prices of energy, availability of renewable sources of energy, and macroeconomic variables representing interest rates and floorspace construction. Both modules estimate the equipment stock for the major end-use services, incorporating assessments of advanced technologies, including representations of renewable energy technologies and effects of both building shell and appliance standards. Both modules include a representation of distributed generation.

Industrial Demand Module

The Industrial Demand Module forecasts the consumption of energy for heat and power and for feedstocks and raw materials in each of 16 industry groups, subject to the delivered prices of energy and macroeconomic variables representing employment and the value of output for each industry. The industries are classified into three

groups—energy-intensive, non-energy-intensive, and nonmanufacturing. Of the eight energy-intensive industries, seven are modeled in the Industrial Demand Module with components for boiler/steam/cogeneration, buildings, and process/assembly use of energy. A representation of cogeneration and a recycling component are also included. The use of energy for petroleum refining is modeled in the Petroleum Market Module, and the projected consumption is included in the industrial totals.

Transportation Demand Module

The Transportation Demand Module forecasts consumption of transportation sector fuels, including petroleum products, electricity, methanol, ethanol, compressed natural gas, and hydrogen by transportation mode, vehicle vintage, and size class, subject to delivered prices of energy fuels and macroeconomic variables representing disposable personal income, GDP, population, interest rates, and the value of output for industries in the freight sector. Fleet vehicles are represented separately to allow analysis of CAAA90 and other legislative proposals, and the module includes a component to explicitly assess the penetration of alternative-fuel vehicles.

Electricity Market Module

The Electricity Market Module represents generation, transmission, and pricing of electricity, subject to delivered prices for coal, petroleum products, and natural gas; costs of generation by centralized renewables; macroeconomic variables for costs of capital and domestic investment; and electricity load shapes and demand. There are three primary submodules—capacity planning, fuel dispatching, and finance and pricing. Nonutility generation, distributed generation, and transmission and trade are represented in the planning and dispatching submodules. The levelized fuel cost of uranium fuel for nuclear generation is directly incorporated into the Electricity Market Module. All CAAA90 compliance options are explicitly represented in the capacity expansion and dispatch decisions. New generating technologies for fossil fuels, nuclear, and renewable technologies compete directly in these decisions.

Renewable Fuels Module

The Renewable Fuels Module (RFM) includes submodules that provide explicit representation of the supply response of biomass (including wood, energy crops, and biomass for cofiring), geothermal, municipal solid waste (including landfill gas), solar thermal, solar photovoltaics, and wind energy. The RFM contains natural resource supply estimates respresenting the regional opportunities for renewable energy development.

Oil and Gas Supply Module

The Oil and Gas Supply Module represents domestic crude oil and natural gas supply within an integrated framework that captures the interrelationships between the various sources of supply: onshore, offshore, and Alaska by both conventional and nonconventional techniques, including enhanced oil recovery and unconventional gas recovery from coalbeds and low-permeability formations of sandstone and shale. This framework analyzes cash flow and profitability to compute investment and drilling in each of the supply sources, subject to the prices for crude oil and natural gas, the domestic recoverable resource base, and technology. Oil and gas production functions are computed at a level of 12 supply regions, including 3 offshore and 3 Alaskan regions. This module also represents foreign sources of natural gas, including pipeline imports and exports with Canada and Mexico and liquefied natural gas imports and exports. The crude oil supply curves are input to the Petroleum Market Module in NEMS for conversion and blending into refined petroleum products. Supply curves for natural gas are input to the Natural Gas Transmission and Distribution Module for use in determining prices and quantities.

Natural Gas Transmission and Distribution Module

The Natural Gas Transmission and Distribution Module represents the transmission, distribution, and pricing of natural gas, subject to end-use demand for natural gas and the availability of domestic natural gas and natural gas traded on the international market. The module tracks the flows of natural gas in an aggregate, domestic pipeline network, connecting the domestic and foreign supply regions with 12 demand regions. This capability allows the analysis of impacts of regional capacity constraints in the interstate natural gas pipeline network and the identification of pipeline capacity and storage expansion requirements. Peak and off-peak periods are represented for natural gas transmission, and core and noncore markets are represented at the burner tip. Key components of pipeline and distributor tariffs are included in the pricing algorithms.

Petroleum Market Module

The Petroleum Market Module (PMM) forecasts prices of petroleum products, crude oil and product import activity, and domestic refinery operations, including fuel consumption, subject to the demand for petroleum products, availability and price of imported petroleum, and domestic production of crude oil, natural gas liquids, and alcohol fuels. The module represents refining activities for three regions–Petroleum Administration for Defense District (PADD) 1, PADD 5, and an aggregate of PADDs 2, 3 and 4. The module uses the same crude oil types as the International Module.

The PMM explicitly models the requirements of CAAA90 and the costs of new automotive fuels, such as oxygenated and reformulated gasoline, and includes oxygenate production and blending for reformulated gasoline. The AEO2001 version reflects legislation that bans or limits the use of the gasoline blending component methyl tertiary butyl ether (MTBE) in 2003 in Arizona, California, Connecticut, Maine, Minnesota, Nebraska, New York, and South Dakota. Because the AEO2001 reference case assumes current laws and regulations, it assumes that the Federal oxygen requirement for reformulated gasoline in

Federal nonattainment areas will remain intact. A new regulation that requires the sulfur content of all gasoline in the United States to be reduced to an annual average of 30 parts per million (ppm) in 2004 and 2007 is also explicitly modeled. Costs include capacity expansion for refinery processing units. End-use prices are based on the marginal costs of production, plus markups representing product distribution costs, State and Federal taxes, and environmental costs.

Coal Market Module

The Coal Market Module simulates mining, transportation, and pricing of coal, subject to the end-use demand for coal differentiated by physical characteristics, such as the heat and sulfur content. The coal supply curves include a response to fuel costs, labor productivity, and factor input costs. Twelve coal types are represented, differentiated by coal rank, sulfur content, and mining process. Production and distribution are computed for 11 supply and 13 demand regions, using imputed coal transportation costs and trends in factor input costs. The Coal Market Module also forecasts the requirements for U.S. coal exports and imports. The international coal market component of the module computes trade in 3 types of coal for 16 export and 20 import regions. Both the domestic and international coal markets are simulated in a linear program.

4. Global Data Structure

The Global Data Structure defines the subset of NEMS variables used for intermodule communication and reporting. The variables consist of endogenous global variables shared among modules, such as prices, consumption, and macroeconomic information. The variables also include global reporting variables, as well as a subset of model control parameters and assumptions. The Global Data Structure excludes variables defined exclusively for use in a single module.

The variables in the Global Data Structure are defined and organized in a set of FORTRAN COMMON blocks that designate groups of global variables. During NEMS execution, each module accesses its global input and output variables through these NEMS COMMON blocks. Most modules also have other variables defined in common blocks for intra-module communication. However, such common blocks declared for a module's private use are not considered a part of the global data structure.

The NEMS COMMON block structure designed to store the Global Data Structure is displayed in Table 3. The specific elements of the COMMON block structure are defined in the "include" files containing declarations for variables. In addition, a data dictionary for the Global Data Structure includes definitions for each variable. The data dictionary is a text format input file to the NEMS data management routine, FILER. Generally, three COMMON blocks can be found in the Global Data Structure for each NEMS module, to hold three categories of information:

- The module's outputs used by other NEMS modules, exclusive of end-use consumption and prices. These common blocks are named to indicate the module and have a suffix "OUT."

- The module's outputs used only for reports (for some modules only). These common blocks are named with a suffix "REP."

- The module's input variables for its key parameters and assumptions (for some modules only). These common blocks are named with a suffix "PARAM."

Table 3. Common Blocks in the NEMS Global Data Structure		
Module Creator	**Common Block Names**	**Description**
Integrating, multiple contributors, or exogenous	QBLK MPBLK MXQBLK MXPBLK QSBLK NCNTRL EMISSION CAPEXP COGEN DSM CONVFACT HEMREP COALEMM	End-Use Sector Quantities (See Table 4) End-Use Sector Prices (See Table 5) Expected Quantities for foresight Expected Prices for foresight SEDS Historical data corresponding to QBLK Control Variables Pollution Emissions and related results Capital Expenditures for Energy Equipment Cogeneration Demand-Side Management program savings (obsolete) Global conversion factors Household Expenditures report variables Variables exchanged between the Coal Market Module and Electricity
Integrating, Emission Policy Submodule	EMABLK AMPBLK ANGTDM ACOAL ACOALPRC	Price adjustments associated with carbon dioxide fees, if any Copies of MPBLK, NGTDMOUT, COALOUT, COALPRC but with prices to utilities adjusted with any carbon dioxide fees
Macroeconomic	MACPARMS MACOUT MACREP	Control parameters, assumptions Output variables Reporting Variables
Residential	RESDOUT RESDREP (misc.)	Output variables Energy by end use stored in a series of small common blocks: HTCN, CLCN, HWCN, CKCN, DRYCN, RFCN, FZCN, LTC, APC, SHC
Commercial	COMPARAM COMOUT COMMREP	Control parameters, assumptions Output variables Reporting Variables

Table 3. Common Blocks in the NEMS Global Data Structure (continued)		
Module Creator	**Common Block Names**	**Description**
Transportation	TRANREP	Reporting Variables
Industrial	INDOUT INDREP	Natural Gas and LPG Feedstocks Reporting Variables
Electricity	EMMOUT UMMOUT UEFPOUT EFPOUT UEFDOUT UDATOUT UECPOUT DSMTFEFP ULDSMOUT UETTOUT UGOILOUT	Electricity Market Outputs, General Uranium outputs Electricity pricing outputs Electricity pricing outputs Fuel-dispatch outputs Electricity central data outputs Capacity planning outputs Demand side management /electricity pricing variables Load and demand side management variables Electricity trade outputs Gas/Oil ("goil") Curve to NGTDM
Renewable	WRENEW	Output variables
Coal	COALOUT COALREP COALPRC	Output variables Reporting variables Coal prices to utilities
Petroleum	PMMPARAM PMMOUT PMMRPT	Control parameters, assumptions Output variables Reporting variables
Oil & Gas Supply	OGSMOUT	Output variables
Natural Gas T & D	NGTDMOUT NGTDMREP NGRPT	Output variables Reporting variables Supplementary reporting variables
International	INTOUT INTPMM	Output variables Variables for use with alternative integrated version of International and Petroleum Market Modules--now obsolete

In addition, a group of COMMON blocks called the Energy Market Data, hold data that are created by various modules. These are:

QBLK	Sectoral end-use quantities
MPBLK	Sectoral end-use prices (prices omitting any carbon dioxide fees if effect)
AMPBLK	Sectoral end-use prices (prices adjusted with any carbon dioxide fees in effect)
MXQBLK	Expectations for end-use quantities
MXPBLK	Expectations for end-use prices
CAPEXP	Capital Expenditures on Energy Equipment

Energy Market Data Representation

The Energy Market Data define the energy consumption product and price details that are used for market definition in NEMS. These variables are the principal values necessary for convergence testing in the integrating algorithm. The Energy Market Data are just part of the NEMS Global Data Structure. The quantity and price structure does not attempt to represent all energy flows, but instead focuses on the primary variables necessary for the design of the NEMS equilibrating methodology. In addition, the Energy Market Data structure defines the end-use energy classification for the NEMS energy balance.

Table 4 presents a list of the consumption products in a grid depicting the sectoral detail. Each item in the grid represents the named variable in NEMS. The sectoral definitions include the four end-use sectors and three conversion sectors. The sectoral and fuel consumption detail is defined to meet several objectives, including energy accounting coverage and consistency, the structure of component modules, and the requirements for inter-module communications. Elements of this design requiring clarification are as follows:

- The electricity sector includes fuel used by electric utilities and independent power producers to generate electricity supplied to the grid. The industrial and commercial sectors include fuel used for on-site electricity generation, primarily in cogeneration applications. This breakout is consistent with the coverage of the Electricity Market Module and the demand modules.

- Fuel consumption in the refinery sector is broken out from the industrial sector for inter-module communication requirements. The Petroleum Market Module determines fuel use by the refinery sector. This information is passed to Industrial Demand Module, where fuel consumption for refining is added to other industrial fuel use. Thus, the industrial energy consumption product demands as defined in Table 4 *include* refinery consumption.

- The synthetic sector includes fuel consumed for conversion and omits energy products used solely as feedstocks in the synthesis itself.

Table 5 presents the prices in the Energy Market Data structure. In general, the energy prices match the corresponding consumption quantities. The exceptions are as follows:

- Detailed refinery sector prices are omitted even though refinery fuel consumption products are defined. This is because there is no corresponding need to break out refinery sector prices from the rest of the industrial sector. The industrial fuel prices are the delivered prices to industrial fuel consumers, including refineries. As a result, the industrial sector prices match the coverage of the corresponding industrial consumption products.

- Prices for some industrial petroleum categories are combined in the industrial other petroleum category to eliminate unnecessary detail. That is, the industrial other petroleum price is defined as the average price of three consumption categories: still gas, petroleum coke, and other petroleum. The other petroleum price is not needed by any NEMS module but is required for reporting purposes to determine the average price of all petroleum products.

- Delivered prices for renewable energy categories are left undefined because there are no meaningful market prices for them. For example, there are no delivered prices associated with hydroelectric, geothermal, wind, solar thermal, and photovoltaic energy sources. In the case of biomass, the diverse nature of the product and the lack of organized market structures preclude the definition of a delivered price. Thus, there is no need to define end-use prices for renewables.

Table 4 and **Table 5** also define the variable names for the NEMS consumption products and end-use prices along with the two-character product code mnemonic for each product. Each array is a two-dimensional, floating point array. The first dimension represents the nine Census Divisions, with a 10th position reserved for possible breakout of California and the 11th position reserved for the National total. The second dimension represents 31 years from 1990 to 2020. Quantities are stored in trillions of Btu. Prices are stored in 1987 dollars per million Btu, as deflated by the implicit GDP price deflator.

A related part of the Energy Market Data structure comprises the variables to hold energy market expectations. The Integrating Module maintains a separate set of arrays to store consumption and price expectations. The expectations arrays are updated according to the foresight options under consideration. The expectations arrays are defined like the standard energy market arrays, each with an additional leading character, X. Not all energy product detail is duplicated.

Table 4. Energy Market Data Consumption Product Arrays

Description	End-Use Sectors				Conversion Sectors			Totals
	Resd. (Q_RS)	Comm. (Q_CM)	Tran (Q_TR)	Indus. (Q_IN)	Refin. (Q_RF)	Elect. (Q_EL)	Synth. (Q_SY)	All (Q_AS)
Purchased Electricity, Peak	QEPRS	QEPCM	QEPTR	QEPIN	QEPRF			QEPAS
Purchased Electricity, Off-Peak	QENRS	QENCM	QENTR	QENIN	QENRF			QENAS
Purchased Electricity (total)	QELRS	QELCM	QELTR	QELIN	QELRF			QELAS
Natural Gas, Firm	QGFRS	QGFCM	QGFTR	QGFIN	QGFRF	QGFEL		QGFAS
Natural Gas, Interrupt.	QGIRS	QGICM	QGITR	QGIIN	QGIRF	QGIEL		QGIAS
Natural Gas (total)	QNGRS	QNGCM	QNGTR	QNGIN	QNGRF	QNGEL		QNGAS
Natural Gas, Pipeline Fuel			QGPTR					
Lease and Plant Fuel				QLPIN				
Steam Coal	QCLRS			QCLIN	QCLRF	QCLEL	QCLSN	QCLAS
Metallurgical Coal				QMCIN				
Motor Gasoline		QMGCM	QMGTR	QMGIN				QMGAS
Jet Fuel			QJFTR					
Distillate	QDSRS	QDSCM	QDSTR	QDSIN	QDSRF	QDSEL		QDSAS
Kerosene	QKSRS	QKSCM		QKSIN				QKSAS
Liquid Petroleum Gas	QLGRS	QLGCM	QLGTR	QLGIN	QLGRF			QLGAS
Residual Fuel, Low Sulfur		QRLCM	QRLTR	QRLIN	QRLRF	QRLEL		QRLAS
Residual Fuel, High Sulfur			QRHTR			QRHEL		QRHAS
Residual Fuel (total)		QRSCM	QRSTR	QRSIN	QRSRF	QRSEL		QRSAS
Petrochemical Feedstocks				QPFIN				
Still Gas				QSGIN	QSGRF			
Petroleum Coke				QPCIN	QPCRF	QPCEL		QPCAS
Asphalt and Road Oil				QASIN				
Other Petroleum			QOTTR	QOTIN	QOTRF			QOTAS
Total Petroleum	QTPRS	QTPCM	QTPTR	QTPIN	QTPRF	QTPEL		QTPAS
Methanol			QMETR					
Ethanol			QETTR					
Liquid Hydrogen			QHYTR					
Uranium						QUREL		
Hydroelectric				QHOIN		QHOEL		QHOAS
Geothermal				QGEIN		QGEEL		QGEAS
Biomass	QBMRS	QBMCM		QBMIN	QBMRF	QBMEL	QBMSN	QBMAS
Municipal Solid Waste				QMSIN		QMSEL		QMSAS
Solar Thermal	QSTRS	QSTCM		QSTIN		QSTEL		QSTAS
Photovoltaic	QPVRS	QPVCM		QPVIN		QPVEL		QPVAS
Wind				QWIIN		QWIEL		QWIAS
Total Renewable	QTRRS	QTRCM	QTRTR	QTRIN		QTREL	QTRSN	QTRAS
Net Electricity Imports						QEIEL		
Net Coal Coke Imports				QCIIN				
Total Sectoral Consumption	QTSRS	QTSCM	QTSTR	QTSIN	QTSRF	QTSEL	QTSSN	QTSAS

Table 5. Energy Market Data Price Product Arrays

Description	Resd. (P_RS)	Comm. (P_CM)	Tran (P_TR)	Indus. (P_IN)	Elect. (P_EL)	All (P_AS)
Purchased Electricity, Peak Purchased Electricity, Off-Peak Purchased Electricity (average)	PEPRS PENRS PELRS	PEPCM PENCM PELCM	PEPTR PENTR PELTR	PEPIN PENIN PELIN		PEPAS PENAS PELAS
Natural Gas, Firm Natural Gas, Interruptible Natural Gas (average) Natural Gas, Pipeline Fuel Lease and Plant Fuel	PGFRS PGIRS PNGRS	PGFCM PGICM PNGCM	PGFTR PGITR PNGTR PGPTR	PGFIN PGIIN PNGIN PLPIN	PGFEL PGIEL PNGEL	PGFAS PGIAS PNGAS
Steam Coal Metallurgical Coal	PCLRS	PCLCM		PCLIN PMCIN	PCLEL	PCLAS
Motor Gasoline Jet Fuel Distillate Kerosene Liquid Petroleum Gas Residual Fuel, Low Sulfur Residual Fuel, High Sulfur Residual Fuel (average) Petrochemical Feedstocks Asphalt and Road Oil Other Petroleum Petroleum(average)	 PDSRS PKSRS PLGRS PTPRS	PMGCM PDSCM PKSCM PLGCM PRLCM PRSCM PTPCM	PMGTR PJFTR PDSTR PLGTR PRLTR PRHTR PRSTR POTTR PTPTR	PMGIN PDSIN PKSIN PLGIN PRLIN PRSIN PPFIN PASIN POTIN PTPIN	 PDSEL PRLEL PRHEL PRSEL PTPEL	PMGAS PDSAS PKSAS PLGAS PRLAS PRHAS PRSAS POTAS PTPAS
Methanol Ethanol Liquid Hydrogen Uranium			PMETR PETTR PHYTR		 PUREL	

Other Variables in the Global Data Structure

In addition to Energy Market Data, the Global Data Structure includes the following information:

Model Control Variables
Key parameters and Assumptions for each of the NEMS modules
Macroeconomic variables, including energy demand drivers such as population
Energy demand characteristics, including demand side management savings
Energy production, conversion, and transportation activities
International energy flows
Emissions
Renewable energy information
Other data for inclusion in central report writing programs

These categories of data are those items necessary for inter-module communications and centralized report writing. There are also other COMMON blocks intended for communicating data within the subroutines of a module, but not between modules. This latter group of common data is not included in the NEMS Global Data Structure.

