



The National Energy Modeling System: An Overview

May 2023

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Introduction

The *National Energy Modeling System: An Overview* (Overview) provides a summary of the National Energy Modeling System (NEMS), which makes projections published in our *Annual Energy Outlook* (AEO).

NEMS is an energy-economy modeling system of U.S. energy markets for the period extending through 2050. This model projects the production, imports, exports, conversion, consumption, and prices of energy, subject to a number of assumptions. The assumptions encompass macroeconomic and financial 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.

Our Office of Energy Analysis develops and maintains NEMS, and analysts perform policy analyses requested by decision makers in the White House; the U.S. Congress; offices within the U.S. Department of Energy, including program offices; and other government agencies. NEMS was first used for projections presented in the AEO1994.

This [NEMS documentation page](#) has more details about each module. The [Assumptions page](#) contains separate reports about the latest assumptions for each module.

NEMS modular structure

The NEMS system contains three main parts:

- A central database to store and pass inputs and outputs between the various components
- Energy modules that represent various demand, transformation, and supply projection activities
- An integration, or convergence, module that determines when the system has reached an equilibrium between supply and demand

NEMS is a modular system ([Figure 1](#)) that consists of the following components:

Four supply modules:

- Renewable Fuels Module (RFM)
- Natural Gas Market Module (NGMM)
- Oil and Gas Supply Module (OGSM)
- Coal Market Module (CMM)

Four demand modules:

- Residential Demand Module (RDM)
- Commercial Demand Module (CMM)
- Industrial Demand Module (IDM)
- Transportation Demand Module (TDM)

Two conversion modules:

- Electricity Market Module (EMM)
- Liquid Fuels Market Module (LFMM)

One module to simulate energy or economy interactions:

- Macroeconomic Activity Module (MAM)

One module to simulate world or domestic liquids interactions:

- International Energy Module (IEM)

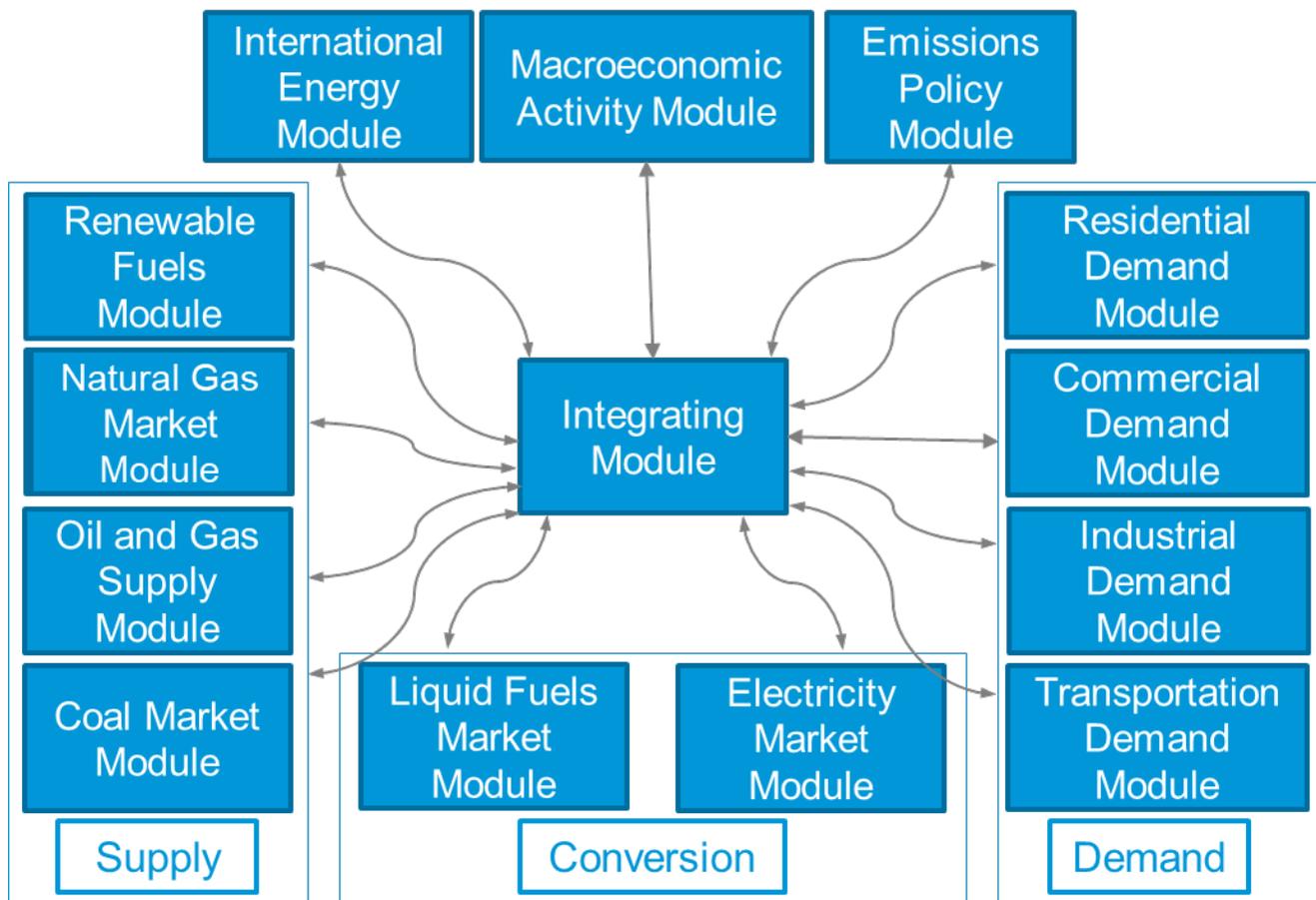
One module to calculate carbon dioxide (CO₂) emissions from fossil fuel consumption and non-combustion uses of fossil fuel inputs:

- Emissions Policy Module (EPM)

One module that provides the mechanism to achieve a general market equilibrium among all the modules:

- Integrating Module

Figure 1. National Energy Modeling System structure



Data source: U.S. Energy Information Administration

The modules represent each of the fuel supply markets, conversion sectors, and end-use consumption sectors of the energy system. The modular design also allows us to use the methodology and level of detail most appropriate for each energy sector. NEMS executes each of the component modules to solve for the prices of energy delivered to end users and the quantities consumed by product, region, and sector. The delivered fuel prices encompass all activities required to produce, import, and transport fuels to end users. The information flows also include such areas as economic activity, domestic production, and international petroleum supply.

NEMS calls each supply, conversion, and end-use demand modules in sequence until the modeling system reaches an equilibrium between supply and demand. The AEO offers a solution for each year through 2050. A list of inputs and outputs into each module is in the [Appendix](#).

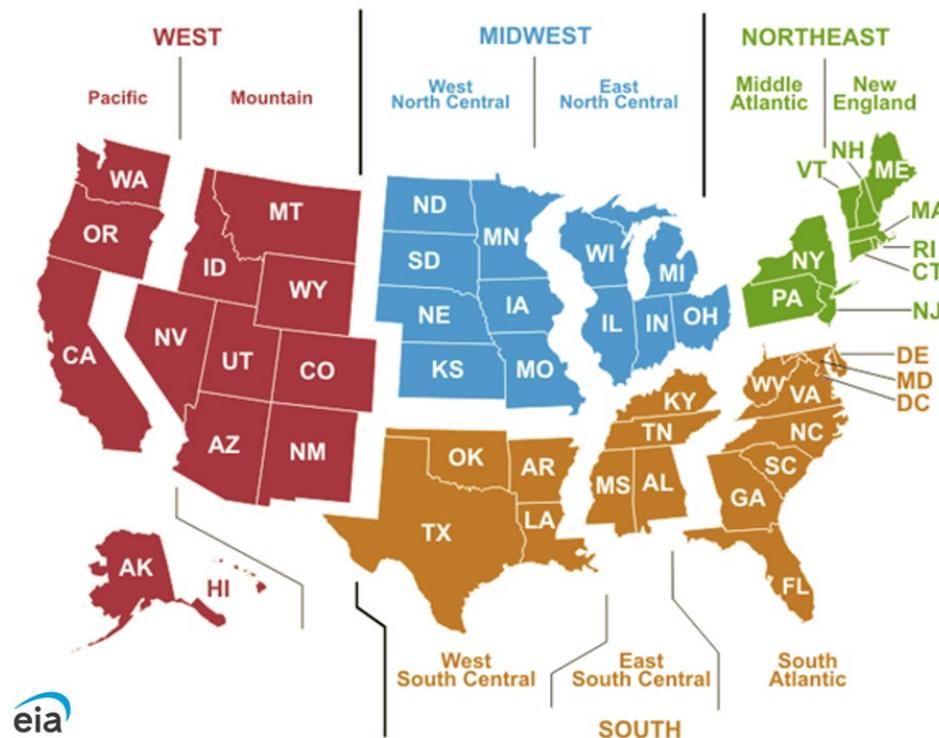
NEMS regions

To represent regional differences in energy markets, the component modules of NEMS function at a regional level.

For instance, NEMS publishes end-use consumption and prices in its demand modules by four census regions and nine census divisions (Figure 2).

More details about the regions used for each module is in the documentation located on the [NEMS documentation page](#).

Figure 2. U.S. regions and census divisions



Data source: U.S. Census Bureau

Complete regional and detailed results are available on the EIA [Analysis and Projections page](#).

Renewable Fuels Module

RFM consists of six submodules that represent major renewable electricity resources: biomass, landfill gas (LFG), solar (thermal and photovoltaic), wind, geothermal, and conventional hydroelectricity energy. RFM also interacts with the Renewable Electricity Storage Submodule (REStore) model to estimate the impact of energy storage on the dispatch of generation in each of the modeled electricity regions. The details of the REStore model are provided as an appendix to the EMM model [documentation](#).

RFM defines the technology, performance, and renewable resource supply for renewable electricity technologies in NEMS, which is used by EMM, along with the renewable cost assumptions that are provided in EMM model documentation, in projecting grid-connected central-station electricity capacity planning and dispatch decisions. We develop projections for residential and commercial grid-connected photovoltaic systems in the end-use demand modules.

