

Introduction

This report presents the major assumptions of the National Energy Modeling System (NEMS) used to generate the projections in the *Annual Energy Outlook 2004*¹ (AEO2004), including general features of the model structure, assumptions concerning energy markets, and the key input data and parameters that are most significant in formulating the model results. Detailed documentation of the modeling system is available in a series of documentation reports.² A synopsis of NEMS, the model components, and the interrelationships of the modules is presented in *The National Energy Modeling System: An Overview*³, which is updated once every two years.

The National Energy Modeling System

The projections in the AEO2004 were produced with the National Energy Modeling System. NEMS is developed and maintained by the Office of Integrated Analysis and Forecasting of the Energy Information Administration (EIA) to provide projections of domestic energy-economy markets in the midterm time period and perform policy analyses requested by decisionmakers in the U.S. Congress, the Administration, including DOE Program Offices, and other government agencies.

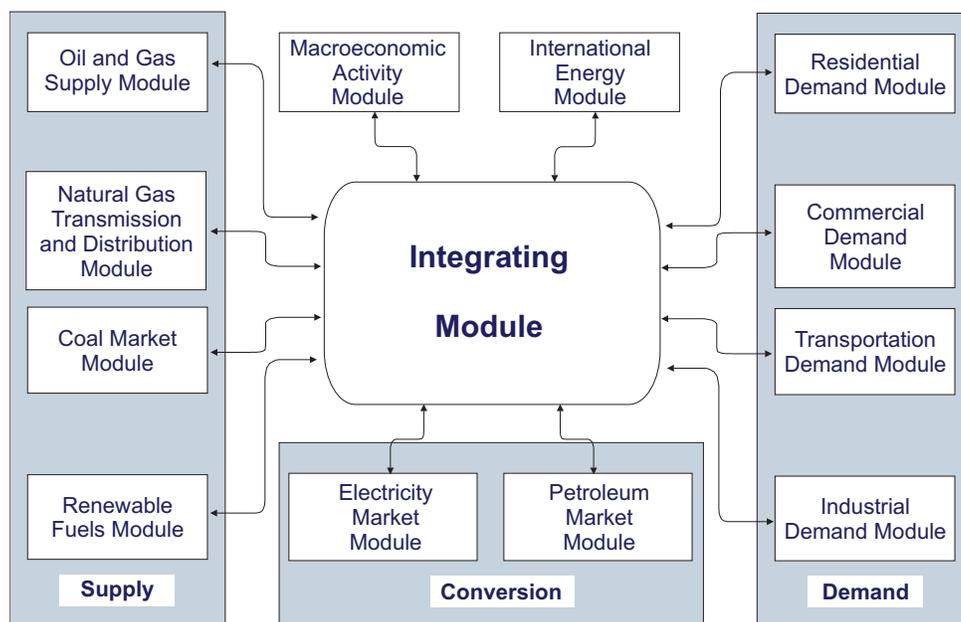
The time horizon of NEMS is approximately 20 years, the midterm period in which the structure of the economy and the nature of energy markets are sufficiently understood that it is possible to represent considerable structural and regional detail. Because of the diverse nature of energy supply, demand, and conversion in the United States, NEMS supports regional modeling and analysis in order to represent the regional differences in energy markets, to provide policy impacts at the regional level, and to portray transportation flows. The level of regional detail for the end-use demand modules is the nine Census divisions. Other regional structures include production and consumption regions specific to oil, gas, and coal supply and distribution, the North American Electric Reliability Council regions and subregions for electricity, and the Petroleum Administration for Defense Districts (PADD) for refineries. Maps illustrating the regional formats used in each module are included in this report. Only national results are presented in the AEO2004, with the regional and other detailed results available on the EIA Home Page. (<http://www.eia.doe.gov/oiaf/aeo/index.html>)

For each fuel and consuming sector, NEMS balances the energy supply and demand, accounting for the economic competition between the various energy fuels and sources. NEMS is organized and implemented as a modular system (Figure 1). The modules represent each of the fuel supply markets, conversion sectors, and end-use consumption sectors of the energy system. NEMS also includes a macroeconomic and an international oil module. The primary flows of information among each of these modules are the delivered prices of energy to the end user and the quantities consumed by product, region, and sector. The delivered prices of fuel encompass all the activities necessary to produce, import, and transport fuels to the end user. The information flows also include other data such as economic activity, domestic production activity, and international petroleum supply availability.