Restart File

At the beginning of a run, the Integrating Module reads initial values for all data in the Global Data Structure from a user-specifiable version of a special file, called the Restart file. The Restart file contains a starting point for the scenario currently under consideration, consisting of results from a prior simulation. During the run, much of this data is updated and changed. For example, alternative values for key module parameters and input assumptions, read separately from the user interface file or other sources, override the values stored in the Restart file. At the end of the run, a new Restart file is created with all the data from the run. The file is available for future runs, as well as to link with reporting and database management routines.

This feature promotes modularity by supplying values for all shared variables, regardless of whether the module that creates them is active in the run. Prices, quantities demanded or supplied, and other variables normally generated by a module that is switched off for the current run, are provided instead by the Restart file.

A database subroutine called FILER is used to store and retrieve the NEMS Global Data Structure as represented in the NEMS restart file. The global data is structured into groups of variables known as "common blocks." The FILER routine moves data between common block memory and disk storage. The NEMS modules may access data from, and write results to the common block variables once the data is loaded into memory. The basic capabilities of FILER are:

- To load data from a file into a standard NEMS COMMON block; and
- To write data from a standard NEMS COMMON block to a file.

This capability is constructed such that files created by FILER (restart files) can also be read by FILER. In addition, FILER can be used to extract subsets of data and create text files or spreadsheets. It can also be used to initialize new global variables with starting values. Generally, FILER is not used for input of most exogenous data in NEMS. The procedure incorporates a data dictionary to define the variables in the Global Data Structure. User access to the FILER program is available outside NEMS through the NEMS macro command, TFILER.

Reporting Features

NEMS has a separate tabular report writing program named "Ftab." Ftab is programmed to produce some 130 tables, many of which are designed to be published in the appendices of the *Annual Energy Outlook,* while others are compiled primarily for debugging or graphics applications. Ftab uses the NEMS Restart file as its primary data source and is capable of preparing tables comparing up to seven different NEMS runs by reading each run's Restart file. By default, Ftab generates printable text-format tables. It can also generate the tables in spreadsheet ("wk1") format, as well as in a specially formatted file for use with the NEMS interactive run review program known as "Graf2000." Graf2000 can present any data from the ftab reports graphically and provides a number of diagnostic capabilities to analyze run results across scenarios.

5. Integrating Module Solution Methodology

The Integrating Module controls the overall flow of the NEMS solution algorithm, and provides the interface and control logic for scenario implementation and execution. In addition, it tests for convergence of the system during each year, as it controls the iteration process.

Using the Energy Market Data portions of the NEMS Global Data Structure as inputs, the Integrating Module measures whether convergence has occurred, and optionally adjusts the Energy Market Data values to accelerate the convergence process. By means of calls to the FILER and File Manager routines, the Integrating Module manages the flow of overall system data; however, beyond reading the user's parameter requests, it has no important input nor output functions of its own.

Relationship of the Integrating Module to Other NEMS Modules

The modular structure of NEMS implies that little model structure resides within the Integrating Module. The component modules represent energy sectors and markets; the Integrating Module oversees the interactions among the various energy sectors, calling upon the component modules as needed. In a very real sense, the structure of the Integrating Module is therefore synonymous with the structure of NEMS, insofar as the Integrating Module defines a structure within which the analytical modules function.

The Integrating Module controls the execution of the other component modules as part of an iterative convergence algorithm. The objective is to equilibrate iteratively on the delivered prices and quantities of energy, thus assuring an economic equilibrium of supply and demand in the domestic energy markets, with feedbacks from the international markets and the U.S. economy as a whole.

The Integrating Module also coordinates communication among the other modules. The primary information flows among these major modules are the delivered prices and quantities of energy by product, region, and sector. However, the data flows are not limited to prices and quantities and include other information such as economic activity, capital expenditures, and impacts of demand side management programs.

Integrating Module Inputs

Given its mediating role in the NEMS system, the Integrating Module has little input data of its own; the major model inputs are processed by each of the component modules. The Integrating Module reads user run description parameters and invokes a data base portion that reads the NEMS Global Data Structure.

As a body, all data used, either read or written, by more than one of the NEMS component modules are referred to as the *NEMS Global Data Structure*. For convenient sharing among the modules, all such variables are stored internally in FORTRAN COMMON blocks. At the end of each NEMS iteration, the Integrating Module invokes a process, called *FILER*, which stores the contents of the COMMON blocks that constitute the NEMS Global Data Structure into a single large file, called the *RESTART* file. At the start of each NEMS run, the Integrating Module makes use of FILER to read an entire RESTART file to initialize the COMMON blocks. Thus, the NEMS Global Data Structure includes both the external file and its internal representation in COMMON.

Because all NEMS shared data are initialized from the RESTART file at the start of each run, it is not strictly necessary for the Integrating Module to invoke all of the component modules; if any module is omitted, its normal output variables can be found by the other modules in exactly the same places they would otherwise occupy, filled with values from the end of an earlier NEMS run. An important function of the Integrating Module is to ascertain which of the component modules are to be used in the current run, and to skip the others at times when they would otherwise be called.

General Modeling Approach

EIA has taken the approach of developing models that characterize the natural decision making of each sector of the energy market, linking or integrating the models together in a simulation framework to represent the aggregate U.S. energy market response to basic assumptions and alternative policies. Optimization models are appropriate to simulate the behavior of a homogeneous industry or sector of the economy, and their use is a standard practice in economic policy analysis. For example, the electric industry's plant dispatch decisions or the movements in the coal transportation sector can be appropriately represented as an optimization model. Other sectors are better represented using simulations of the outcome of decision rather than modeling the decisions directly.

The fundamental integrating methodology used by NEMS involves a control program, the Integrating Module, that commences the solution process with an initial set of estimates of energy prices and quantities. It calls each of the modules in turn to generate new end-use demands for energy in the demand modules, and new end-use prices at which the demands can be satisfied in the supply and conversion modules. This new set of prices and quantities is then used for another round of calling the modules and so on, until the model has computed price estimates at which supply and demand are in balance.

NEMS design criteria do not specify the modeling approaches to be taken by the individual analytical modules. A variety of approaches can be found among the existing modules, ranging in complexity from simple accounting models through detailed mathematical optimization algorithms. Some sectors have implemented multiple approaches that the user can select by choosing alternative complete modules.

Figure 2 in Chapter 2 depicts the relationship of the Integrating Module of NEMS toh each of the component modules. Generally, the component modules of NEMS do not interact with one another directly, but instead communicate through the Integrating Module. The organization has a number of benefits. It allows each module to be executed or omitted independently. More importantly, it provides centralized control over such Integrating

Module functions as execution sequence, convergence checks, equilibration procedures, and data access. Finally, the organization promotes a division of labor for the development and maintenance of NEMS, as each module is the responsibility of a single team.

The following section provides a more explicit, detailed formulation of the Integrating Module solution algorithm. It includes a complete mathematical specification as well as a detailed flow chart of the algorithm.

Mathematical Specification

In many ways, NEMS follows the standard structure of energy models. It has separate models for determining the supply of each fuel. These models are incorporated in the Oil and Gas Supply Module (OGSM), the Renewable Fuels Module, and the Coal Production Submodule. These modules produce supply curves. The supply curves consist of estimates of reserve additions that take account of the longer run effects of prices and the quality of the resource base followed by short-run supply curves that capture the short-run utilization of the reserves in clearing markets annually. The short-run supply curves are inserted into the fuel market models that determine the market clearing prices and quantities and distribution patterns. These models are contained in the Natural Gas Transmission and Distribution Module (NGTDM), the Coal Distribution submodule (CDS), and Coal Export submodule (CES). The transformation components model the conversion of fuel from one form to another. These include the Petroleum Marketing Module (PMM), which converts crude oil to refined products, and the Electricity Marketing Module (EMM), which converts natural gas, petroleum products, and other fuels to electricity. These modules consist of capacity expansion models and short-run capacity-utilization models. Finally, the demand models, including the Commercial, Residential, Industrial, and Transportation modules include short-run and long-run demand responses to price changes in fuels. The short-run response measures the effect of equipment utilization and the long-run response measures the change in energy-consuming capital stock.

The supply curves from the supply models provide prices for fuel quantity used. Although the demand models do not directly provide demand curves, their response to different input prices defines the inherent demand curves. These demand curves or demand model responses provide the quantities of fuels demanded for given fuel prices. The NEMS solution algorithm attempts to determine a vector of prices and quantities so that supply and demand are matched. Thus, the NEMS integrating algorithm must solve the set of simultaneous equations implied by the supply, demand, and conversion models.

Equation Solving Techniques

The standard equation solving techniques are Jacobi and Gauss-Seidel algorithms. Suppose that a set of equations is defined

$$f_i(x_1, ..., x_n) = 0 \text{ for } i = 1,...n. \tag{1}$$

If one has a trial solution $x_1^t,...,x_n^t$, in a Jacobi iteration t, for each x_i one solves for x_i^{t+1} in

$$f_i(x_1^t, ..., x_{i-1}^t, x_i^{t+1}, x_{i+1}^t, ..., x_n^t) = 0. \tag{2}$$

That is, one fixes all variables other than x_i at the previous trial solution and solves for a new x_i^{t+1} as a single dimensional line search. For example, if in iteration three of NEMS, the coal model is called to determine the price of coal, the coal demand and all other inputs to the model would be obtained from iteration two of NEMS using the Jacobi method. This is the case even if, for example, the industrial model has already been called during the third NEMS iteration, and therefore, updated information on demand for coal from the industrial sector is available.

On the other hand, with the Gauss-Seidel algorithm one iterates sequentially through i and uses the most recent values for the x's at each step. The equation solved at each step i looks as follows:

$$f_i(x_1^{t+1}, ..., x_{i-1}^{t+1}, x_i^{t+1}, x_{i+1}^t, ..., x_n^t) = 0. \tag{3}$$

Continuing the example introduced above with the Gauss-Seidel algorithm, when the coal model is called in iteration three of NEMS the results of any other models already run during iteration three are used. If inputs are required from other models that come after the coal model in the NEMS calling sequence, the results from iteration two of these models must be used.

Under certain conditions, it can be shown that the Jacobi iteration can never be faster than Gauss-Seidel and of course, could be considerably slower. It is intuitively more appealing to use the most recent information, which is why the NEMS uses the Gauss-Seidel algorithm.

Convergence Properties of the Jacobi and Gauss-Seidel Algorithms

It is worth reviewing some of the general convergence properties of the Jacobi and Gauss-Seidel algorithms, especially their relationship to the convergence in NEMS. The matrix of first partial derivatives of equation (1), hereafter denoted J, is a square matrix known as the Jacobian. The spectral radius of a matrix is the largest absolute value of the eigenvalues associated with a matrix.[1] If the spectral radius of the iteration matrix derived from J is less than one, these algorithms converge to a solution. If not, then these algorithms do not necessarily converge. One can think of the spectral radius as the measure of the contractor in a contraction map, since the rate of convergence is inversely proportional to the spectral radius.

In situations where the spectral radius is greater than one, convergence can still be achieved by using relaxation techniques. That is, when the solution is oscillating and diverging, one can take a convex combination of the old and new solutions to dampen the oscillation. This technique, known as successive over relaxation, modifies the iteration matrix so that it has a spectral radius less than one. It can be shown that there is a sufficiently small $w > 0$ such that when one uses $(1-w)x_t + wx_{t+1}$ as the trial solution, a

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[1]Let $Ax=\lambda x$ be a linear system of equations, with A a matrix, x a vector, and λ a scalar. The values of λ satisfying this equation are the eigenvalues of the matrix A.

solution to the equations will be achieved. In complex models such as NEMS the parameter w must be determined empirically, and could impede convergence if the solution is monotonically converging and w is chosen less than one. The application of relaxation to the NEMS solution process is discussed in the section **Acceleration Techniques**.

With NEMS, however, there are solution points which are either nondifferentiable or for which there are no Jacobians because of the discontinuities caused by incorporating linear programs in the system. The presence of such points greatly complicates the solution procedure of the NEMS system.

Discontinuities and Convergence in NEMS

The existence of supply and demand curves in NEMS was discussed in the previous section. Though the supply and demand curves are generally treated as continuous functions, various models contain linear programs or their analogues that can only incorporate step functions. Any such continuous functions must be approximated by a series of discrete steps. The inclusion of such discrete functions leads to discontinuities in the representation of the supply and demand curves in NEMS. Such discontinuities cause significant problems in the solution process.

Several modules incorporate algorithms that yield these discontinuous results. For example, the petroleum refining and distribution model is a linear program that represents crude oil supply curves as discrete step functions. These step-function approximations are updated during each solution iteration, so that the model can be considered to be a nonlinear program which is solved by successive linear approximations. The electricity fuel dispatch (EFD) model, now implemented as a linear program, also contains discontinuities due to the discrete nature of the merit-order plant dispatch algorithm which determines the fuel mix required to produce electricity. The coal distribution model is also a linear program. Thus, each of these models introduces discontinuities into the NEMS solution process.

The effect on the solution process of having discontinuities can be seen by using step function demand curves with continuous supply curves. The same conclusions may be drawn as long as either or both of the supply and demand curves are step functions. Figures 3a and 3b depict the two ways in which the continuous supply curve and step demand curves can intersect:

In these figures the supply curve determines the price used in the demand curves, which then feed back a quantity. The solution path resulting from application of the Gauss-Seidel algorithm is delineated by arrows: a horizontal arrow shows the quantity response from the demand curve and a vertical arrow shows the price response from the supply curve.

When the supply curve intersects the horizontal portion of the demand curve, there is an oscillation in the solution between quantities Q_0 and Q_1 and prices P_0 and P_1 (Figure 3a). When the intersection of the supply and demand curves is on the vertical portion of the demand curve, one can achieve the equilibrium with the Gauss-Seidel algorithm using relaxation, even if the unrelaxed algorithm yields an oscillation in the solution (Figure 3b). In Figure 3a there is no w for which convergence will occur. However, a value for w can

always be found so that the oscillation occurs around no more than one (or possible two) steps. This is useful because if one can specify sufficiently small steps so that the entire step falls within the convergence tolerance, this oscillation is no longer a convergence problem.