We include additional details in the RFM [documentation](#).

Oil and Gas Supply Module

OGSM is a comprehensive framework used to analyze oil and natural gas supply potential and related issues. Primarily, it projects domestic crude oil and natural gas production in response to price data received endogenously (within NEMS) from NGMM and LFMM. Projected natural gas and crude oil wellhead prices are determined within NGMM and LFMM, respectively. As the supply component only, OGSM cannot project prices, which are the outcome of the equilibration of both demand and supply.

OGSM provides expected natural gas production to NGMM for use in its short-term domestic nonassociated gas production functions and associated-dissolved natural gas production. Nonassociated gas production refers to natural gas produced from gas wells; associated-dissolved natural gas is natural gas produced from oil wells. The interaction of supply and demand in NGMM determines nonassociated gas production.

OGSM provides domestic crude oil production to LFMM. The interaction of supply and demand in LFMM determines the level of imports. System control information (such as projection year) and expectations (such as expected price paths) come from the Integrating Module. Major exogenous inputs include resource levels, finding-rate parameters, costs, production profiles, and tax rates—all of which are critical determinants of the oil and natural gas supply outlook of OGSM.

We include additional details in the OGSM [documentation](#).

Natural Gas Market Module

NGMM models the transmission, distribution, and pricing of natural gas in NEMS. The model code is a quadratic program that maximizes consumer plus producer surplus, minus transportation costs, subject to linear mass balance and capacity constraints. For all months in a year, NGMM determines the production, flows, and prices of natural gas in a state-level representation of the U.S. pipeline network¹ and a regional-level representation of the Canada's and Mexico's pipeline network, connecting domestic and foreign supply regions with demand regions. End-use natural gas consumption by sector, storage, and liquefied natural gas (LNG) export terminals are all integrated into the network by demand region.

NGMM accepts various exogenous inputs. For instance, imports of LNG into North America are set to historical levels in the United States and set exogenously for Canada and Mexico, according to results from our [International Energy Outlook](#). NGMM also receives inputs from other NEMS modules such as macroeconomic variables from MAM, expected production of nonassociated natural gas and associated-dissolved natural gas from OGSM, and the amount of commercial floorspace by census division from CDM.