Figure 3A. The Supply Curve Cuts Across the Horizontal Portion of the Demand Curve
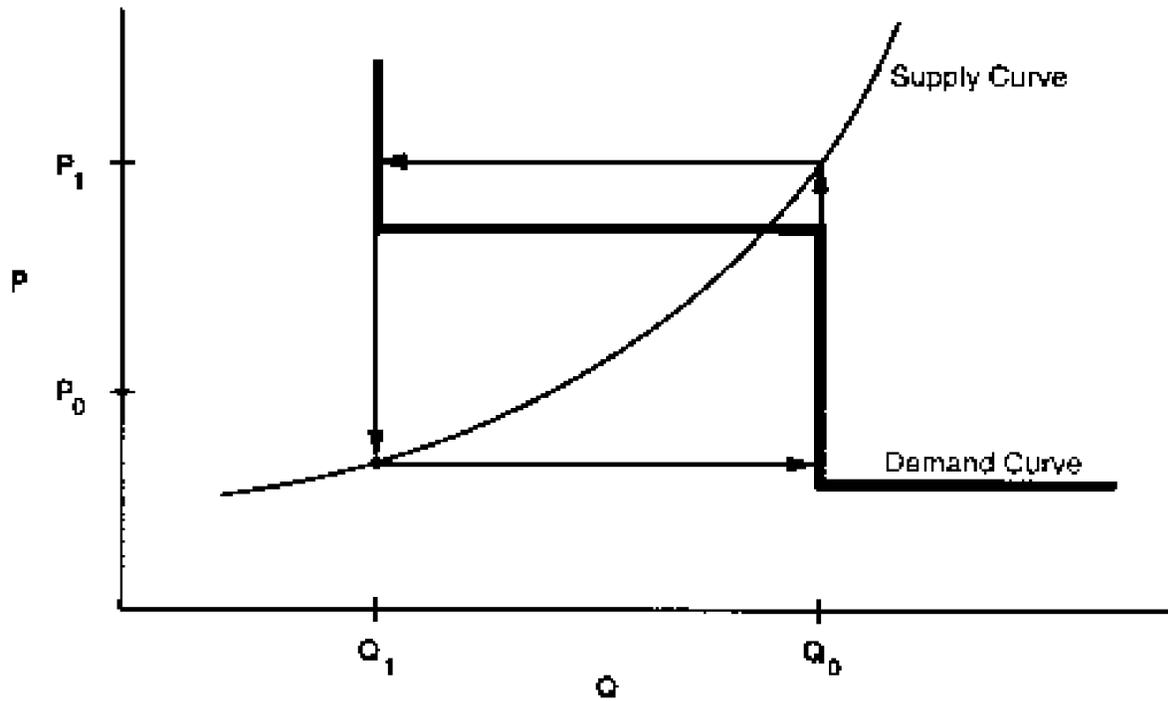
Figure 3B. The Supply Curve Cuts Across the Vertical Portion of the Demand Curve
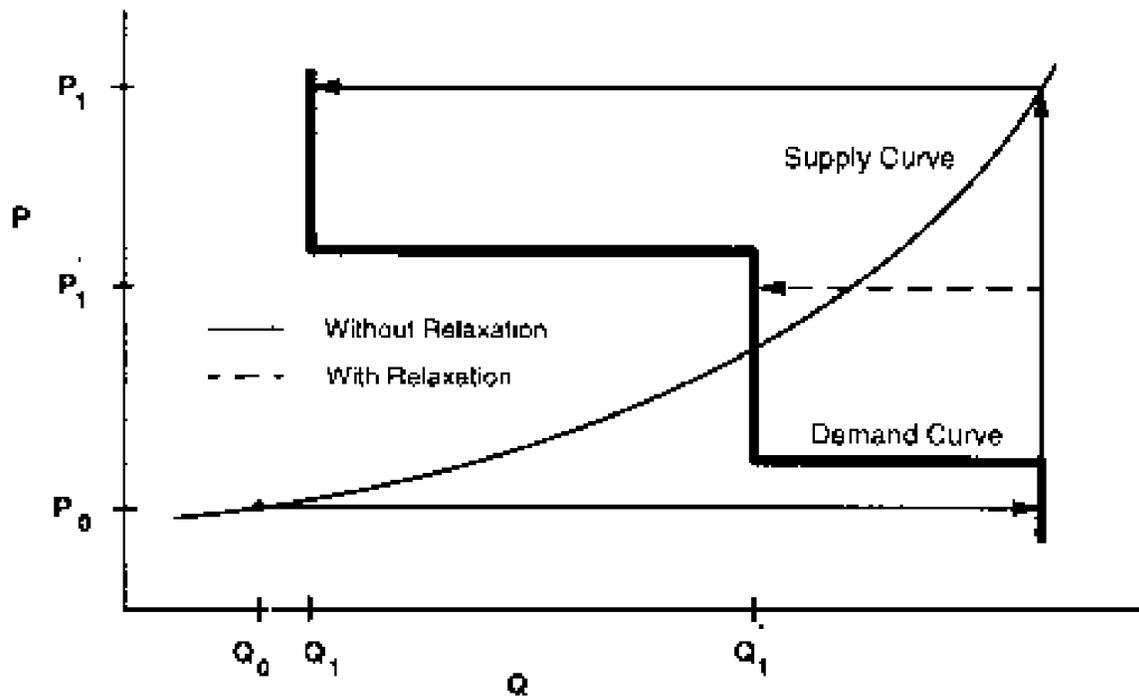
Application of Gauss-Seidel to NEMS

The NEMS integrating algorithm is an application of the Gauss-Seidel algorithm designed to solve a set of simultaneous nonlinear equations. The approach partitions the equations and variables into subsets. For NEMS, the subsets consist of predefined fuel supply, energy conversion, and sectoral demand modules. Each subset of equations is solved keeping the other variables constant at their trial values and ignoring the effects of current variables on equations in other subsets. The process is repeated for each subset, updating the trial values for each variable from the prior solution.

More formally, for a stylized NEMS, the nonlinear system of equations could be represented by

$$x_i = g_i(x) \quad \text{for} \quad i = 1, ..., n \tag{4}$$

having the market clearing or equilibrium solution vector

$$x = (x_1, ..., x_n).$$

Here, each x_i is a single variable. A trial solution for iteration k for a certain year is denoted by x^k, where

$$x^k = (x_1^{\,k}, ..., x_n^{\,k}).$$

Each $g_i(x)$ uses one or more of the elements of the trial solution vector x^k, excluding its own solution, x_i^k.

Further, we define a series of nonlinear equations $f_i(x^k)$ that represent the amount by which any trial solution $g_i(x^k)$ deviates from an equilibrium solution:

$$f_i(x^k) = x_i^k - g_i(x^k).$$

To reiterate, the solution vector x represents the set of solutions to the model: prices of energy products, quantities of energy products demanded, and certain key economic quantities. The functions $g_i(x)$ represent the formulas by which the x are calculated, and $f_i(x)$ represent the discrepancies between the calculated values for the solution vector and the solution vector itself. The $g_i(x)$ represent the relationships in the modules between prices and demands: for those i that correspond to supply modules and conversion markets the $g_i(x)$ are prices, for demand modules the $g_i(x)$ are quantities.

At the end of iteration k for a certain year, the discrepancy $f_i(x^k)$ from the equilibrium solution can be estimated as follows:

$$f_i(x^k) = x_i^{k-1} - g_i(x^{k-1}), \tag{5}$$

$$f_i(x^k) = x_i^{k-1} - x_i^{k}. \tag{6}$$

where x^{k-1} is the trial solution vector from the previous iteration for the same year.

In the block Gauss-Seidel scheme, unknowns are grouped together in such a way that a subsystem (e.g., a NEMS module) must be solved before any of the unknowns can be determined. The NEMS equations are divided into n groups (modules) and the subsystem of equations belonging to a given group is solved for the corresponding unknowns using approximate values for the other unknowns. For example, suppose the unknowns are divided into groups $(x_1..x_n)$ such that X_1, X_2, ..., X_{m1} belong to group x_1; X_{m1+1}, X_{m1+2}, ..., X_{m2} belong to group x_2; $X_{m(k-1)+1}$, $X_{m(k-1)+2}$, ..., X_{mk} belong to group x_k etc. In our case, n corresponds to the number of separate modules in NEMS (residential demand, commercial, industrial, transportation, petroleum markets, electric generation, oil and gas supply, etc.) In the NEMS context each x_i represents the set of *outputs* from the module $(g_i(x))$, given approximate values for the other unknowns in the remaining NEMS modules. Consequently, there are n blocks of variables to be solved for as groups using each of the n model blocks, $g_i(x)$. At iteration $k+1$, the solution can be represented by

$$x_1^{k+1}, x_2^{k+1}, ..., x_{i-1}^{k+1}, x_i^k, ..., x_n^k$$

In the above representation of the solution, the first i-1 groups of unknowns (x's) have been solved for in iteration $k+1$ and the other groups remain to be determined. The i-th group will be solved for next in the scheme. To solve for the next estimate of x_i, we determine x_i in the functional relationship

$$(g_i(x_1^{k+1}, x_2^{k+1}, ..., x_{i-1}^{k+1}, x_i^k, x_{i+1}^k, ..., x_n^k)) = (x_1^{k+1}, x_2^{k+1}, ..., x_{i-1}^{k+1}, x_i^{k+1}, x_{i+1}^k, ..., x_n^k)$$

Notice that x_i^k is usually not used to solve module i but is included here for completeness. Starting at the beginning of iteration ($k+1$), the algorithm proceeds as follows:

Step 0: Start with $x = (x_1^k, x_2^k, ..., x_n^k)$.

Step 1: Solve the first module in iteration ($k+1$)

Solve for x_1^{k+1} by solving for x_1 in the nonlinear system

$$g_1(x_1^{k+1}, x_2^k, ..., x_n^k) = (x_1^{k+1}, x_2^k, ..., x_n^k).$$

The solution yields a new estimate of the unknowns $x = (x_1^{k+1}, x_2^k, ..., x_n^k)$.

Step 2: Solve the second module in iteration ($k+1$).

Solve for x_2^{k+1} by solving for x_2 in the nonlinear system

$$g_2(x_1^{k+1}, x_2, x_3^k, ..., x_n^k) = (x_1^{k+1}, x_2^{k+1}, x_3^k, ..., x_n^k).$$

The solution yields a new estimate of the unknowns $x = (x_1^{k+1}, x_2^{k+1}, x_3^k, ..., x_n^k)$.

In general, when solving for the i-th group of variables,

Step i: Solve the i-th module in iteration ($k+1$).

Solve for x_i^{k+1} by solving for x_i in the nonlinear system

$$g_i(x_1^{k+1}, x_2^{k+1}, x_{i-1}^{k+1}, x_i, x_{i+1}^k, ..., x_n^k) = (x_1^{k+1}, x_2^{k+1}, ..., x_{i-1}^{k+1}, x_i^{k+1}, x_{i+1}^k, ..., x_n^k).$$

The solution for x_i above in g_i updates the solution estimate to

$$x = (x_1^{k+1}, x_2^{k+1}, ..., x_{i-1}^{k+1}, x_i^{k+1}, x_{i+1}^k, ..., x_n^k).$$

The process continues until a k+1 iteration estimate is derived for all groups of x_j.

At the end of the k+1 iteration, we compare, pointwise, every component of every group of variables in the k+1 iteration versus the k-th iteration values. A final solution, x^{k+1}, has been achieved if, after all modules have been executed, the absolute values of the proportional changes in the x_i remain smaller than a specified tolerance, ε :

$$\left| \frac{x_i^{k+1} - x_i^k}{(x_i^{k+1} + x_i^k)/2} \right| < \varepsilon$$

for i = 1, ..., n. Values of ε can be chosen on a variable-specific basis. Defaults are in the range of 5 percent for the Census Division variables, less for the national macroeconomic variables.

After the convergence criterion has been met, another iteration is performed to test whether a true equilibrium has been reached, and to allow the modules to perform final processing for the year; so that the final converged solution vector for the year is x^{k+1}.

To handle cases where the procedure does not converge on a solution or does not achieve the specified tolerance, a limit on the number of iterations terminates the algorithm for the current year. In such cases, the model performs the additional iteration mentioned in the previous paragraph, reports the convergence status with a list of the variables failing to converge, and then proceeds to the next projection year. The final solution for the year is therefore the result of one iteration beyond the non-converged trial solution.

The equations are partitioned in the fuel supply and sectoral demand modules, with the x_i consisting primarily of quantities and prices of fuels by region and consuming sector. These variables are defined as

$P^k_{f,s,r,y}$ =   Energy product price (current iteration)

$P^{k-1}_{f,s,r,y}$ =   Energy product price (previous iteration)

$Q^k_{f,s,r,y}$ =   Energy product quantity consumed (current iteration)

$Q^{k-1}_{f,s,r,y}$ =   Energy product quantity consumed (previous iteration)

indices:

f fuel/energy product (natural gas, coal, petroleum products, electricity, etc)

s	consuming sector (residential, commercial, industrial, transportation, electric , refinery, synthetic)
r	region (census divisions)
y	year

In several modules, planning decisions must be made to acquire additional capacity which will be required in future years. These include the Electricity Capacity Expansion (ECP) submodule, the Capacity Expansion Module for natural gas, the Oil and Gas Supply module.

In order to make such decisions, information on future demands, prices, and macroeconomic variables such as interest rates must be provided. While each module solves one year at a time, their simulations of planning activities involve an extrapolation of energy market conditions. Those modules making new capacity construction decisions apply an assumption about foresight in their expectations of future energy prices and quantities. In NEMS, a set of price and quantity variables is defined to store expectations:

$XP_{f,s,r,\hat{y}}$	=	Expected prices of energy products beyond the current forecast year (for $\hat{y} > y$)
$XQ_{f,s,r,\hat{y}}$	=	Expected consumption of energy products beyond the current forecast year

The foresight mode determines how the expectation variables are to be calculated: under perfect foresight, the various NEMS modules are invoked for years beyond the current iteration year; otherwise, the Integrating Module calculates minor extrapolations of present-year conditions. Foresight is therefore always calculated by looking forward to the consequences of conditions in the present iteration year, not by attempting to reach some end state determined *a priori*. The treatment of expectations is discussed in greater detail under **Expected Value Foresight**.

Additional variables, representing such values as macroeconomic activity, world oil prices and trade, and emissions, may be added to the convergence algorithm, but are omitted here for clarity. In terms of the energy market interactions, the sectoral demand models estimate current-year energy demands $Q_{f,s,r,y}$ and energy-related capital stock additions as functions of current and expected energy prices. The supply models estimate end-use prices $P_{f,s,r,y}$ and capacity additions as functions of current and expected energy demands. The conversion modules (electricity, refinery, and synthetics) are viewed primarily as supply components, but they are both consumers of primary energy and suppliers of energy products.

Solution Algorithm Flow Chart

Figure 4 presents a detailed flow of the Integrating Module solution algorithm. The objective of the algorithm is to execute the system of component modules repeatedly until convergence is reached. The solution procedure for one iterative cycle involves execution of the component modules, as well as updating expectation variables. The component modules include the International Energy Activity Module, the Macroeconomic Activity Module, the sectoral demand models, the conversion models, and the supply models.

Figure 4. Integrating Module Flow Chart
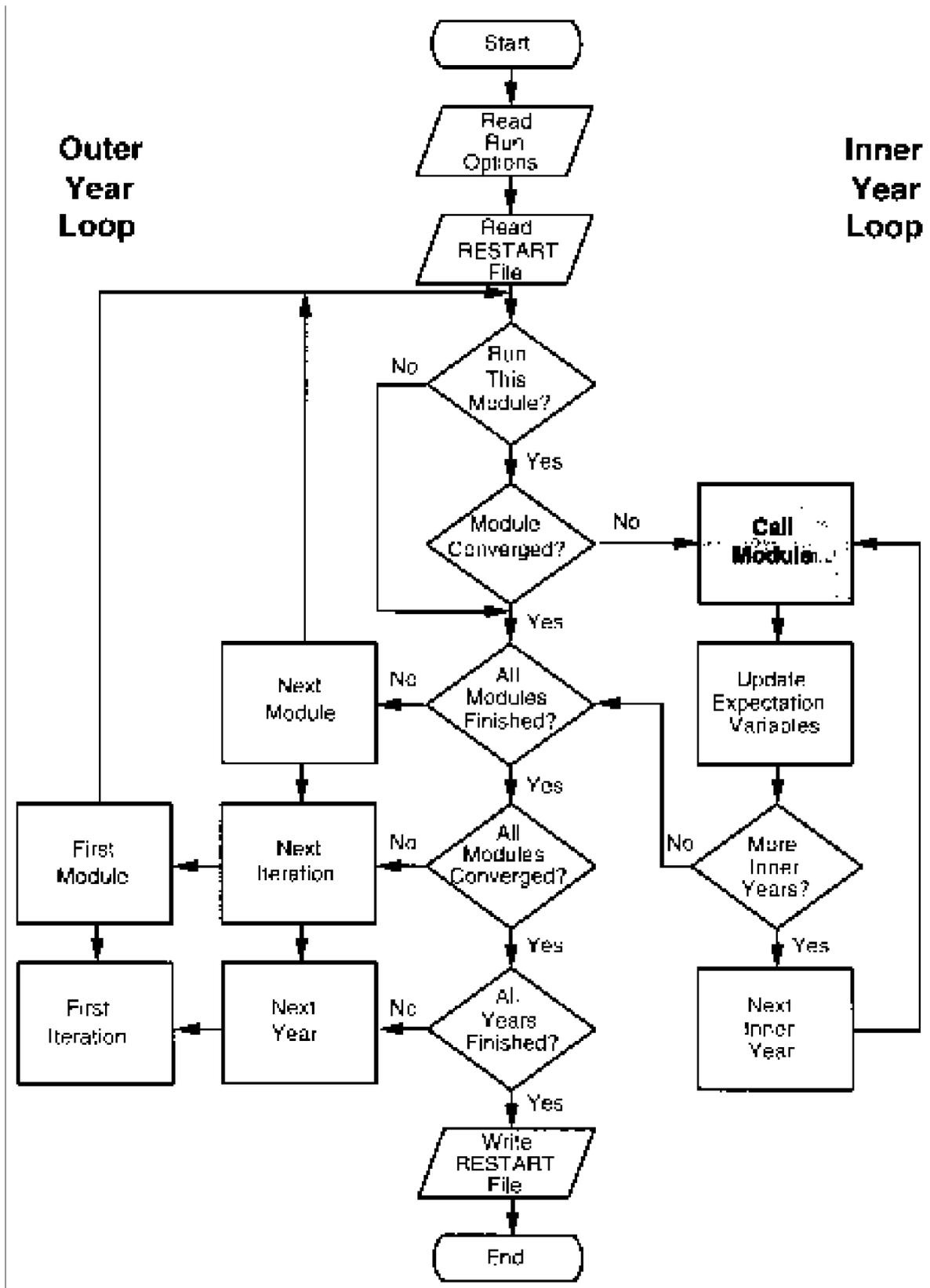
Through program control options, the looping over years takes place either within an iterative cycle (Inner Year Loop) or outside the iterative cycle (Outer Year Loop). That is, component modules may either be called repeatedly to execute for all years in a given iteration, or may be executed one year at a time. The flexible year looping was designed to support different approaches for foresight, as discussed in detail under **Expected Value Foresight** below. However, the looping for all years at a time, for the perfect foresight approach, has never been exercised for the system as a whole and is now considered obsolete. The solution of each module one year at a time is the only solution method in use.

In **Figure 4**, the *Outer Year Loop* is executed once for each year in the forecast horizon when all modules are being executed for one year during each iteration. In that case, the *Inner Year Loop* executes for a single year as well. When modules execute for all years during each iteration, the *Inner Year Loop* controls the year indexing, and the *Outer Year Loop* is entered only once.

To accommodate flexible year looping, the solution procedure for a given iteration begins with the establishment of starting and ending year index ranges for the inner year loop. The next step is to update the expectation variables over the specified inner year range (either a single year or all years):

$XP^k_{f,s,r,y}$ = $f(P^{k-1}_{f,s,r,y})$ (update price expectations from previous iteration prices)

$XQ^k_{f,s,r,y}$ = $f(Q^{k-1}_{f,s,r,y})$ (update quantity expectations from previous iteration quantities)

Next, each of the modules is executed in turn. Normally, for each year in the inner year range, the International Energy Module and the Macroeconomic Module are called first, followed by the sectoral demand models.

$Q^k_{f,s,r,y} = f(P^{k-1}_{f,s,r,y}, XP^k_{f,s,r,y}, $ *macroeconomic, other variables)*

The conversion and supply models are then called, using updated demand quantities, to return prices:

$P^k_{f,s,r,y} = f(Q^k_{f,s,r,y}, XQ^k_{f,s,r,y}, $ *macroeconomic, other variables)*

After all modules have been executed for an inner year, the next inner year is begun. The order of calling the modules is flexible.

Convergence

After a module has been called, a check for convergence for that specific module is made, and the storage of previous iteration values is performed. Modules that had converged on an earlier iteration in the current year are bypassed. These intervening convergence checks isolate the specific modules that are not converging. An additional global convergence check requires all submodules to have converged. A separate convergence check is made for prices and quantities, consisting of a comparison of the absolute value of the percent changes to an assumed tolerance, ε, as follows:

$$\left| \frac{Q^{k}_{f,s,r,y} \quad Q^{k\,1}_{f,s,r,y}}{(Q^{k}_{f,s,r,y} \quad Q^{k\,1}_{f,s,r,y}) \, / \, 2} \right| \; < \; \varepsilon$$

$$\left| \frac{P^{k}_{f,s,r,y} \quad P^{k\,1}_{f,s,r,y}}{(P^{k}_{f,s,r,y} \quad P^{k\,1}_{f,s,r,y}) \, / \, 2} \right| \; < \; \varepsilon$$

Here, the denominators use an average to avoid convergence difficulties if either the starting value or a trial solution value is equal to zero. To avoid unnecessary iterations for changes in insignificant values, the quantity convergence check is omitted for changes less than a user-specified minimum level.

The last step is to store the current quantities and prices for the next iteration's convergence check:

$$Q^{k+1}_{f,s,r,y} = Q^{k}_{f,s,r,y}$$
$$P^{k+1}_{f,s,r,y} = P^{k}_{f,s,r,y}$$

The cycle is repeated until convergence is achieved for all submodules over the specified inner year range or until the maximum number of iterations is reached. When one of these two conditions occurs, an additional iteration, referred to as the "Final Convergence and Reporting Loop" is executed. This has several purposes. First, it is used to test whether a solution meeting the convergence criteria is maintained on two successive iterations. If so, there is a greater likelihood that the solution is an equilibrium solution. Second, it provides a signal for each module to write any reporting data out to disk, thus saving resources on intermediate iterations. Third, it provides a signal to the Integrating Module that all modules are to be executed, even if they had already converged on prior iterations. If the modules fail to converge on the Final Convergence and Reporting Loop, the convergence algorithm is repeated. In such cases, the model may converge on a subsequent iteration, thus triggering the Final Convergence and Reporting Loop a second time.

Once the model completes the Final Convergence and Reporting Loop, or when the maximum number of iterations is reached, the cycle for the current inner year range is completed. If the specified inner year range is only one year, the outer year index is incremented and the algorithm is repeated for the next year.

Whenever a year fails to converge within the user-specified number of iterations, the model completes the Final Convergence and Reporting Loop, accepts the resulting solution as the final solution, and proceeds to the next model year. The unconverged final solution should be examined in detail by the user, to verify its validity. Furthermore, later years' solutions in modules that refer to earlier years' solutions in their formulations can be affected adversely by the data in the unconverged final solution.

A model "execution log" is generated to record the progress of the model as it proceeds from one iteration to the next. The convergence status after execution of each module is reported in the log. Also reported are the names of any variables failing to converge, along with their values on the current and previous iterations, and their fractional changes. If the values of any tested variables fail to converge within the specified number of iterations, a message is written to the execution log, and execution continues with the next year. During or after a model run, the user may review the execution log to examine the convergence status.

When a nonconvergent situation arises, the results of the run must be viewed with caution. An assessment should be made as to the type of convergence problem and its effect on the results. A failure to converge may indicate a programming error, or it may be an accurate reflection of the modeling configuration. Generally, convergence problems must be evaluated on a case-by-case basis.

Other than specifying the run options through the run submission user interface, and substituting modified files containing data upon which the NEMS modules depend, there is no intervention required of the user to ensure a successful model run. The user should examine the execution run log and other output reports to ensure that convergence has been achieved, and that the results are credible. In the case of a problem with convergence, appropriate modules may be "switched off," the allowable number of iterations may be increased, or other such parameters may be adjusted through the user interface and the simulation resubmitted.

Summary of Convergence Problems and Resolution

Integrated developmental testing of NEMS revealed a number of convergence problems. Factors leading to convergence problems were assessed and changes were made as needed to the individual NEMS modules. In a few cases, provisions to pass additional information between modules were required to develop stable convergence properties. Many of the convergence problems involved interactions between the Electricity Market Module (EMM) and the three supply modules providing it with fuel prices: the Natural Gas

Transmission and Distribution Module (NGTDM), the Petroleum Market Module (PMM), and the Coal Market Module (CMM).

The Electricity Fuel Dispatch (EFD), a submodule of the EMM, determines what generating capacity should be running at a particular time to meet the demand for electricity. The type of capacity used (fossil fuel, nuclear, renewables) and the manner in which it is deployed (base load, intermediate load, or peak) determines the fuel demands for the EFD based on a merit-order dispatch simulation. The EFD also simulates the capability of dual-fired plants to switch between natural gas and oil based on relative fuel prices and other operating costs. These modeling characteristics may result in discrete changes in the quantity of fuels required as relative prices change, often leading to convergence oscillations in the natural gas market as depicted in Figures 3a and 3b.

Merit order switching in the electricity market commonly occurred between natural gas and other fuels, between types of coal (graded by sulfur content), and sometimes between types of natural gas (competitive versus firm). Several techniques were used to reduce this effect, depending on the specific cause of the switch. These included incorporating demand curves in the PMM and NGTDM modules, implementing price relaxation in the integrating module, and transferring the calculations of sulfur allowance pricing and coal choices by sulfur content from the EMM to the coal market module.

With the exception of a generic price relaxation algorithm in the Integrating Module (described below under Acceleration Techniques), these convergence problems were addressed through changes in the individual supply and conversion modules of NEMS. Two of these modules (Coal Market Module and the NGTDM) have been re-implemented in recent years, and the documentation of those modules should be consulted for current modeling details (see Appendix A for references).

Acceleration Techniques

The NEMS Integrating Module incorporates a number of features that provide the user some amount of control over the speed with which the equilibration process converges on a final solution. Foremost among such features in terms of accelerating convergence while at the same time increasing the overall robustness of the solution process is a user-controllable feature known as *relaxation*.

As the Integrating Module iteratively directs the energy supply, demand, and other modules to recalculate the energy market data, the calculated prices and quantities can be expected to oscillate about the equilibrium solution as they converge on the supply and demand equilibrium for the current year. If the relaxation option is selected for the run by the user, then these swings from iteration to iteration are dampened by a user-specified factor, which may accelerate convergence and lead to a more stable and robust solution process. Using the notation developed above,

$$x^{k+1} = x^k + r \cdot (x^{k+1} - x^k)$$

where r = relaxation factor.

Another acceleration technique is the selection of the appropriate initial solution. As many runs are simulations of alternative scenarios to a prior run, an appropriate choice of initial solution could speed convergence significantly. At the start of a NEMS run, initial values for all years for all variables in the Global Data Structure, including the energy market data, are read from a user-specified version of the RESTART file. In turn, the final solution for all years at the end of the NEMS run is stored and becomes available for use as the initial solution for subsequent runs.

The choice of restart files may have an affect on the speed of convergence. A restart file provides an initial set of demands and prices for the modules to use as input. In addition, for those modules employing linear programs, the restart file is associated with a set of initial bases. The restart file based on the last iteration of the same year of another run provided the most efficient initial point for the starting iteration.

Expected Value Foresight

Approaches to foresight ($XP_{f,s,r,y}$ and $XQ_{f,s,r,y}$) are important for theoretical and practical reasons. Mid- and long-term energy forecasting involves assessing changes in energy-using capital stocks and choices among energy supply alternatives. This analysis requires simulation of such decisions as the selection of durable appliances, planning electricity-generating capacity additions, and building gas pipelines. The economic evaluation of these decisions requires energy demand and price expectations for life-cycle cost and capacity addition calculations. An objective in this aspect of the modeling is to simulate such decision making in the aggregate for predictive and analytical purposes, representing how players in the energy marketplace make long term planning decisions, rather than by deriving the theoretically optimal long-term expansion path. As a result, the formulation of foresight assumptions is open to alternative approaches based on observed industry practices.

NEMS could, in principle, approach the issue of foresight by prescribing a desirable end state for the energy marketplace, and calculating backwards in time to prescribe how best to arrive there. However, as a simulation, NEMS calculates foresight as an extrapolation of the present state of energy markets, subject to announced policies. Rather than determining how to arrive at the planned future, NEMS can evaluate whether present plans could result in the desired end state.

In reality, different methodologies for treating foresight are used in different sectors and supply areas, and alternate approaches to representing expectations may yield

significantly different planning decisions. Consequently, treatment of foresight becomes an important modeling decision.

There is no one best approach to treating foresight. The National Research Council Committee on NEMS recommended that several options for modeling foresight be developed.[2] As a result, an objective in NEMS was to build the flexibility to support different approaches to foresight to allow for experimentation and future modeling changes. In addition, it is desirable to have the option to treat foresight consistently throughout the modeling system.

The purpose of dealing with foresight and expectations in the Integrating Module is to be able to represent different types of foresight consistently. At the same time the Integrating Module allows individual modules to handle foresight independently, should industry practice require different approaches. To achieve this flexibility, each NEMS module is intended to be constructed so that an on-off switch is examined to determine whether the module uses the system-generated expectations or not. If this central-control switch is turned on, the module uses system expectations; otherwise, the module uses expectations it generates for itself.

The system-generated expectations include several types:

● The "myopic expectations" option is one in which expected prices for any forecast period are assumed to be constant in real dollar terms relative to the current period in which decisions are being made. Generally, this case applies only to expected prices because an assumption of constant energy demands would rarely be assumed.

● "Adaptive expectations," also known as "extrapolative expectations," is an approach that assumes planners extrapolate recent trends when making long-term decisions. For the system-generated expectations, this assumption about foresight is implemented by extrapolating the current projection year prices and quantities using the average annual growth over the previous few projection years. For example, the expectations generated in model year 2000 for use in 2001 would be determined from the growth over the last few model years (e.g., 1998 to 2000), with the number of years being a model option. For expectations generated within individual modules, more elaborate behavioral models, or adaptive expectations, are used.

● The "perfect foresight" approach is based on rational expectations theory. The approach generates an internally consistent scenario for which the formation of expectations is consistent with the projections realized in the model. In practice, perfect foresight describes the configuration and solution algorithm

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[2]National Research Council, *The National Energy Modeling System*, Washington D.C.: National Academy Press, 1992.

that achieves the convergence of expected values and realized values. A variation in the integrating algorithm is required to implement perfect foresight. Instead of solving for an equilibrium for each year, the Integrating Module calls each model for all years of the forecast horizon during each iteration. The objective is to converge across all years simultaneously rather than solving one year at a time. While the perfect foresight algorithm is included in the integrating module, the procedure has never been exercised for the entire system and is considered obsolete.

Among those modules using alternative expectations is the Electricity Market Module (EMM). The EMM requires fuel price expectations for natural gas, oil, and coal for use in its capacity planning submodule. The capacity planning submodule also requires expectations for electricity demand. In the past, algorithms to generate these expectations were implemented in the NEMS integrating model. In recent years, new approaches for electricity demand and coal price expectations have been implemented directly in the EMM model. At present, the oil and natural gas prices expectations for EMM are still implemented in the integrating moduel. The approaches are described below:

- Oil product price expectations are calculated from an external forecast of world oil prices, assuming a constant markup between the regional product price and the world oil price. In each forecast year, the assumed markup is derived from the prior forecast year:

$$P_{c+k} = (P_c - W_c) + W_{c+k} \quad \text{for k=1,...,40}$$

where P_c and W_c are the product price and the exogenous world oil price from the previous forecast year, and P_{c+k} and W_{c+k} are the prices in the expectation years.

- Delivered natural gas prices are derived from expected wellhead prices, assuming a constant markup between the delivered prices and the wellhead price. The wellhead price expectations are based on a nonlinear function which relates the expected wellhead gas price to cumulative domestic gas production. The equation is of the following form:

$$P_k = A * Q_k^e + B \quad,$$

where P is the wellhead price, Q is the cumulative production from 1991 to year "k", "e" is a user-specified parameter, and "A" and "B" are determined each year, as explained below.

The approach was developed to have the following properties:

— Prices should be upward sloping as a function of cumulative gas production.

— The rate of change in wellhead prices is a function of the economical reserves that remain to be discovered and produced. The value of the parameter e determines the shape of the function.

The approach assumes that at some point in the future a given target price, PF, results when cumulative gas production reaches a given level, QF. Thus, the target values PF and QF are assumed inputs to the approach. In the Annual Energy Outlook 2001, the assumed value of PF was $6.50/mcf (1998 dollars), corresponding to a cumulative production (QF) of 2000 tcf. For simplicity, the annual production is assumed to be constant at the prior year's level. The parameters of the price equation, A and B, are determined each projection year such that the price equation will intersect the future target point. That is:

let D = Last year's gas production
let PS = Last year's wellhead gas price
let QS = Last year's cumulative gas production since 1991

$A = (PF - PS) / (QF^e - QS^e)$
$B = PF - A*QF^e$

Extrapolate cumulative production for future years k= 1,...40:

$Q_k = Q_{k-1} + D$

Generate expected well-head prices:

$P_k = A*Q_k^e + B$

For example, the calculation of price expectations generated in 2005 in the reference case run used the following values for variables above:

D	20.65	Gas production estimated for prior year, 2004, tcf
QS	264.30	Cumulative gas production, 1991 through 2004, tcf
PS	2.40	Gas price estimated for prior year, 2004, 1998 $/mcf
QF	2000.00	Cumulative gas production through some point in the future
PF	6.50	Gas price when QF is reached
e	0.70	Exponent on cumulative production
Q_{2005}	285.00	Cumulative gas production, 2005, tcf

Parameters A and B were calculated as 0.265 and 1.082, respectively. Thus, the expected price equation for 2005-on becomes:

$P_k = .265(Q_k^{0.70}) + 1.082$
with $P_{2005} = 2.47$ (98$/mcf).

When cumulative gas production reaches 636 tcf in 2022, the price equations yields:

$$P_{2022} = .265 (636^{0.7}) + 1.082$$
$$= 3.52$$

For the *Annual Energy Outlook 2001*, the approach was modified such that one value of the parameter "e" (0.7) would apply until future natural gas prices reached a given trigger price, assumed to be $3.50/mcf (1998 dollars). When expected prices exceeded that trigger, representing the price at which unconventional gas sources would become economical, a second value for e (1.3) was implemented. In the 2005 example above, such a price is reached in 2022. Thus, the approach generates an initial price trajectory that is "concave down" through 2022, and a subsequent trajectory that is "concave up" with respect to cumulative gas production (See Figure 5).

Figure 5. Example of natural gas price expectations, 2005
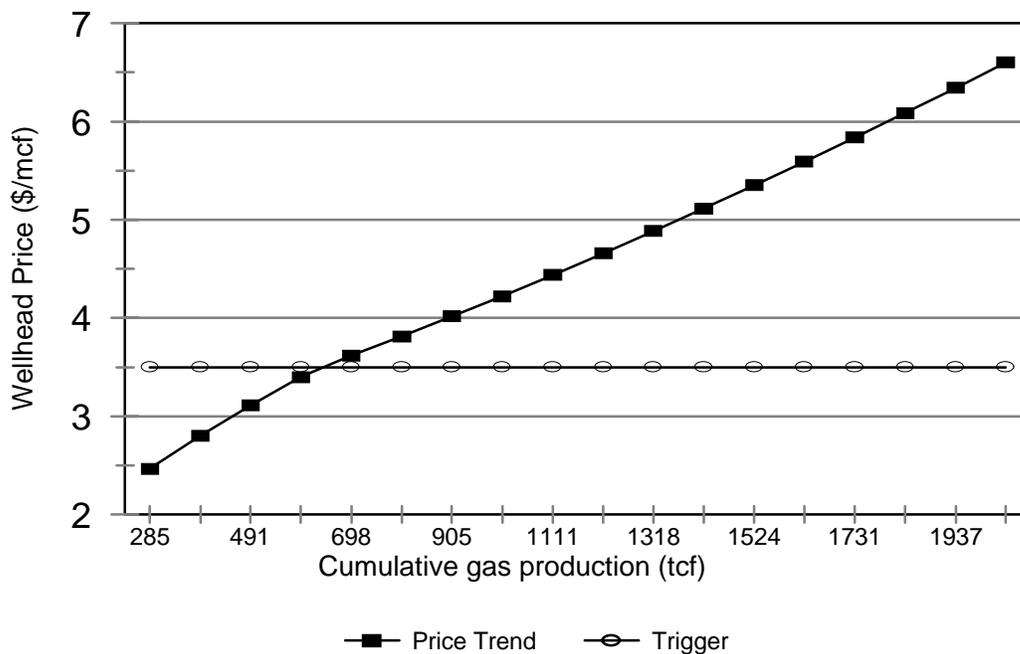
Carbon Dioxide and Methane Emission Calculations

The Integrating Module estimates carbon dioxide and methane emissions associated with the use of energy. Projections of energy-related methane emissions were added to NEMS for the *Annual Energy Outlook 2001*. Based on global warming potential, carbon dioxide is the largest contributor to man-made greenhouse gas emissions, accounting for approximately 83 percent of the emissions in the United States. Methane is the second largest source of man-made greenhouse gas emissions, with an estimated 9 percent share. Some 98 percent of the carbon dioxide emissions are attributed to energy use, while 37 percent of methane emissions arise from the production and use of energy.

Other sources of man-made methane emissions are agriculture, waste management, and industrial processes.

Carbon Dioxide Emissions

Carbon dioxide emissions are dependent on the carbon content of the fuel and the fraction of the fuel consumed in combustion. The product of the carbon dioxide coefficient and the combustion fraction yields a carbon dioxide emission factor. The emissions factors are expressed in millions of metric tons of carbon emitted per quadrillion Btu of energy use, or equivalently, in kilograms of carbon per million Btu.

For fuel uses of energy, the combustion fractions are assumed to be .99 for liquid fuels and .995 for gaseous fuels. The carbon dioxide potential in nonfuel use of energy, such as for asphalt and petrochemical feedstocks, is assumed to be sequestered in the product and not released to the atmosphere. For energy categories that are mixes of fuel and nonfuel uses, the combustion fractions are based on the proportion of fuel use.

Table 6 presents the carbon dioxide coefficients, combustion fractions, and emission fractions for 1999. The adjusted emission factors are input into the emission policy submodule through a file ("epmdata"). Because some of the factors have varied over time, factors for recent history years in NEMS are entered separately. Factors for the last available year, 1999, apply for all projection years.