We include additional details in the NGMM [documentation](#).

¹ Alaska's natural gas market is modeled in the NGMM independent of the integrated network.

Coal Market Module

CMM projects U.S. coal production, consumption, exports, imports, distribution, and prices. CMM consists of the Coal Production Submodule (CPS), which generates a set of supply curves by year in the projection period; the Domestic Coal Distribution Submodule (DCDS), which determines the least-cost supplies of coal by supply region; and the International Coal Distribution Submodule, which projects U.S. coal imports and exports.

To generate a set of supply curves, CMM receives various inputs from other NEMS modules such as electricity prices by census division from EMM, national-level distillate fuel prices from LFMM, and real interest rates from MAM.

CMM provides information to other modules such as regional delivered coal prices and quantities for the end-use sectors in NEMS. The DCDS provides detailed input information to EMM, including coal contracts, coal diversity information (subbituminous and lignite coal constraints), coal transportation rates, and coal supply curves, which EMM uses to develop expectations about future coal prices and coal availability to make improved projections of coal planning decisions.

We include additional details in the CMM [documentation](#).

Residential Demand Module

RDM generates projections of energy demand (or energy consumption) for the residential sector by end-use service, fuel type, and U.S. census division.

RDM uses inputs from NEMS, such as energy prices and macroeconomic indicators, to generate outputs needed in the NEMS integration process. RDM uses these inputs to generate energy consumption by fuel type and census division in the residential sector. NEMS uses these projections to compute equilibrium energy prices and quantities.

The primary module inputs include fuel prices, housing stock characteristics, housing starts, population, and technology characteristics. The technology characteristics used in the module include installed capital costs (in real dollars), equipment efficiency, and expected equipment lifetimes.

The primary module output is projected residential sector energy consumption by fuel type, end-use service, and census division. The module also projects housing stock and energy consumption per housing unit. In addition, the module can produce a disaggregated projection of appliance stock and efficiency for certain types of equipment.

We include additional details in the RDM [documentation](#).

Commercial Demand Module

CDM develops projections of energy demand (or energy consumption) in the commercial sector by end-use service, fuel type, and U.S. census division.

The primary inputs to the CDM include fuel prices, commercial building floorspace growth, interest rates, and technology cost and performance parameters.

The primary output of the CDM is projected commercial sector energy consumption by fuel type, end use, building type, census division, and year. The module also provides annual projections of construction of new commercial floorspace by building type and census division; equipment market shares by technology, end use, fuel, building type, and census division; and average efficiency of equipment mix by end use and fuel type.

NEMS uses the projected commercial sector fuel demands generated by CDM to calculate the supply and demand equilibrium for individual fuels.

We include additional details in the CDM [documentation](#).

Industrial Demand Module

IDM estimates U.S. energy consumption by energy source (fuels and feedstocks) for 15 manufacturing and 6 nonmanufacturing industries. IDM subdivides manufacturing industries further into energy-intensive manufacturing industries and non-energy-intensive manufacturing industries.

From NEMS, IDM receives fuel prices, employment data, and the value of industrial shipments. Based on the values of these variables, IDM passes back to NEMS estimates of fuel consumption for 17 main fuels, including feedstocks and renewables for each of 21 industry groups. IDM projects energy consumption at the census region level; energy consumption is allocated to the census division-level based on the latest [State Energy Data System \(SEDS\)](#) data.

IDM models manufacturing industries through either a detailed process-flow procedure or an end-use accounting procedure. IDM models the nonmanufacturing industries with less detail because the processes are simpler and fewer data are available. In both cases, IDM models industrial energy consumption based on U.S. economic output disaggregated by NAICS code, as determined by MAM.

We include additional details in the IDM [documentation](#).

Transportation Sector Demand Module

TDM encompasses a series of semi-independent submodules and components that address different aspects of the transportation sector. This comprehensive module primarily provides projections of transportation energy demand by fuel type, including motor gasoline, distillate, jet fuel, and alternative fuels (such as electricity, compressed natural gas [CNG], and LNG).