Any carbon dioxide emitted by renewable sources is considered balanced by the carbon dioxide sequestration that occurred in its creation. Therefore, following convention, net emissions of carbon dioxide from renewable sources is taken as zero, and no emission coefficient is reported. Renewable fuels include hydroelectric power, biomass, photovoltaic, geothermal, ethanol, and wind energy.

Table 6. Carbon Dioxide Emissions Factors (Kilograms-carbon per million Btu)

Fuel Type	Carbon dioxide Coefficient at Full Combustion	Combustion Fraction	Adjusted Emissions Factor (Model Input)
Petroleum			
Motor Gasoline	19.33	0.990	19.17
Liquefied Petroleum Gas			
Used as Fuel	17.18	0.995	17.09
Used as Feedstock	16.88	0.200	3.38
Jet Fuel	19.33	0.990	19.14
Distillate Fuel	19.95	0.990	19.75
Residual Fuel	21.49	0.990	21.28
Asphalt and Road Oil	20.62	0.000	0.00
Lubricants	20.24	0.600	12.14
Petrochemical Feedstock	19.37	0.200	3.87
Kerosene	19.72	0.990	19.52
Petroleum Coke	27.85	0.500	13.93
Petroleum Still Gas	17.51	0.995	17.42
Other Industrial	20.31	0.990	20.11
Coal			
Residential and Commercial . .	26.00	0.990	25.74
Metallurgical	25.56	0.990	25.30
Industrial Other	25.63	0.990	25.38
Electric	25.76	0.990	25.50
Natural Gas			
Used as Fuel	14.47	0.995	14.40
Used as Feedstock	14.47	0.774	11.20

Source: Energy Information Administration, (EIA) Emissions of Greenhouse Gases in the United States 1999, DOE/EIA-0573(99) (Washington, DC, October 2000).

Several adjustments to the carbon dioxide calculations are made in the industrial, transportation, and electricity generation sectors, as follows.

Industrial: The use of fossil fuels for non-fuel use of certain end-use products such as feedstocks for chemical production causes a significant amount of the carbon dioxide potential to be sequestered in the product. The amount of carbon dioxide sequestered depends on product characteristics that are not defined explicitly in NEMS. Following EIA's practice, an average sequestration fraction is used for each nonfuel use. In the Industrial Module, the two major feedstocks are liquified petroleum gases (LPG) and natural gas. Consumption of these fuels is divided into feedstock and combustion categories. For the feedstock uses, an appropriate sequestration rate is applied to account for the average proportion of carbon dioxide sequestered among products in this category. "Other" petroleum products consist of lubricants and miscellaneous petroleum products.

Transportation: The total consumption of motor gasoline reported by the Transportation Module includes both gasoline, gasoline-ethanol mixtures, and gasoline containing oxygenates with ethanol precursors. Since ethanol is considered a renewable fuel with zero net carbon dioxide emissions, the total consumption of motor gasoline was reduced by the amount of ethanol used in its production before multiplication by the emission coefficient. This modification represents less than one million metric tons carbon equivalent of carbon dioxide. Furthermore, since "other" petroleum was considered primarily lubricants, the emission coefficient and sequestration rate for lubricants was used for all of "other" petroleum.

Electricity Generation Market: Carbon dioxide emissions for coal are computed for each of seven categories of coal, as determined in the Electricity Market Module and Coal Market Module. The carbon dioxide emissions factors each coal category are provided by the Coal Market Module. This methodology incorporates changes in the mix of coal types used over time.

Methane Emissions

Methane emissions from energy-related activities occur as methane is released in various stages of the production and transportation of coal, oil, and natural gas. Additional emissions occur as a result of incomplete combustion of fossil fuels and wood.

The methodology for estimating methane emissions in NEMS follows the accounting procedures used in EIA's annual report, *Emissions of Greenhouse Gases in the United States*, and relies heavily on the data sources used for that report (see the on-line Appendix A, at http://www.eia.doe.gov/oiaf/1605/ggrpt/appendixa.html#meth, for background on the methane emissions calculations.) Those data sources include the Environmental Protection Agency's greenhouse gas studies and data publications, the Mine Safety and Health Administration, and reporting guidelines specified by the United Nation's Intergovernmental Panel on Climate Change (IPCC). In NEMS, some of the methane emissions calculations are simplified or recast such that emissions can be estimated as a function of endogenous energy production or consumption variables. This was necessary because NEMS does not represent certain energy industry characteristics, such as pipeline mileage by type, that would be needed to apply the full methodology used in EIA's emissions report. As a result, the methane emission calculations in NEMS will not necessarily capture technological changes in the energy industry that could be adopted to reduce methane emissions. Instead, they are best considered as indicators of emissions if current emission rates and trends continue, with somewhat limited potential for policy analysis.

Coal-Related Methane Emissions

Methane is found with coal in varying concentrations. Higher concentrations occur in deep mines; less in surface mines. Accordingly, methane emissions for underground and surface mining are calculated separately. Most emissions from underground mining occur from ventilation and degasification systems, with some offset from methane recovery systems. Post-mining emissions are also included for both underground- and surface-mined coal. Table 7 provides the emission factor assumptions used to project emissions as a function of coal production, with breakouts based on the

following classifications:

Underground Mining: In underground mining, methane ventilation is usually required for safety. Those underground mines requiring ventilation are referred to as "gassy," while underground mines not requiring ventilation are referred to as "nongassy." Methane emissions at gassy mines are based on reported data on mine ventilation as regulated by the Mine Safety and Health Administration. Regional emissions factors are derived based on recent coal production at the mines, aggregated to five coal supply regions (or basins). Emissions factors at nongassy mines are based on a study indicating emissions from nongassy mines are about two percent of the total underground mining emissions.   The regional splits between gassy vs. nongassy mine production at underground mines are assumed to remain constant over the projection period.

Degasification: Another source of methane emissions is the degasification of coal seams, also associated with underground mining. Degasification is employed where the methane concentrations are too high for standard ventilation techniques. Emissions factors for this methane source were derived from EPA estimates of emissions and the amount of regional coal production at mines with degasification systems. These emission factors, along with the fraction of production from the mines on a regional basis, are assumed to remain constant over the projection period.

Methane recovery: In some cases, methane from degasification of coal mines is captured and burned locally or provided to the natural gas industry. Methane recovery from coal mining is subtracted as on offset to emissions. The projected coal-bed methane recovery is exogenous and based on assumed recovery projects obtained from the NEMS oil and gas supply module. Methane recovery from waste sites is not considered an energy-related offset; it is instead accounted for under waste management by IPCC convention.

Surface Mining: Methane emitted from surface-mined coal is a relatively small share of the total coal-related methane emissions.   The methane emissions factor for surface-mined coal is taken as a constant in NEMS.

Post-Mining: Post-mining emissions of methane occur during coal transportation, handling, and processing. The emission factor is higher for underground-mined coal than surface-mined coal due to the higher methane content.

Table 7. Coal-Related Methane Assumptions

	Northern Appalachia	Central Appalachia	Southern Appalachia	Eastern Interior	Western
Fraction of underground coal production at:					
Gassy mines	0.885	0.368	0.971	0.876	0.681
Nongassy mines	0.115	0.632	0.029	0.124	0.319
Production from mines with degasification systems (fraction of underground coal production)	0.541	0.074	0.810	0.067	0.056
Emission factors (kilograms methane per short ton of coal produced)					
Underground Mining					
Gassy Mines	6.047	5.641	27.346	2.988	6.027
Nongassy Mines	0.362	0.076	15.959	0.285	0.245
Degasified Mines	4.085	37.724	22.025	0.310	0.000
Surface Mining	0.706	0.706	0.706	0.706	0.706
Post-Mining, underground-mined	1.505	1.505	1.505	1.505	1.506
Post-Mining, surface-mined	0.061	0.061	0.061	0.061	0.061

Methane recovery at active coal mines (million metric tons carbon equivalent)	United States
1999	5.842
2000	5.908
2005	6.250
2010	6.613
2015	6.996
2020	7.401

Source: Compiled in May 2000 from the data system used to compile *Emissions of Greenhouse Gases in the United States 1998*, DOE/EIA-0573(98), (Washington, DC, October 1999). The current version of this report can be found at http://www.eia.doe.gov/oiaf/1605/ggrpt/index.html.

Oil and Gas Industry Methane Emissions

As the primary constituent of natural gas, methane escapes or is vented in the course of natural gas production and transportation. Emissions from these sources are grouped into four classes: production, processing, transmission and storage, and distribution. Methane emissions also occur as a result of crude oil exploration and development, and to a smaller extent, during oil transporation and refining. Methane emissions from this source is treated as a single class in NEMS. In its annual report, *Emissions of Greenhouse Gases in the United States*, EIA develops emission estimates from detailed EPA studies of emissions in the natural gas and oil industries. EPA estimated methane emissions factors as functions of activity indicators, such as number of wells in operation, miles of

gathering pipeline, gas throughput, gas volumes processed, miles of transmission pipeline and miles of distribution pipeline. The activity data are multiplied by emissions factors derived from point-in-time emissions to develop the annual series of emissions. Because NEMS does not represent most of these activity indicators in its projections, it was not feasible to extend EPA's emissions methodology directly in NEMS.

Instead, a set of linear relationships was developed to relate emissions in each of the five industry classes (four natural gas classes and a class for oil production) to one or two NEMS endogenous variables. These relationships were estimated using the 1981 to 1997 annual emissions (1980 and 1998 observations used where available). The estimated coefficients of these equations are summarized in Table 8, along with the r-squared and t-statistics obtained. The times series data used for the equations are provided in Tables 9 (dependent variables) and 10 (independent variables). As indicated in Table 8, two of the equations, natural gas production and natural gas distribution, were fitted with a time variable to capture trends in the activity data. The positive coefficients reflect increasing emissions of methane resulting from such factors as increased development of small-volume wells and increasing share of distribution pipeline mileage.

A benchmarking adjustment to these equations is used to calibrate to the last year of history data, which became available after the equations were estimated. A benchmark factor, equal to the ratio of the actual and estimated emissions in 1999, is applied throughout the forecast period.

Table 8. Estimation of Linear Equations for Natural Gas- and Oil-Related Methane Emissions

Emissions Source (million metric tons CH4)	R-Squared	Intercept (and T-Stat)	Variable 1 Name and Units	Variable 1 Coefficient (and T-Stat)	Variable 2 Name and Units	Variable 2 Coefficient (and T-Stat)
Natural Gas Production	.984	-38.77 (-26.57)	Time Trend (calendar year)	0.02003 (26.86)	Dry gas Production (thousand cubic feet)	0.02186 (5.47)
Natural Gas Processsing	.694	-0.9454 (-3.67)	Natural gas liquids production (million barrels per day)	0.9350 (6.03)	Not applicable	Not applicable
Natural Gas Transmission and Storage	.380	2.503 (6.55)	Pipeline fuel use (thousand cubic feet)	1.249 (2.92)	Dry gas Production (thousand cubic feet)	-0.06614 (-2.04)
Natural Gas Distribution	.973	-58.16 (14.58)	Time Trend (calendar year)	0.0297 (14.5)	Natural Gas Consumption (quadrillion Btu)	.0196 (3.13)
Oil Production, Refining, and Transport	.846	0.0319 (3.26)	Oil Consumption (quadrillion Btu)	.002764 (9.39)	Not applicable	Not applicable

Source: EIA, Office of Integrated Analysis and Forecasting

Table 9. Summary of Data Used for Methane Emission Regressions, Independent Variables

| | Methane Emissions by Class Million metric tons CH4 | | | | |
| | Natural Gas | | | | Oil |
	Production	Processing	Transmission and Storage	Distribution	Production, Refining, and Transport
1980	1.2905	n/a	1.9581	1.0507	0.1208
1981	1.3191	0.5532	1.9717	1.0630	0.1163
1982	1.3011	0.5289	2.0241	1.0819	0.1133
1983	1.2679	0.4919	2.0442	1.0951	0.1143
1984	1.3522	0.5208	2.0198	1.1054	0.1177
1985	1.3462	0.5017	2.0714	1.1306	0.1193
1986	1.3292	0.4835	1.9665	1.1545	0.1229
1987	1.3803	0.4808	1.9963	1.1755	0.1235
1988	1.4257	0.4778	2.0747	1.2012	0.1267
1989	1.4492	0.4784	2.1862	1.2279	0.1266
1990	1.4684	0.6457	2.0981	1.3630	0.1262
1991	1.4899	0.7058	2.2148	1.3857	0.1261
1992	1.4923	0.6982	2.2346	1.4360	0.1258
1993	1.5130	0.7112	2.1478	1.4756	0.1267
1994	1.5492	0.7067	2.1093	1.4938	0.1282
1995	1.5677	0.7172	2.1446	1.5217	0.1283
1996	1.5786	0.7347	2.1102	1.5469	0.1297
1997	1.6530	0.7147	2.2023	1.5516	0.1326
1998	1.6697	0.7041	n/a	n/a	n/a

Source: EIA, Office of Integrated Analysis and Forecasting, data system used to compile *Emissions of Greenhouse Gases in the United States 1998*, DOE/EIA-0573(98), (Washington, DC, October 1999). Note: data compiled in May 2000 prior to availability of the October 2000 report data.

Table 10. Summary of Data Used for Methane Emission Regressions, Dependent Variables

	Dry Gas Production (tcf)	Natural Gas Liquids Production mil. barrels/day	Pipeline Fuel Use (tcf)	Natural Gas Consumption (quadrillion Btu)	Oil Consumption (quadrillion Btu)
1980	19.4031	n/ap	0.6346	19.8773	34.2024
1981	19.1813	1.6074	0.6423	19.4039	31.9310
1982	17.8201	1.5493	0.5964	18.0011	30.2316
1983	16.0945	1.5576	0.4900	16.8349	30.0539
1984	17.4665	1.6331	0.5288	17.9505	31.0513
1985	16.4539	1.6081	0.5038	17.2809	30.9222
1986	16.0590	1.5496	0.4850	16.2213	32.1961
1987	16.6206	1.5942	0.5192	17.2108	32.8651
1988	17.1026	1.6282	0.6139	18.0296	34.2220
1989	17.3106	1.5445	0.6293	18.8008	34.2111
1990	17.8097	1.5578	0.6598	18.7163	33.5525
1991	17.6978	1.6582	0.6013	19.0352	32.8454
1992	17.8399	1.7007	0.5877	19.5444	33.5266
1993	18.0955	1.7345	0.6243	20.2791	33.8415
1994	18.8210	1.7254	0.6854	20.7077	34.7349
1995	18.5987	1.7610	0.7003	21.5807	34.6634
1996	18.7926	1.8339	0.7114	21.9666	35.8641
1997	18.9023	1.8159	0.7516	21.9722	36.3812
1998	18.9773	1.7520	n/ap	n/ap	n/ap

Source: EIA, Annual Energy Review 1998, DOE/EIA-0384(98) (Washington, DC, July 1999), and compiled May

2000. For most current version of this data, see http://www.eia.doe.gov/aer.

Methane Emissions Factors for Energy Combustion

Methane emissions related to energy combustion are a small share of total methane emissions. Methane emissions from fuel use are the result of incomplete combustion of the fuel. For stationary sources, a disproportionate share of these emissions occur with residential wood burning, as wood stoves and fireplaces are relatively inefficient combustors. In transportation, methane emission factors vary depending on the class of vehicle. In passenger cars, methane emissions depend on the type of catalytic converter and, thus, the vintage of the automobile stock. For simplicity, the integrating module calculates methane emissions for mobile sources using constant emission rates for each vehicle class (Table 11).

Table 11. Methane Emissions Factors for Energy Combustion (metric tons carbon equivalent per trillion Btu)

Stationary Combustion: by Fuel	Residential	Commercial	Industrial	Electricity
Coal	3.30	57.59	13.82	3.46
Residual Fuel	n/ap	9.21	16.70	4.03
Distillate Fuel	28.80	3.46	0.93	0.00
Natural Gas	5.50	6.60	7l.70	0.55
Liquid Gases	6.64	6.64	7.88	n/ap
Wood	5050.13	16.83	15.32	n/ap

Mobile Combustion: by Vehicle Class	Transportation
Passenger Cars	82.87
Buses	43.02
Motorcycles	1094.15
Light-Duty Trucks	65.45
Other Trucks	22.04

Emissions Policy Submodule

The Emissions Policy Submodule (EPM) implements four carbon dioxide policy evaluation options. None of the policy options are assumed to take place in runs for the *Annual Energy Outlook 2001*. However, the options could be used to simulate potential market-based approaches to meet National carbon dioxide emission objectives. The four policy options are as follows:

1) <u>Carbon Dioxide Tax</u>. A nominal or real dollar tax per kilogram of carbon for fossil fuels is

converted to a dollar-per-Btu tax for each fuel/sector based on the carbon dioxide emission factor.[3] A different tax may be set for each year. Fossil fuel prices are adjusted to include the tax. The demand and conversion models respond to the adjusted fossil fuel prices to induce carbon dioxide emissions reductions. Revenue from the tax is passed to the macroeconomic module. There, treatment of such revenue (e.g., reducing the deficit or reducing other taxes), depends on option settings in the macroeconomic module. Generally, large changes in government revenue would require additional offline analysis to assess macroeconomic feedbacks.

2) <u>Auction of Permits</u>. An auction to distribute emissions permits is simulated. The total number of permits sold corresponds to the total carbon dioxide emission goal as set by the user. A different goal may be set for each year. Essentially, this option determines the permit fee necessary to achieve the carbon dioxide goal by clearing the auction market. The permit fee is treated as a carbon dioxide emissions tax and used as an adjustment to the fossil fuel prices. A new auction price is set each NEMS iteration until the emissions reach the goal. The permit auction is assumed to operate with no initial allocation of emission permits. As in Option 1, Carbon Dioxide Tax, revenue from the auction is passed to the macroeconomic module where its effect may require additional analysis.

3) <u>Market For Permits</u>. A market for tradable carbon dioxide 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 dioxide tax and auction options, the full market price of the permits is added to the energy prices on a dollar-per-Btu basis. 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 dioxide 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 dioxide emission by a particular sector in a region will be reflected in the individual end-use fuel cost for that sector.

The evaluation of the initial distribution of permits depends on the sector. For those sectors in which the product prices are based on marginal cost, as modeled in the Petroleum Marketing Module, the value of the initial distribution of permits may be ignored; it does not affect the price of products. However, in the regulated electricity sector, where the average cost is used to determine price, the revenue attributed to the free use or sales of the initially distributed permits would possibly be passed through to the consumers. The value of the initial distribution of permits is calculated, but it is not used for electricity pricing purposes. Instead, the full cost of the permits, as though there were no initial distribution, is reflected in the electricity price.

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[3]A single tax rate applies to all categories of carbon dioxide. A switch in the control file allows the tax rate to be treated as either a carbon dioxide tax ($ per kilogram carbon) or as a Btu tax ($ per million Btu). This flexibility allows the emissions policy module to be used to analyze simple energy tax policies as well.

As with the auction, a new permit fee is set each iteration. The fee is adjusted once each iteration in response to the total carbon dioxide emissions obtained. The price of an allowance is adjusted until the total carbon dioxide produced is within a tolerance of the goal for that year.

4) <u>Market for Permits with Emission Offsets</u>. The offset option allows for the goal on tradeable emissions permits to increase through a user-specified supply of offsets. Part of a greenhouse gas emission reduction strategy may be an offset policy. An offset policy gives credit to reductions in emissions from sources whose total emissions would be difficult to quantify precisely, such as the capture of coal bed methane. Offsets could also be available from activities like reforestation, to reflect the increase in carbon dioxide sequestration. The amount of offsets for reforestation and coal bed methane capture must be specified at various permit prices; the higher the price, the greater the assumed offsets. The offset, in millions of tons available at a given allowance price, is added to the carbon dioxide goal . While some test values for offsets are available, any formal use of this option would require additional research to arrive at appropriate assumptions. Another possible use of this option would be to simulate the availability of international carbon dioxide emission allowances at various prices.

Emissions Policy Submodule Implementation and Mathematical Specification

The Emissions Policy Submodule (EPM) is called at the end of each NEMS iteration, after all the other modules have been called. With all four of the EPM options, some form of energy price adjustment is calculated to account for the carbon dioxide tax, or permit fee, for the next iteration. The carbon dioxide fee is either fixed (for a straight carbon dioxide tax) or is varied each NEMS iteration until a carbon dioxide goal is met (for the permit auction and permit market options).

The fee on carbon dioxide emissions is modeled as an adjustment on the end-use price of the fuel. Two sets of end-use price variables are maintained in NEMS: an *unadjusted* set of prices without any carbon dioxide fee added, and an *adjusted* set of prices that includes the carbon dioxide fee. The *unadjusted* prices are those determined by the NEMS supply and conversion modules. The *adjusted* prices, with the carbon dioxide fee included, are the prices variables actually used by the demand models. In the integrating module, after each module is executed, the adjusted fuel prices are reassigned based on the current carbon dioxide fee.

Input-Output Linkages

The input data for EPM comes primarily from other modules of NEMS. The only other exogenous data are the policy options to be implemented and the carbon dioxide emissions factors. If a carbon dioxide tax scenario is to be implemented, the tax rate must also be specified. Alternatively, a carbon dioxide goal may be specified, and the carbon dioxide tax to meet that goal will be set in the EPM once each iteration of the NEMS solution algorithm. Output from the EPM consists of adjustments of the end-use prices of fuels consumed by the demand and conversion modules. The adjustments are additions to prices in dollars per million Btu. Revenue, in billions, from the carbon dioxide penalty is also calculated, where it can be used by the Macroeconomic module or for offline

analysis of macroeconomic feedbacks.

The EPM inputs and outputs are stored in the NEMS global data structure. As input, three common blocks contain the NEMS end-use fuel prices: MPBLK, NGTDMOUT and COALPRC. These prices, established in the NEMS supply and conversion modules, are the input prices to the EPM. As output, EPM determines a dollar-per-Btu adjustment to each product-sector price to reflect any carbon dioxide tax or allowance fee. EPM adds the adjustment to the NEMS end-use fuel prices and stores them in a parellel set of price common blocks: AMPBLK, ANGTDM, and ACOALPRC.   When no carbon dioxide policy options are in effect, the adjusted price common blocks (AMPBLK, ANGTDM, ACOALPRC) match the unadjusted price common blocks from the supply modules (MPBLK, NGTDMOUT, and COALPRC). The energy price adjustments, equal to the difference between the two sets of prices, are stored in the EMABLK common block.   If nonzero, these prices adjustments are used as starting values when either of the carbon dioxide goal options (auction or permit market) are in effect.

The total carbon dioxide emission from both combustion and non-combustion sources is calculated in the EPM from information in the common blocks QBLK, INDOUT, EMMOUT, and COALEMM. The common QBLK contains the quantities of end-use fuels consumed. In QBLK, feedstock uses of liquid gas and natural gas are not broken out separately from total industrial liquid gas and natural gas, respectively. The feedstock portion of these fuels is obtained from two variables, INQLGPF and INQNGPF, in the common block INDOUT. The EMMOUT common has natural gas consumption reported by EMM region for firm, interruptible, and competitive categories. The COALEMM block contains coal consumption by SO2 classification category and emissions factors for coal aggregated to those same categories. Several policy options result in revenue from the carbon dioxide penalty flowing to the government. This revenue is furnished to the MACRO module through the EMISSION common block.

Emissions Policy Submodule Algorithm

The EPM is executed once each iteration to determine total carbon dioxide emissions produced, the revenue created by any tax or permit fees for carbon dioxide emissions, and, depending upon the scenario, the level of offsets produced. For the carbon dioxide goal policy options, a heuristic algorithm (subroutine REGFALSI) sets a new carbon dioxide fee to bring the carbon dioxide emissions closer to the carbon dioxide goal.

The following outline depicts the steps in the submodule flow, showing subroutine calls and variable names in parentheses.

I.   First Year, First Iteration Processing

     A. Read control file, "epmcntl," to get settings for the four policy options
       (TAX_FLAG, PERMIT_FLAG, MARKET_FLAG, OFFSET_FLAG)
     B. Read emissions policy data file "epmdata" (Call EPM_READ).

1) Read yearly arrays with the emission tax (EMTAX), carbon dioxide goal (EMISSIONS_GOAL), and maximum tax (MAX_TAX).
2) Read coal region mapping variable (obsolete).
3) Read yearly arrays with emission factors for each fuel/sector product (variable names are the same as the corresponding NEMS energy consumption variables but start with "E" instead of "Q").
4) Read supply curve prices, quantities for reforestation offsets (PREF, OFFSETREF).
5) Read supply curve prices and quantities for coal bed methane offsets (PCB, OFFSETCB).

II.   Calculate carbon dioxide emissions and sum to a national total (Call SUM_EMISSIONS).

III.   Calculate revenues from carbon dioxide tax or carbon dioxide permit fees (Call ACCNTREV).

IV.   Under a market permit system, allocate revenue to end-use sectors based on initial sector shares of carbon dioxide emissions (Call INITREV).

V.   Under a market permit system with offsets, determine what level of emission offsets are available to raise the carbon dioxide cap, given the current carbon dioxide tax (Call OFFSETS).

VI.   With a permit auction or market, assign a new carbon dioxide tax to reduce the absolute difference between the carbon dioxide emissions and the carbon dioxide goal (Call REGFALSI)

VII.   Calculate energy price adjustments of end-use fuels from the carbon dioxide tax by multiplying the carbon dioxide tax by the fuels' emission factors (Call PRICE_ADJUST).

VIII.   After every NEMS module called, reassign the adjusted prices by adding the carbon dioxide tax price adjustments to the unadjusted prices (Call COPY_ADJUST).

Emission Policy Submodule Mathematical Specification

The following subroutine descriptions provide the mathematical specifications for these calculations.

SUBROUTINE EPM

This subroutine is the main controlling subroutine for the Emissions Policy Submodule. Initially, the subroutine reads flags to determine the scenario type: carbon dioxide tax, auction of permits, market for permits, and permit market with offsets. Based on these flags, the module calls the appropriate subroutines. For all options, carbon dioxide emissions are estimated (SUM_EMISSIONS), and the revenue from any carbon dioxide fee, regardless of whether it is from a carbon dioxide tax, auction, or permit trading policy is calculated (ACCNTREV). For the permit trading policy, a routine is called to distribute an initial allocation of the revenues, equivalent to distributing "free" permits to the consuming sectors in proportion to their base year carbon dioxide emissions (INITREV). For an auction or permit market policy, a new permit fee is established each NEMS iteration, such that the emissions goal is met within a given tolerance level (REGFALSI). For the carbon dioxide emissions offset option, the offsets that would be created at the previous market clearing price are added to the emissions goal (OFFSETS).

Called by: Integrating Module, Subroutine NSOLVE

Calls: EPM_READ
                SUM_EMISSIONS
                ACCNTREV
                INITREV
                REGFALSI
                OFFSETS
                PRICE_ADJUST

Equations: None.

SUBROUTINE SUM_EMISSIONS

Description: This subroutines calculates carbon dioxide emissions by sector and
returns to national total, AMTPOL. Carbon dioxide emissions are
the product of end use fuel consumption and the corresponding
emissions factor. The emissions are aggregated by Census region
and sector. The variables for fuel quantities are defined in the
common blocks QBLK and EMMOUT.

Called by: EPM

Calls: None

Equations:

$$AMTPOL \sum_i \sum_j \sum_k Em(ik) \; Qf(ijk)$$

where

AMTPOL =   Total carbon dioxide emissions from all fuel i (billion
kilogram-carbon) from all regions j in year k,
Em(ik) =   Carbon dioxide emission factor for fuel i (kilogram-
carbon /million-Btu) in year k,
Qf(ijk) =   Quantity of fuel i consumed (trillion-Btu) in region j
and year k.

SUBROUTINE ACCNTREV

Description: This subroutine calculates the total revenue raised from each sector by the emissions fee (tax or permit fee). Revenue is calculated by multiplying the quantity of end-use fuel consumption by an emissions factor and the emissions fee.

Called by: EPM

Calls: None

Equations:

$$REV(l) \quad \sum_{i \subset l} \sum_{j} \sum_{k} EMTAX(k) Em(ik) Qf(ijk)/1000$$

where

REV(l) = Total revenue collected in sector l from all fuel i from all regions j and in year k (Billion 1987 $),

Em(ik) = Emission factor for fuel i (kilograms-carbon /million-Btu) in year k,

EMTAX(k) = Carbon dioxide tax or permit fee (87$/kilogram carbon) in year k

Qf(ijk) = Quantity of fuel i consumed in region j and year k (trillion- Btu)

SUBROUTINE INITREV

Description: If a marketable permit system is being modeled, a given number of permits will be distributed initially to the affected sources. This subroutine calculates the value of this initial allocation of permits by multiplying the number of permits by the carbon dioxide permit fee.

Called by: EPM

Calls: None.

Equations:

$$CallocInit \quad Sallocinit \quad Palloc$$

where

CallocInit =   Total value of initial allocation of permits (billion 1987 $),

SallocInit =   Permits allocated initially (billion kilograms-carbon)

Palloc   =   Price of a permit (87$/kilograms-carbon).

SUBROUTINE OFFSETS

Description: Offsets may be used to credit reductions in greenhouse gas emissions against the emissions goal. This subroutine uses linear interpolation to determine from an ordered price schedule, or offset supply curve, the offsets that would be made available at a particular permit price.

Called by: EPM

Calls: none

$$OFFST \quad OFFSET(I) \quad \frac{OFFSET(I \; 1) \quad OFFSET(I)}{PRICE(I \; 1) \quad PRICE(I)}$$

where

OFFST	=	Total offsets (billion-kilogram-carbon),
PRICE(I)	=	Highest price on the offset supply schedule that is less than the current (or trial) emissions fee (87$/kilogram),
PRICE(I+1)	=	Lowest price on the offset supply schedule that is greater than the current emissions fee (87$/kilogram),
OFFSET(I)	=	Offset quantity corresponding to PRICE(I) (billion-kilogram-carbon),
OFFSET(I+1)	=	Offset quantity corresponding to PRICE(I+1) (billion-kilogram-carbon.)

SUBROUTINE: PRICE_ADJUST

Description: This subroutine assigns the price adjustment of each fuel to reflect the carbon dioxide emissions tax of permit fee by multiplying it by the fuel's emission factor. These price adjustments are used in subroutine COPY_ADJUST to establish adjusted fuel prices that include the carbon dioxide tax or permit fee.

Called by: EPM

Calls: None.

Equations:

$$Eadj(ik) \quad Em(ik) \quad EMTAX(k)$$

where

$Em(ik)$	=	Emission factor for fuel i (kilograms-carbon /million-Btu) in year k,
$EMTAX(k)$	=	Carbon dioxide tax ($/kilogram-carbon) in year k
$Eadj(ik)$	=	Price adjustment of fuel i ($/million-Btu) in year k.

SUBROUTINE: REGFALSI

Description: This subroutine adjusts the carbon dioxide tax (or carbon dioxide
                permit fee) such that the carbon dioxide emission goal is met. In
                general, the routine will increase the tax if the carbon dioxide
                emissions exceed the goal and decrease the tax if the emissions fall
                below the goal.

                The routine first establishes a tax range to try to bracket emissions
                within an interval around the goal. Let f(x) be the difference between
                the carbon dioxide emissions and the carbon dioxide goal for a carbon
                dioxide tax of x. Note the f(x)>0 implies the tax is too low, while f(x)<0
                implies the tax is too high. The objective is to find x, where f(x)=0.
                Initially, the subroutine must adjust the value of x to find two values of
                the carbon dioxide penalty, x_i and a_i, where $x_i < a_i$, $f(x_i) < 0$, and $f(a_i) > 0$.
                Once these conditions hold, a new trial tax, u, is established within the
                interval between x_i and a_i using the equation below.

                This interpolation method to find the root is known as *the method of
                false position*, or *regula falsi.*

Called by: EPM

Calls: None.

Equations:

$$u = \frac{[a_i f(x_i) - x_i f(a_i)]}{f(x_i) - f(a_i)}$$

                where

                a_i =   Carbon dioxide tax on some previous iteration i such that
                               $f(a_i) < 0$,
                x_i =   Carbon dioxide tax on some previous iteration i such that
                               $f(x_i) > 0$,
                u   =   New carbon dioxide tax.

                In the next iteration, x_i is replaced with u if f(u) < 0, or a_i is replaced with
                u if f(u) > 0. Using this procedure, the value of u is found such that f(u)
                = 0 to some tolerance.

SUBROUTINE: COPY_ADJUSTED

Description: This subroutine updates the adjusted price common blocks, adding a fuel-specific cost adjustment to reflect a carbon dioxide tax or permit fee on each fuel. All of the prices in the unadjusted price common blocks MPBLK, COALOUT and NGDTMOUT, are copied to the corresponding adjusted price common blocks AMPBLK, ACOAL and ANGTDM each time a NEMS module is executed, and the fuel-specific price adjustments for specific variables calculated in subroutine PRICE_ADJUST are added.

Called By: NSOLVE

Calls: none

Equations:

$$Padj(ijk) \quad Pbase(ijk) \quad Eadj(ik)$$

where

Padj(ijk) = Adjusted price of fuel i in region j and year k (87$/million-Btu),

Pbase(ijk) = Unadjusted price of fuel i (87$/million-Btu) in region j and year k.

Eadj(ik) = Price adjustment of fuel i (87$/million-Btu) in year k.

SUBROUTINE: EPM_READ

Description: This subroutine reads the initial carbon dioxide penalty, emissions factors, and offset curves for the EPM.

Called by: EPM

Calls: None.

Equations: None.

Emission-Related Variable Listing

EMISSIONS Common Block
(emoblk)

Description	Variable	Type	Units	indices
Coalbed Recovery Offset Prices	PCB	REAL*4	87$/kg Carbon	(MAX_INDEX)
	PREF4	REAL*4	87$/kg Carbon	(MAX_INDEX)
Reforestation Offset Prices	OFFSETCB	REAL*4	billion kg Carbon	(MAX_INDEX)
Offset for coalbed methane	OFFSETREF	REAL*4	billion kg Carbon	(MAX_INDEX)
Offset for Reforestation	EMTAX	REAL*4	87$/kg Carbon	(Year)
Tax or Permit Price	TOTAL_EMISSIONS	REAL*4	billion kg Carbon	(Year)
National carbon dioxide emissions	EMISSIONS_GOAL	REAL*4	billion kg Carbon	(Year)
Carbon dioxide emissions Goal	INIT_ALLOC	REAL*4	billion kg Carbon	(5,Year)
Initial carbon dioxide permit allocation by 5 sectors				