TDM consists of four submodules that represent a variety of travel modes that are different in design and use but share the same purpose: to convey passengers and freight. The four submodules are:

- Light-Duty Vehicle (LDV)
- Air Travel
- Freight Transport (heavy truck, rail, and marine)
- Miscellaneous Energy Demand

To generate projections, TDM receives a variety of exogenous inputs from other NEMS modules. The primary source of these inputs is MAM, which provides projections of economic variables, such as new vehicle sales and demographic indicators. Other inputs exogenous to TDM, but endogenous to NEMS, include the fuel price projections from the various supply modules.

TDM produces projections of travel demand and associated energy demand, disaggregated by census division, vehicle and fuel type, and conventional and alternative vehicle technology, vehicle stock and efficiency.

We include additional details in the TDM [documentation](#).

Electricity Market Module

EMM estimates the actions taken by electricity producers (electric utilities and nonutilities) to meet demand in the most economical manner. Based on fuel prices and electricity demands that other NEMS modules provide, the EMM determines the most economical way to supply electricity within environmental and operational constraints.

In each model year, EMM receives electricity demand projections from the NEMS demand modules, fuel prices from the NEMS fuel supply modules, expectations from the NEMS system module, and macroeconomic parameters from the NEMS macroeconomic module. EMM then outputs electricity prices to the demand modules, fuel consumption to the fuel supply modules, emissions to the Integrating Module, and capital requirements to MAM.

EMM is made up of the following primary submodules:

- Electricity load and demand
- Electricity capacity planning
- Electricity fuel dispatch
- Electricity finance and pricing

In addition, EMM includes the REStore submodule, which interfaces with RFM, to estimate the impact of energy storage on the dispatch of generation in each of the modeled electricity regions.

We include additional details in the EMM [documentation](#).

Liquid Fuels Market Module

LFMM projects liquid fuels prices, production activities, and movements of petroleum into and out of the United States and among domestic regions. LFMM projects prices, imports, and exports of petroleum products such as motor gasoline and diesel.

LFMM also projects capacity expansion and fuel consumption at domestic refineries, the distribution of natural gas liquids from natural gas processing plants, and the production of renewable fuels (including ethanol, biomass-based diesel, and cellulosic biofuels) and non-petroleum fossil fuels (including coal-to-liquids and natural gas-to-liquids).

Some of the primary inputs into LFMM include domestic petroleum product demands; the costs of energy inputs such as natural gas, electricity, and coal; product specifications; and international crude oil supply curves. LFMM also takes inputs from other NEMS modules such as demand for liquid fuels from the end-use modules: RDM, CDM, IDM, and TDM. LFMM also outputs information to other NEMS modules such as refinery fuel consumption to IDM.

We include additional details in the LFMM [documentation](#).

Macroeconomic Activity Module

MAM links the energy modules in NEMS to the rest of the economy by providing projections of economic driver variables for use by the supply, demand, and conversion modules of NEMS.

MAM's baseline economic projection contains the initial economic assumptions used in the NEMS to help determine energy demand and supply. MAM can also provide NEMS with alternative economic assumptions representing a range of uncertainty about economic growth. Different assumptions regarding the path of world oil prices or of the penetration of new technologies can also be modeled in MAM.

MAM consists of three sets of models:

- S&P Global's model of the U.S. economy
- EIA's Industrial Output and Employment by Industry Models
- EIA's regional models

All of the MAM models are linked, which provides a fully integrated approach to estimating economic activity at the national, industrial, and regional levels. Some of the key inputs into MAM's regional models are projections of national output, employment by industry, population, national income, and housing stock. MAM also accepts exogenous inputs such as energy prices, consumption, and domestic production. MAM's regional models then calculate levels of industrial output, employment by industry, population, incomes, and housing activity for each of the nine census divisions ([Figure 2](#))

We provide additional details in the MAM [documentation](#).

International Energy Module

IEM, working with LFMM, simulates the interaction between U.S. and global petroleum markets. It uses assumptions of economic growth and expectations of future U.S. and world crude oil-like liquids production and consumption to estimate the effects of changes in U.S. liquid fuels markets on the international petroleum market.

Some of the primary inputs to IEM include the Brent crude oil spot price, projected global crude oil-like liquids supply and demand curves, world supply shares of each crude oil type, petroleum products imports and export supply and demand curves, and projected U.S. domestic crude oil production.

For each year of the projection period, IEM calculates the Brent crude oil price. The module also projects international crude oil market conditions, including consumption, price, and supply availability, as well as the effects of the U.S. petroleum market on the world petroleum market. IEM provides supply curves for foreign crude oil types imported into the United States. Furthermore, IEM provides supply curves for petroleum products imported into the United States and demand curves for petroleum products exported from the United States, as well as petroleum products demand curves for Refinery Region 9 (Maritime Canada and Caribbean region).

We provide additional details in the IEM [documentation](#).

Emissions Policy Module

EPM projects fossil fuel-related carbon dioxide (CO₂) emissions by fuel and by sector and industrial activities that capture carbon in products, such as the manufacturing of plastics. EPM is also capable of modeling emissions pricing in the form of either a national carbon fee or cap-and-trade program.

EPM is called at the end of each NEMS iteration, after all the other modules have been called. The input data for EPM come primarily from other modules of NEMS. Exogenous data include the policy options to be implemented and the CO₂ emission factors. If a CO₂ tax scenario is to be implemented, the tax rate must also be specified. Alternatively, a CO₂ goal may be specified, and the CO₂ tax to EPM consists primarily of projected CO₂ emissions.

Further information about adjustments to the CO₂ calculations that we make in the industrial, transportation, and electricity generation sectors can be found in the Integrating Module [documentation](#).

Integrating Module

The Integrating Module controls the execution of each of the component modules. To facilitate the modular process, the components do not pass information to each other directly but rather communicate through a central data storage location. This modular design allows modules to execute individually, allowing decentralized development of the system and independent analysis and testing of individual modules that appropriately reflect each energy sector.

The Integrating Module controls the NEMS solution algorithm, executing the NEMS component modules iteratively to achieve energy market equilibrium for each projection year. Using energy quantity and price variables as its inputs, the Integrating Module tests whether convergence has occurred, and it optionally adjusts the solution values to aid the convergence process.

The Integrating Module processes energy consumption and price information aggregated primarily at the census-division level (Figure 2). In addition, the Integrating Module processes some intermodule energy market data at regional levels tied to electricity supply regions. We provide additional details in the Integration Module [documentation](#).

Appendix

Table 1. Summary of inputs and outputs of NEMS modules

| Module | Module outputs | Inputs from NEMS | Exogenous inputs |
|------------------------|--|---|---|
| Macroeconomic Activity | Gross domestic product Other economic activity measures, including housing starts, commercial floorspace growth, vehicle sales, and population Price indexes and deflators Manufacturing and non-manufacturing sector production and employment Interest rates | Petroleum and other liquids, natural gas, coal, and electricity prices Oil, natural gas, and coal production Electric power sector and natural gas industry output Natural gas processing plant output End-use energy consumption by fuel | Macroeconomic variables defining alternative economic growth cases |
| International Energy | Computed world oil price World crude oil-like liquids supply and demand curves Supply curves for 11 foreign crude oil types Non-U.S. crude oil-like liquids demands | Gross domestic product deflator U.S. and world crude oil-like liquids production and consumption U.S. crude oil imports by crude oil type | Expected U.S. and world crude oil-like liquids supply and demand curves Expected world liquid fuels production and consumption by region |
| Residential Demand | Energy demand by service and fuel type Changes in housing and appliance stocks Appliance stock efficiency Distributed electricity generation and capacity | Energy product prices Housing starts Population | Current housing stocks, square footage, and retirement rates Current appliance stocks and life expectancy New appliance types, efficiencies, and costs Housing shell retrofit indices Unit energy consumption |