Adjusted Price Common Block

Description	Variable	Type	Units	Indices
Purch. Elec, Peak. Resid	AEPRS	REAL	87$/MMBTU	(Reg,Yr)
Purch. Elec, Peak. Comm	AEPCM	REAL	87$/MMBTU	(Reg,Yr)
Purch. Elec, Peak. Trans	AEPTR	REAL	87$/MMBTU	(Reg,Yr)
Purch. Elec, Peak. Indust	AEPIN	REAL	87$/MMBTU	(Reg,Yr)
Purch. Elec, Peak. Refinery	AEPAS	REAL	87$/MMBTU	(Reg,Yr)
Purch. Elec, Nonpeak. Resid	AENRS	REAL	87$/MMBTU	(Reg,Yr)
Purch. Elec, Nonpeak. Comm	AENCM	REAL	87$/MMBTU	(Reg,Yr)
Purch. Elec, Nonpeak. Trans	AENTR	REAL	87$/MMBTU	(Reg,Yr)
Purch. Elec, Nonpeak. Indust	AENIN	REAL	87$/MMBTU	(Reg,Yr)
Purch. Elec, Nonpeak. All Sect	AENAS	REAL	87$/MMBTU	(Reg,Yr)
Purch. Elec. Resid	AELRS	REAL	87$/MMBTU	(Reg,Yr)
Purch. Elec. Comm	AELCM	REAL	87$/MMBTU	(Reg,Yr)
Purch. Elec. Trans	AELTR	REAL	87$/MMBTU	(Reg,Yr)
Purch. Elec. Indust	AELIN	REAL	87$/MMBTU	(Reg,Yr)
Purch. Elec. All Sectors	AELAS	REAL	87$/MMBTU	(Reg,Yr)
Natural Gas, Core. Resid	AGFRS	REAL	87$/MMBTU	(Reg,Yr)
Natural Gas, Core. Comm	AGFCM	REAL	87$/MMBTU	(Reg,Yr)
Natural Gas, Core. Trans	AGFTR	REAL	87$/MMBTU	(Reg,Yr)
Natural Gas, Core. Indust	AGFIN	REAL	87$/MMBTU	(Reg,Yr)
Natural Gas, Core. Electr	AGFEL	REAL	87$/MMBTU	(Reg,Yr)
Natural Gas, Core. All Sect	AGFAS	REAL	87$/MMBTU	(Reg,Yr)
Natural Gas, Noncore. Resid	AGIRS	REAL	87$/MMBTU	(Reg,Yr)
Natural Gas, Noncore. Comm	AGICM	REAL	87$/MMBTU	(Reg,Yr)
Natural Gas, Noncore. Trans	AGITR	REAL	87$/MMBTU	(Reg,Yr)
Natural Gas, Noncore. Indust	AGIIN	REAL	87$/MMBTU	(Reg,Yr)
Natural Gas, Noncore. Electr	AGIEL	REAL	87$/MMBTU	(Reg,Yr)
Natural Gas, Noncore. All Sect	AGIAS	REAL	87$/MMBTU	(Reg,Yr)
Natural Gas. Residential	ANGRS	REAL	87$/MMBTU	(Reg,Yr)
Natural Gas. Commercial	ANGCM	REAL	87$/MMBTU	(Reg,Yr)
Natural Gas. Transportation	ANGTR	REAL	87$/MMBTU	(Reg,Yr)
Natural Gas. Industrial	ANGIN	REAL	87$/MMBTU	(Reg,Yr)
Natural Gas. Electricity	ANGEL	REAL	87$/MMBTU	(Reg,Yr)
Natural Gas. All Sectors	ANGAS	REAL	87$/MMBTU	(Reg,Yr)
Natural Gas. Pipeline	AGPTR	REAL	87$/MMBTU	(Reg,Yr)
Lease and Plant Fuel	ALPIN	REAL	87$/MMBTU	(Reg,Yr)
Coal. Residential	ACLRS	REAL	87$/MMBTU	(Reg,Yr)
Coal. Commercial	ACLCM	REAL	87$/MMBTU	(Reg,Yr)
Coal. Industrial	ACLIN	REAL	87$/MMBTU	(Reg,Yr)
Coal. Electricity	ACLEL	REAL	87$/MMBTU	(Reg,Yr)
Coal. Synthetics	ACLSN	REAL	87$/MMBTU	(Reg,Yr)
Coal. All Sectors	ACLAS	REAL	87$/MMBTU	(Reg,Yr)
Metallurgical Coal. Industiral	AMCIN	REAL	87$/MMBTU	(Reg,Yr)
Motor Gasoline. Commercial	AMGCM	REAL	87$/MMBTU	(Reg,Yr)
Motor Gasoline. Trans	AMGTR	REAL	87$/MMBTU	(Reg,Yr)
Motor Gasoline. Industrial	AMGIN	REAL	87$/MMBTU	(Reg,Yr)
Motor Gasoline. All Sectors	AMGAS	REAL	87$/MMBTU	(Reg,Yr)
Jet Fuel. Trasnportation	AJFTR	REAL	87$/MMBTU	(Reg,Yr)
Distillate.Residential	ADSRS	REAL	87$/MMBTU	(Reg,Yr)
Distillate.Commercial	ADSCM	REAL	87$/MMBTU	(Reg,Yr)
Distillate.Transportation	ADSTR	REAL	87$/MMBTU	(Reg,Yr)
Distillate.Industrial	ADSIN	REAL	87$/MMBTU	(Reg,Yr)
Distillate.Electric-Petro Coke	ADSEL	REAL	87$/MMBTU	(Reg,Yr)
Distillate.All Sectors	ADSAS	REAL	87$/MMBTU	(Reg,Yr)

Description	Variable	Type	Units	Indices
Kerosene. Residential	AKSRS	REAL	87$/MMBTU	(Reg,Yr)
Kerosene. Commercial	AKSCM	REAL	87$/MMBTU	(Reg,Yr)
Kerosene. Industrial	AKSIN	REAL	87$/MMBTU	(Reg,Yr)
Kerosene. All Sectors	AKSAS	REAL	87$/MMBTU	(Reg,Yr)
Liquid Petroleum Gases. Resid	ALGRS	REAL	87$/MMBTU	(Reg,Yr)
Liquid Petroleum Gases. Comm	ALGCM	REAL	87$/MMBTU	(Reg,Yr)
Liquid Petroleum Gases. Trans	ALGTR	REAL	87$/MMBTU	(Reg,Yr)
Liquid Petroleum Gases. Indust	ALGIN	REAL	87$/MMBTU	(Reg,Yr)
Liquid Petroleum Gases.All Sect	ALGAS	REAL	87$/MMBTU	(Reg,Yr)
Residual Fuel,Low Sulfum. Comm	ARLCM	REAL	87$/MMBTU	(Reg,Yr)
Residual Fuel,Low Sulfur.Trans	ARLTR	REAL	87$/MMBTU	(Reg,Yr)
Residual Fuel,Low Sulfur.Ind	ARLIN	REAL	87$/MMBTU	(Reg,Yr)
Residual Fuel,Low Sulfur.Ele	ARLEL	REAL	87$/MMBTU	(Reg,Yr)
Residual Fuel,Low Sul. All Sec	ARLAS	REAL	87$/MMBTU	(Reg,Yr)
Residual Fuel,High Sul. Trans	ARHTR	REAL	87$/MMBTU	(Reg,Yr)
Residual Fuel,High Sul. Electr	ARHEL	REAL	87$/MMBTU	(Reg,Yr)
Residual Fuel,High Sul. All Sec	ARHAS	REAL	87$/MMBTU	(Reg,Yr)
Residual Fuel. Commercial	ARSCM	REAL	87$/MMBTU	(Reg,Yr)
Residual Fuel. Transportation	ARSTR	REAL	87$/MMBTU	(Reg,Yr)
Residual Fuel. Industrial	ARSIN	REAL	87$/MMBTU	(Reg,Yr)
Residual Fuel. Electricity	ARSEL	REAL	87$/MMBTU	(Reg,Yr)
Residual Fuel. All Sectors	ARSAS	REAL	87$/MMBTU	(Reg,Yr)
Petrochemical Feedstocks. Ind	APFIN	REAL	87$/MMBTU	(Reg,Yr)
Asphalt, Road Oil. Indust	AASIN	REAL	87$/MMBTU	(Reg,Yr)
Other Petroleum. Trans	AOTTR	REAL	87$/MMBTU	(Reg,Yr)
Other PEtroleum. Indust	AOTIN	REAL	87$/MMBTU	(Reg,Yr)
Other Petroleum. Indust	AOTAS	REAL	87$/MMBTU	(Reg,Yr)
Total Petroleum. Resid	ATPRS	REAL	87$/MMBTU	(Reg,Yr)
Total Petroleum. Comm	ATPCM	REAL	87$/MMBTU	(Reg,Yr)
Total Petroleum. Trans	ATPTR	REAL	87$/MMBTU	(Reg,Yr)
Total Petroleum. Indust	ATPIN	REAL	87$/MMBTU	(Reg,Yr)
Total Petroleum. Refinery	ATPRF	REAL	87$/MMBTU	(Reg,Yr)
Total Petroleum. Electr	ATPEL	REAL	87$/MMBTU	(Reg,Yr)
Total Petroleum. All Sectors	ATPAS	REAL	87$/MMBTU	(Reg,Yr)
Methanol. Transportation	AMETR	REAL	87$/MMBTU	(Reg,Yr)
Ethanol. Transportation	AETTR	REAL	87$/MMBTU	(Reg,Yr)
Liquid Hydrogen. Transporation	AHYTR	REAL	87$/MMBTU	(Reg,Yr)
Uranium. Electricity	AUREL	REAL	87$/MMBTU	(Reg,Yr)

Emissions Factors Common Block

Description	Variable	Type	Units	Indices
Natural Gas, Core. Residential	EGFRS	REAL	Kg C/MMBtu	(Year)
Natural Gas, Core. Commercial	EGFCM	REAL	Kg C/MMBtu	(Year)
Natural Gas, Core. Transport	EGFTR	REAL	Kg C/MMBtu	(Year)
Natural Gas, Core. Industrial	EGFIN	REAL	Kg C/MMBtu	(Year)
Natural Gas, Core. Electricity	EGFEL	REAL	Kg C/MMBtu	(Year)
Natural Gas, Noncore. Resid	EGIRS	REAL	Kg C/MMBtu	(Year)
Natural Gas, Noncore. Comm	EGICM	REAL	Kg C/MMBtu	(Year)
Natural Gas, Noncore. Transp	EGITR	REAL	Kg C/MMBtu	(Year)
Natural Gas, Noncore. Indust	EGIIN	REAL	Kg C/MMBtu	(Year)
Natural Gas, Noncore. Electr	EGIEL	REAL	Kg C/MMBtu	(Year)
Natural Gas. Residential	ENGRS	REAL	Kg C/MMBtu	(Year)
Natural Gas. Commercial	ENGCM	REAL	Kg C/MMBtu	(Year)
Natural Gas. Transportation	ENGTR	REAL	Kg C/MMBtu	(Year)
Natural Gas. Industrial	ENGIN	REAL	Kg C/MMBtu	(Year)
Natural Gas. Electricity	ENGEL	REAL	Kg C/MMBtu	(Year)
Natural Gas. Pipeline	EGPTR	REAL	Kg C/MMBtu	(Year)
Lease and Plant Fuel	ELPIN	REAL	Kg C/MMBtu	(Year)
Coal. Residential	ECLRS	REAL	Kg C/MMBtu	(Year)
Coal. Commercial	ECLCM	REAL	Kg C/MMBtu	(Year)
Coal. Industrial	ECLIN	REAL	Kg C/MMBtu	(Year)
Coal. Electricity	ECLEL	REAL	Kg C/MMBtu	(Year)
Metallurgical Coal. Industrial	EMCIN	REAL	Kg C/MMBtu	(Year)
Motor Gasoline. Commercial	EMGCM	REAL	Kg C/MMBtu	(Year)
Motor Gasoline. Transportation	EMGTR	REAL	Kg C/MMBtu	(Year)
Motor Gasoline. Industrial	EMGIN	REAL	Kg C/MMBtu	(Year)
Jet Fuel. Transportation	EJFTR	REAL	Kg C/MMBtu	(Year)
Distillate. Residential	EDSRS	REAL	Kg C/MMBtu	(Year)
Distillate. Commercial	EDSCM	REAL	Kg C/MMBtu	(Year)
Distillate. Transportation	EDSTR	REAL	Kg C/MMBtu	(Year)
Distillate. Industrial	EDSIN	REAL	Kg C/MMBtu	(Year)
Distillate. Elect(+Petro Coke)	EDSEL	REAL	Kg C/MMBtu	(Year)
Kerosene. Residential	EKSRS	REAL	Kg C/MMBtu	(Year)
Kerosene. Commercial	EKSCM	REAL	Kg C/MMBtu	(Year)
Kerosene. Industrial	EKSIN	REAL	Kg C/MMBtu	(Year)
Liquid Petroleum Gases. Resid	ELGRS	REAL	Kg C/MMBtu	(Year)
Liquid Petroleum Gases. Comm	ELGCM	REAL	Kg C/MMBtu	(Year)
Liquid Petroleum Gases. Trans	ELGTR	REAL	Kg C/MMBtu	(Year)
Liquid Petroleum Gases. Indust	ELGIN	REAL	Kg C/MMBtu	(Year)

Description	Variable	Type	Units	Indices
Residual Fuel,Low Sulfur.Comm	ERLCM	REAL	Kg C/MMBtu	(Year)
Residual Fuel,Low Sulfur.Tran	ERLTR	REAL	Kg C/MMBtu	(Year)
Residual Fuel,Low Sulfur.Ind	ERLIN	REAL	Kg C/MMBtu	(Year)
Residual Fuel,Low Sulfur.Ele	ERLEL	REAL	Kg C/MMBtu	(Year)
Residual Fuel,High Sul.Trans	ERHTR	REAL	Kg C/MMBtu	(Year)
Residual Fuel,High Sul.Elect	ERHEL	REAL	Kg C/MMBtu	(Year)
Residual Fuel. Commercial	ERSCM	REAL	Kg C/MMBtu	(Year)
Residual Fuel. Transportation	ERSTR	REAL	Kg C/MMBtu	(Year)
Residual Fuel. Industrial	ERSIN	REAL	Kg C/MMBtu	(Year)
Residual Fuel. Electricity	ERSEL	REAL	Kg C/MMBtu	(Year)
Methanol. Transporation	EMETR	REAL	Kg C/MMBtu	(Year)
Ethanol. Transporation	EETTR	REAL	Kg C/MMBtu	(Year)
Pet Feedstocks Industrial	EPFIN	REAL	Kg C/MMBtu	(Year)
Pet Code Industrial	EPCIN	REAL	Kg C/MMBtu	(Year)
Still Gas Industrial	ESGIN	REAL	Kg C/MMBtu	(Year)
Other Pet Industrial	EOTIN	REAL	Kg C/MMBtu	(Year)
Pet Coke Electricity	EPCEL	REAL	Kg C/MMBtu	(Year)
VLS Bit Coal Emissions By NERC	EBCELNR	REAL	Kg C/MMBtu	(Year)
LS Bit Coal Emissions By NERC	EBDELNR	REAL	Kg C/MMBtu	(Year)
MS Bit Coal Emissions By NERC	EBMELNR	REAL	Kg C/MMBtu	(Year)
HS Bit Coal Emissions By NERC	EBHELNR	REAL	Kg C/MMBtu	(Year)
VLS Sub Coal Emissions By NERC	ESCELNR	REAL	Kg C/MMBtu	(Year)
LS Sub Coal Emissions By NERC	ESDELNR	REAL	Kg C/MMBtu	(Year)
MS Sub Coal Emissions By NERC	ESMELNR	REAL	Kg C/MMBtu	(Year)
HS Sub Coal Emissions By NERC	ESHELNR	REAL	Kg C/MMBtu	(Year)
VLS Lig Coal Emissions By NERC	ELCELNR	REAL	Kg C/MMBtu	(Year)
LS Lig Coal Emissions By NERC	ELDELNR	REAL	Kg C/MMBtu	(Year)
MS Lig Coal Emissions By NERC	ELMELNR	REAL	Kg C/MMBtu	(Year)
HS Lig Coal Emissions By NERC	ELHELNR	REAL	Kg C/MMBtu	(Year)
E Util Firm NG Emissioins	EGFELGR	REAL*4	Kg C/MMBtu	(Year)
E Util Inter NG Emissions	EGIELGR	REAL*4	Kg C/MMBtu	(Year)
E Util Compet NG Emissions	EGCELGR	REAL*4	Kg C/MMBtu	(Year)

Quantity Common Block

Description	Variable	Type	Units	Indices
Purch Elec, Peak.Residential	QEPRS	REAL	Trill Btu	(Reg,Yr)
Purch Elec, Peak. Comm	QEPCM	REAL	Trill Btu	(Reg,Yr)
Purch Elec, Peak. Trans	QEPTR	REAL	Trill Btu	(Reg,Yr)
Purch Elec, Peak. Industrial	QEPIN	REAL	Trill Btu	(Reg,Yr)
Purch Elec, Peak. Refinery	QEPRF	REAL	Trill Btu	(Reg,Yr)
Purch Elec, Peak. All Sectors	QEPAS	REAL	Trill Btu	(Reg,Yr)
Purch Elec, Nonpeak. Resid	QENRS	REAL	Trill Btu	(Reg,Yr)
Purch Elec, Nonpeak. Comm	QENCM	REAL	Trill Btu	(Reg,Yr)
Purch Elec, Nonpeak. Trans	QENTR	REAL	Trill Btu	(Reg,Yr)
Purch Elec, Nonpeak. Ind	QENIN	REAL	Trill Btu	(Reg,Yr)
Purch Elec, Nonpeak. Refinery	QENRF	REAL	Trill Btu	(Reg,Yr)
Purch Elec, Nonpeak. All Sect	QENAS	REAL	Trill Btu	(Reg,Yr)
Purch Elec. Residential	QELRS	REAL	Trill Btu	(Reg,Yr)
Purch Elec. Commercial	QELCM	REAL	Trill Btu	(Reg,Yr)
Purch Elec. Transportation	QELTR	REAL	Trill Btu	(Reg,Yr)
Purch Elec. Industrial	QELIN	REAL	Trill Btu	(Reg,Yr)
Purch Elec. Refinery	QELRF	REAL	Trill Btu	(Reg,Yr)
Purch Elec. All Sectors	QELAS	REAL	Trill Btu	(Reg,Yr)
Natural Gas Core. Residential	QGFRS	REAL	Trill Btu	(Reg,Yr)
Natural Gas Core. Commercial	QGFCM	REAL	Trill Btu	(Reg,Yr)
Natural Gas Core. Trans	QGFTR	REAL	Trill Btu	(Reg,Yr)
Natural Gas Core. Industrial	QGFIN	REAL	Trill Btu	(Reg,Yr)
Natural Gas Core. Refinery	QGFRF	REAL	Trill Btu	(Reg,Yr)
Natural Gas Core. Electr	QGFEL	REAL	Trill Btu	(Reg,Yr)
Natural Gas Core. All Sect	QGFAS	REAL	Trill Btu	(Reg,Yr)
Natural Gas Noncore. Resid	QGIRS	REAL	Trill Btu	(Reg,Yr)
Natural Gas Noncore. Comm	QGICM	REAL	Trill Btu	(Reg,Yr)
Natural Gas Noncore. Trans	QGITR	REAL	Trill Btu	(Reg,Yr)
Natural Gas Noncore. Indust	QGIIN	REAL	Trill Btu	(Reg,Yr)
Natural Gas Noncore. Refinery	QGIRF	REAL	Trill Btu	(Reg,Yr)
Natural Gas Noncore. Electr	QGIEL	REAL	Trill Btu	(Reg,Yr)
Natural Gas Noncore. All Sect	QGIAS	REAL	Trill Btu	(Reg,Yr)
Natural Gas Residential	QNGRS	REAL	Trill Btu	(Reg,Yr)
Natural Gas Commercial	QNGCM	REAL	Trill Btu	(Reg,Yr)
Natural Gas Transportation	QNGTR	REAL	Trill Btu	(Reg,Yr)
Natural Gas Industrial	QNGIN	REAL	Trill Btu	(Reg,Yr)
Natural Gas Refinery	QNGRF	REAL	Trill Btu	(Reg,Yr)
Natural Gas Electricity	QNGEL	REAL	Trill Btu	(Reg,Yr)
Natural Gas All Sectors	QNGAS	REAL	Trill Btu	(Reg,Yr)
Natural Gas Pipeline	QGPTR	REAL	Trill Btu	(Reg,Yr)
Lease and Plant Fuel	QLPIN	REAL	Trill Btu	(Reg,Yr)
Coal. Residential	QCLRS	REAL	Trill Btu	(Reg,Yr)
Coal. Commercial	QCLCM	REAL	Trill Btu	(Reg,Yr)
Coal. Industrial	QCLIN	REAL	Trill Btu	(Reg,Yr)
Coal. Refinery	QCLRF	REAL	Trill Btu	(Reg,Yr)
Coal. Electricity	QCLEL	REAL	Trill Btu	(Reg,Yr)
Coal. Synthetics	QCLSN	REAL	Trill Btu	(Reg,Yr)
Coal. All Sectors	QCLAS	REAL	Trill Btu	(Reg,Yr)
Metallurgical Coal Industrial	QMCIN	REAL	Trill Btu	(Reg,Yr)
Motor Gasoline. Commercial	QMGCM	REAL	Trill Btu	(Reg,Yr)
Motor Gasoline. Transportation	QMGTR	REAL	Trill Btu	(Reg,Yr)
Motor Gasoline. Industrial	QMGIN	REAL	Trill Btu	(Reg,Yr)
Motor Gasoline. All Sectors	QMGAS	REAL	Trill Btu	(Reg,Yr)

Description	Variable	Type	Units	Indices
Jet Fuel Transportation	QJFTR	REAL	Trill Btu	(Reg,Yr)
Distillate Residential	QDSRS	REAL	Trill Btu	(Reg,Yr)
Distillate Commercial	QDSCM	REAL	Trill Btu	(Reg,Yr)
Distillate Transportation	QDSTR	REAL	Trill Btu	(Reg,Yr)
Distillate Industrial	QDSIN	REAL	Trill Btu	(Reg,Yr)
Distillate Refinery	QDSRF	REAL	Trill Btu	(Reg,Yr)
Distillate Electr(+petro coke)	QDSEL	REAL	Trill Btu	(Reg,Yr)
Distillate All Sectors	QDSAS	REAL	Trill Btu	(Reg,Yr)
Kerosene. Residential	QKSRS	REAL	Trill Btu	(Reg,Yr)
Kerosene. Commercial	QKSCM	REAL	Trill Btu	(Reg,Yr)
Kerosene. Industrial	QKSIN	REAL	Trill Btu	(Reg,Yr)
Kerosene. All Sectors	QKSAS	REAL	Trill Btu	(Reg,Yr)
Liquid Petroleum Gases Resid	QLGRS	REAL	Trill Btu	(Reg,Yr)
Liquid Petroleum Gases Comm	QLGCM	REAL	Trill Btu	(Reg,Yr)
Liquid Petroleum Gases Trans	QLGTR	REAL	Trill Btu	(Reg,Yr)
Liquid Petroleum Gases Ind	QLGIN	REAL	Trill Btu	(Reg,Yr)
Liquid Petroleum Gases Refine	QLGRF	REAL	Trill Btu	(Reg,Yr)
Liquid Petroleum Gases All Sec	QLGAS	REAL	Trill Btu	(Reg,Yr)
Residual Fuel Low Sulfur Comm	QRLCM	REAL	Trill Btu	(Reg,Yr)
Residual Fuel Low Sulfur Trans	QRLTR	REAL	Trill Btu	(Reg,Yr)
Residual Fuel Low Sulfur Ind	QRLIN	REAL	Trill Btu	(Reg,Yr)
Residual Fuel Low Sulfur Refine	QRLRF	REAL	Trill Btu	(Reg,Yr)
Residual Fuel Low Sulfur Electr	QRLEL	REAL	Trill Btu	(Reg,Yr)
Resid Fuel Low Sulfur All Sec	QRLAS	REAL	Trill Btu	(Reg,Yr)
Resid Fuel High Sulfur Trans	QRHTR	REAL	Trill Btu	(Reg,Yr)
Resid Fuel High Sulfur Electr	QRHEL	REAL	Trill Btu	(Reg,Yr)
Resid Fuel High Sulfur All Sec	QRHAS	REAL	Trill Btu	(Reg,Yr)
Residual Fuel. Commercial	QRSCM	REAL	Trill Btu	(Reg,Yr)
Residual Fuel. Transportation	QRSTR	REAL	Trill Btu	(Reg,Yr)
Residual Fuel. Industrial	QRSIN	REAL	Trill Btu	(Reg,Yr)
Residual Fuel. Refinery	QRSRF	REAL	Trill Btu	(Reg,Yr)
Residual Fuel. Electricity	QRSEL	REAL	Trill Btu	(Reg,Yr)
Residual Fuel. All Sectors	QRSAS	REAL	Trill Btu	(Reg,Yr)
Petrochemical Feedstocks. Ind	QPFIN	REAL	Trill Btu	(Reg,Yr)
Still Gas. Industrial	QSGIN	REAL	Trill Btu	(Reg,Yr)
Still Gas. Refinery	QSGRF	REAL	Trill Btu	(Reg,Yr)
Petroleum Coke. Industrial	QPCIN	REAL	Trill Btu	(Reg,Yr)
Petroleum Coke. Refinery	QPCRF	REAL	Trill Btu	(Reg,Yr)
Petroleum Coke. Electricity	QPCEL	REAL	Trill Btu	(Reg,Yr)
Petroleum Coke. All Sectors	QPCAS	REAL	Trill Btu	(Reg,Yr)
Asphalt and Road Oil Ind	QASIN	REAL	Trill Btu	(Reg,Yr)
Other Petr Trans-lubes,aviat gas	QOTTR	REAL	Trill Btu	(Reg,Yr)
Other Petroleum. Industrial	QOTIN	REAL	Trill Btu	(Reg,Yr)
Other Petroleum. Refinery	QOTRF	REAL	Trill Btu	(Reg,Yr)
Other Petroleum. All Sectors	QOTAS	REAL	Trill Btu	(Reg,Yr)
Total Petroleum. Residential	QTPRS	REAL	Trill Btu	(Reg,Yr)
Total Petroleum. Commercial	QTPCM	REAL	Trill Btu	(Reg,Yr)
Total Petroleum. Trans	QTPTR	REAL	Trill Btu	(Reg,Yr)
Total Petroleum. Industrial	QTPIN	REAL	Trill Btu	(Reg,Yr)
Total Petroleum. Refinery	QTPRF	REAL	Trill Btu	(Reg,Yr)
Total Petroleum. Electricity	QTPEL	REAL	Trill Btu	(Reg,Yr)
Total Petroleum. All Sectors	QTPAS	REAL	Trill Btu	(Reg,Yr)

Description	Variable	Type	Units	Indices
Methanol. Transporation	QMETR	REAL	Trill Btu	(Reg,Yr)
Ethanol. Transporation	QETTR	REAL	Trill Btu	(Reg,Yr)
Liquid Hydrogen. Trans	QHYTR	REAL	Trill Btu	(Reg,Yr)
Uranium. Electricity	QUREL	REAL	Trill Btu	(Reg,Yr)
Hydropower. Industrial	QHOIN	REAL	Trill Btu	(Reg,Yr)
Hydropower. Electricity	QHOEL	REAL	Trill Btu	(Reg,Yr)
Hydropower. All Sectors	QHOAS	REAL	Trill Btu	(Reg,Yr)
Geothermal. Industrial	QGEIN	REAL	Trill Btu	(Reg,Yr)
Geothermal. Electricity	QGEEL	REAL	Trill Btu	(Reg,Yr)
Geothermal. All Sectors	QGEAS	REAL	Trill Btu	(Reg,Yr)
Biomass. Residential	QBMRS	REAL	Trill Btu	(Reg,Yr)
Biomass. Commercial	QBMCM	REAL	Trill Btu	(Reg,Yr)
Biomass. Industrial	QBMIN	REAL	Trill Btu	(Reg,Yr)
Biomass. Refinery	QBMRF	REAL	Trill Btu	(Reg,Yr)
Biomass. Electricity	QBMEL	REAL	Trill Btu	(Reg,Yr)
Biomass. Synthetics	QBMSN	REAL	Trill Btu	(Reg,Yr)
Biomass. All Sectors	QBMAS	REAL	Trill Btu	(Reg,Yr)
Municipal Solid Waste Ind	QMSIN	REAL	Trill Btu	(Reg,Yr)
Municipal Solid Waste Electr	QMSEL	REAL	Trill Btu	(Reg,Yr)
Municipal Solid Waste All Sec	QMSAS	REAL	Trill Btu	(Reg,Yr)
Solar Thermal. Residential	QSTRS	REAL	Trill Btu	(Reg,Yr)
Solar Thermal. Commercial	QSTCM	REAL	Trill Btu	(Reg,Yr)
Solar Thermal. Industrial	QSTIN	REAL	Trill Btu	(Reg,Yr)
Solar Thermal. Electricity	QSTEL	REAL	Trill Btu	(Reg,Yr)
Solar Thermal. All Sectors	QSTAS	REAL	Trill Btu	(Reg,Yr)
Photovoltaic. Residential	QPVRS	REAL	Trill Btu	(Reg,Yr)
Photovoltaic. Commercial	QPVCM	REAL	Trill Btu	(Reg,Yr)
Photovoltaic. Industrial	QPVIN	REAL	Trill Btu	(Reg,Yr)
Photovoltaic. Electricity	QPVEL	REAL	Trill Btu	(Reg,Yr)
Photovoltaic. All Sectors	QPVAS	REAL	Trill Btu	(Reg,Yr)
Wind. Industrial	QWIIN	REAL	Trill Btu	(Reg,Yr)
Wind. Electricity	QWIEL	REAL	Trill Btu	(Reg,Yr)
Wind. All Sectors	QWIAS	REAL	Trill Btu	(Reg,Yr)
Total Renewables. Residential	QTRRS	REAL	Trill Btu	(Reg,Yr)
Total Renewables. Commercial	QTRCM	REAL	Trill Btu	(Reg,Yr)
Total Renewables. Trans	QTRTR	REAL	Trill Btu	(Reg,Yr)
Total Renewables. Industrial	QTRIN	REAL	Trill Btu	(Reg,Yr)
Total Renewables. Electricity	QTREL	REAL	Trill Btu	(Reg,Yr)
Total Renewables. Synthetics	QTRSN	REAL	Trill Btu	(Reg,Yr)
Total Renewables. All Sectors	QTRAS	REAL	Trill Btu	(Reg,Yr)
Net Electricity Imports Electr	QEIEL	REAL	Trill Btu	(Reg,Yr)
Net Coal Coke Imports Ind	QCIIN	REAL	Trill Btu	(Reg,Yr)
Total Energy Consump. Resid	QTSRS	REAL	Trill Btu	(Reg,Yr)
Total Energy Consump. Comm	QTSCM	REAL	Trill Btu	(Reg,Yr)
Total Energy Consump. Trans	QTSTR	REAL	Trill Btu	(Reg,Yr)
Total Energy Consump. Ind	QTSIN	REAL	Trill Btu	(Reg,Yr)
Total Energy Consump. Refine	QTSRF	REAL	Trill Btu	(Reg,Yr)
Total Energy Consump. Electr	QTSEL	REAL	Trill Btu	(Reg,Yr)
Total Energy Consump. Synthet	QTSSN	REAL	Trill Btu	(Reg,Yr)
Total Energy Consump. All Sec	QTSAS	REAL	Trill Btu	(Reg,Yr)
Breakout of natural gas feedstock	INQNGPF	REAL	Trill Btu	(Reg,Yr)
Breakout of LPG feedstock	INQLGPF	REAL	Trill Btu	(Reg,Yr)

Appendix A. Bibliography

The National Energy Modeling System is documented in a series of model documentation reports, available by contacting the National Energy Information Center (202/586-8800) or through the internet at http://www.eia.doe.gov/bookshelf/docs.html. Most of the references in the Bibliography refer to these documentation reports and their publication numbers. The model documentation reports listed below are those available as of November 2000. However, most of these reports will be updated by early 2001 to reflect modeling changes for the *Annual Energy Outlook 2001*.

The reports listed below, unless cited otherwise, were produced by the Energy Information Administration.

Annual Energy Outlook 2001, DOE/EIA-0383(2001) (Washington, DC, December 2000)

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

Commercial Sector Demand Module of the National Energy Modeling System, Model Documentation 2000, DOE/EIA-M066(2000) (Washington, DC, January 2000).

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

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

Emissions of Greenhouse Gases in the United States 1999, DOE/EIA-0573(99), (Washington, DC, October 2000.

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

International Energy Module, Model Documentation 1999, DOE/EIA-M071(1999) (Washington, DC, February 1999).

Macroeconomic Activity Module (MAM) of the National Energy Modeling System–Model Documentation 2000, DOE/EIA-M065(2000) (Washington, DC, 2000).

The National Energy Modeling System: An Overview 2000, DOE/EIA-0581(2000), (Washington, DC, March 2000).
Natural Gas Transmission and Distribution Model of the National Energy Modeling System, Model Documentation 2000, DOE/EIA-M062(2000) (Washington, DC, January 2000).

Oil and Gas Supply Module (OGSM), Model Documentation 2000, DOE/EIA-M063(2000) (Washington, DC, February 2000).

Petroleum Market Model of the National Energy Modeling System, Model Documentation 2000, DOE/EIA-M059(2000) (Washington, DC, January 2000).

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

Residential Sector Demand Module of the National Energy Model System, Model Documentation 2000, DOE/EIA-M067(2000) (Washington, DC, January 2000).

Transportation Sector Model of the National Energy Modeling System, Model Documentation (Volume 1) 2000, DOE/EIA-M070(2000)1 (Washington, DC, January 2000).

Transportation Sector Model of the National Energy Modeling System, Model Documentation (Volume 2) 2000, DOE/EIA-M070(2000)2 (Washington, DC, January 2000).

World Oil Refining Logistics Demand Model "World" Reference Manual, DOE/EIA-M058 (Washington, DC, March 1994).

Appendix B. Model Abstract

Model Name: Integrating Module of the National Energy Modeling System

Description: The National Energy Modeling System (NEMS) represents a general equilibrium solution of the interactions between the U.S. energy markets and the economy. The model achieves a supply-and-demand balance in the end-use demand regions, defined as the nine Census Divisions, by solving for the prices of each energy type such that the quantities producers are willing to supply equal the quantities consumers wish to consume. The system reflects market economics, industry structure, and energy policies and regulations that influence market behavior.

Last Model Update: October 2000

Part of Another Model? Part of the National Energy Modeling System.

Model Interfaces: NEMS comprises the following modules, with model contacts as indicated:

Integrating Module	Dan Skelly, 202-586-1722
Residential Sector Demand Module	John H. Cymbalsky, 202-586-4815
Commercial Sector Demand Module	Erin Boedecker, 202 586-4791
Transportation Sector Demand Module	David M. Chien, 202-586-3994
Industrial Sector Demand Module	Crawford Honeycutt, 202-586-1420
Macroeconomic Activity Module	Ron Earley, 202-586-1398
International Energy Activity Module	Dan Butler, 202-586-9503
Coal Market Module	Mike Mellish, 202-586-2136
Renewable Fuels Module	Zia Haq, 202-586-2869
Electricity Market Module	Jeff Jones, 202-586-2038
Natural Gas Transmission and Distribution Module	Joseph Benneche, 202-586-6132
Oil and Gas Market Module	Ted McCallister, 202-586-4820
Petroleum Market Module	Bruce Bawks, 202-586-6579

Sponsor:

- **Office:** Office of Integrated Analysis and Forecasting
- **Division:** Demand and Integration Division (EI-84)
- **Model Contact:** Dan Skelly
- **Telephone:** (202) 586-1722
- **E-Mail Address:** dskelly@eia.doe.gov

Documentation:

- Energy Information Administration, *Integrating Module of the National Energy Model System: Model Documentation*, DOE/EIA-M057(2001) (Washington, DC, January, 2000).

- Energy Information Administration, *The National Energy Modeling System: An Overview 2000*, DOE/EIA-0581(2000) (Washington, DC, March 2000).

Archive:

- NEMS-2001 archive package for the *Annual Energy Outlook 2001,* DOE/EIA-0383(2001

Coverage:

- **Geographic:** Nine Bureau of Census Divisions. Some component analytical modules represent energy production or conversion at different levels of regional detail.
- **Time Unit/Frequency:** Annual through 2020
- **Product(s):** Natural gas, electricity, coal, steam coal, metallurgical coal, distillate fuel oil, residual fuel oil, motor gasoline, jet fuel, liquefied petroleum gases, petrochemical feedstocks, kerosene, other petroleum products, methanol, ethanol, nuclear power, hydropower, and other renewable sources.
- **Economic Sector(s):** Residential, commercial, industrial, and transportation end-use consumption; coal supply; oil and gas production and natural gas markets; utility and nonutility capacity, and generation of electricity; oil product pricing.

Modeling Features:

- **Model Structure:** NEMS provides an equilibrium framework in which the economic forces of supply and demand can be simulated. Its modular structure allows each individual module to be represented in a different fashion if desired.
- **Modeling Technique:** NEMS is a simulation of the impacts of present and planned energy market conditions upon the supplies of and demands for energy products. Different techniques are applied in different sectors, as appropriate.
- **Special Features:** The primary design feature of NEMS is its modularity. That is, the model is organized by fuel production—oil, natural gas, coal, and electricity—and by end-use consumption sector. The modularity allows any single module or group of modules to be run independently as a debugging aid or for stand-alone analysis. Furthermore, modularity also allows the flexibility for each sector to be represented in the most appropriate way, highlighting the particular issues important for the sector, including the most appropriate regional structure.

Non-DOE Input Sources: All data sources are listed under the appropriate modules of NEMS, which are listed in the Model Interfaces section.

DOE Data Input Sources: All data sources are listed under the appropriate modules of NEMS, which are listed in the Model Interfaces section.

Computing Environment:

- **Hardware Used**: Two networked Compaq Proliant Servers, model 5500R, each with four 550 mhz Pentium III Xeon processors, 2.5 gigabytes RAM, 54 gigabytes hard disk space; supplemented by a "peer-to-peer" computer sharing system using 8 Dell workstations (model Precision 410), each with two 500mhz Pentium III processors, 512 megabyte RAM and 18 gigabytes hard disk space.
- **Operating System**: Windows NT 4
- **Language/Software Used**: Compaq Visual Fortran 6.1; Ketron's Optimization Modeling Library; MKS Toolkit;
- **Memory Requirement** (image size): 305 megabytes
- **Storage Requirement**: 2 gigabytes
- **Estimated Run Time**: 2.5-3 hours CPU time for a single run with all modules on. Often, 3 runs are executed in sequence, or "cycled," to improve convergence. Such 3-cycle runs take between 7.5 and 9 hours.