| Module | Module outputs | Inputs from NEMS | Exogenous inputs |
|-----------------------|---|--|---|
| Commercial Demand | Energy demand by service and fuel type Changes in floorspace and appliance stocks Combined heat and power (CHP) and distributed electricity generation and capacity | Energy product prices Interest rates Floorspace growth | Existing commercial floorspace Floorspace survival rates Appliance stocks and survival rates New appliance types, efficiencies, and costs Energy use intensities |
| Industrial Demand | Energy demand by service and fuel type Electricity sales to the grid CHP electricity generation and capacity | Energy product prices Economic output by industry Refinery fuel consumption Lease and plant fuel consumption CHP fuel consumption, electricity generation, and capacity from refineries and oil and natural gas production | Production stages in energy-intensive industries Technology possibility curves Unit energy consumption of outputs Capital stock retirement rates |
| Transportation Demand | Fuel demand by mode Sales, stocks, and characteristics of vehicle types by size class Vehicle miles traveled Fuel economy by technology type Alternative-fuel vehicle sales and stock 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 Population | Existing vehicle stocks by vintage and fuel economy and vehicle survival rates New vehicle technology characteristics Fuel availability Commercial availability Vehicle safety and emissions regulations Vehicle degradation rates |
| Electricity Market | Electricity prices and price components Fuel demands Capacity additions Capital requirements Emissions Renewable capacity Avoided costs | Purchased electricity Fuel prices CHP supply and fuel consumption Electricity sales to the grid Renewable technology characteristics, allowable capacity, and costs Renewable capacity factors Interest rates | Financial data Tax assumptions Capital costs Operation and maintenance costs Operating parameters Emissions rates New technologies Existing facilities Transmission constraints |
| Renewable Fuels | Energy production capacities Capital costs Operating costs (including wood supply prices for the wood submodule) Capacity factors Available capacity Biomass fuel costs | 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 |

| Module | Module outputs | Inputs from NEMS | Exogenous inputs |
|---------------------|---|---|--|
| | Biomass supply curves | | Biomass resource data, demand elasticities, and coefficients |
| Oil and Gas Supply | U.S. crude oil, natural gas, and natural gas plant liquids production Canadian conventional natural gas supply curves Combined heat and power from oil and natural gas production Drilling levels | U.S. and Canadian natural gas production and wellhead prices World oil price Electricity price Gross domestic product Inflation rate | Resource levels Exploration and development costs Production profiles Tax parameters |
| Natural Gas Market | U.S. natural gas wellhead prices, production, and delivered prices Canadian natural gas wellhead price and production Natural gas consumption for lease and plant fuel, pipeline fuel, and in facilities that liquefy natural gas for export Pipeline and distribution tariffs Interregional natural gas flows Storage and pipeline capacity expansion Supplemental natural gas production Imports and exports of liquefied natural gas (LNG) Imports and exports of natural gas from Mexico and Canada | Natural gas demands U.S. and Canadian natural gas supply curves Macroeconomic variables Associated-dissolved natural gas production | Historical consumption, patterns, and supplies Pipeline company-level financial data Pipeline and storage capacity and utilization data Historical end-use citygate and wellhead prices State and federal tax parameters Pipeline and storage expansion cost data Liquefied natural gas supply curves Consumption projections for Canada and Mexico |
| Liquid Fuels Market | Petroleum product prices Imports, exports, and net import expenditures of liquid fuels Refinery activity, fuel use, and capacity additions Ethanol production, price, and motor gasoline blend percent Biodiesel production Liquids produced from coal, natural gas, and biomass CHP Refinery processing gain Refinery profitability and margins | Petroleum product demand by fuel and sector U.S. crude oil production Brent crude oil spot price International crude oil-like supply curves Natural gas prices Electricity prices Coal 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 CHP unit capacities and operating parameters |

| Module | Module outputs | Inputs from NEMS | Exogenous inputs |
|------------------|---|--|---|
| Coal Market | Coal production and distribution | Coal demand | Base year production, prices, productive capacity, capacity utilization, and coal quality parameters Contract quantities Labor productivity, costs, and cost escalators Domestic and international transportation costs International supply curves Demand for U.S. coal exports |
| | Minemouth coal prices | Interest rates | |
| | End-use coal prices | Price indices and deflators | |
| | U.S. coal exports and imports | Diesel fuel prices | |
| | Transportation rates | Electricity prices | |
| | Coal quality by source, destination, and end-use sector | | |
| | World coal flows | | |
| Emissions Policy | Level of emissions | NEMS end-use fuel prices Projected quantities of fuel consumption | Exogenous data include the policy options to be implemented and the carbon dioxide emission factors |

Data source: U.S. Energy Information Administration
 Note: NEMS=National Energy Modeling System