The integrating module of NEMS controls the execution of each of the component modules. To facilitate modularity, the components do not pass information to each other directly but communicate through a central data storage location. This modular design provides the capability to execute modules individually, thus allowing decentralized development of the system and independent analysis and testing of individual modules. This modularity allows use of the methodology and level of detail most appropriate for each energy sector. NEMS solves by calling each supply, conversion, and end-use demand module in sequence until the delivered prices of energy and the quantities demanded have converged within tolerance, thus achieving an economic equilibrium of supply and demand in the consuming sectors. Solution is reached annually through the midterm horizon. Other variables are also evaluated for convergence such as petroleum product imports, crude oil imports, and several macroeconomic indicators.

Each NEMS component also represents the impact and cost of legislation and environmental regulations that affect that sector. NEMS reflects all current legislation and environmental regulations that are defined sufficiently to be modeled. The potential impacts of pending or proposed legislation, regulations, or standards—or sections of legislation that have been enacted but that require funds that have not been appropriated or where targets have not been specified—are not reflected in the sectors. A list of the Federal

Figure 1. National Energy Modeling System



Source: Energy Information Administration, Office of Integrated Analysis and Forecasting.

and selected State legislation and regulations included in the AEO, including how it is incorporated, is provided in Appendix A. NEMS also includes an analysis of the impacts of voluntary programs to reduce energy demand and carbon dioxide emissions, which are separately described under each module.

Component Modules

The component modules of NEMS represent the individual supply, demand, and conversion sectors of domestic energy markets and also include international and macroeconomic modules. In general, the modules interact through values representing the prices of energy delivered to the consuming sectors and the quantities of end-use energy consumption. This section provides brief summaries of each of the modules.

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), industrial output, interest rates, disposable income, prices, and employment. Industrial drivers are calculated for 35 industrial sectors. This module uses the following Global Insight models: Macroeconomic Model of the U.S. Economy, National Industry Shipments Model, National Employment Model, and Regional Disaggregation Model. In addition, EIA has constructed a Commercial Floorspace Model to forecast 13 floorspace types in 9 Census Divisions.

International Energy Module

The International Energy Module represents 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 (PMM) of NEMS, in response to changes in U.S. import requirements. Fourteen international petroleum product supply curves, including curves for oxygenates, are also calculated and provided to the PMM.

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 forecasts 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 changes in the efficiency of energy use for residential end uses and in light-duty vehicle fuel efficiency. Estimates of average expenditures for households are provided 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, based on delivered energy prices, the menu of equipment available, the 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, based on 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. The commercial module incorporates combined heat and power (CHP) technology. Both modules include a forecast 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 shipments 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. The air transportation module was substantially revamped for *AEO2004*. The model represents the industry practice of parking aircraft to reduce operating costs and the movement of aircraft from the passenger to cargo markets as aircraft age. For air freight shipments, the model employs narrow-body and wide-body aircraft only. The model also uses an infrastructure constraint that limits air travel growth to levels commensurate with industry-projected infrastructure expansion and capacity growth.

Electricity Market Module

The Electricity Market Module represents generation, transmission, and pricing of electricity, subject to delivered prices for coal, petroleum products, natural gas, and biofuels; costs of generation by all generation plants, including capital costs; macroeconomic variables for costs of capital and domestic investment; enforced environmental emissions laws and regulations; and electricity load shapes and demand. There are four primary submodules—capacity planning, fuel generation dispatch, load and demand-side management, and finance and pricing. Nonutility generation, distributed generation, and transmission and trade are modeled in the planning and dispatch submodules. The levelized fuel cost of uranium fuel for nuclear generation is directly incorporated into the Electricity Market Module. All CAAA90 compliance

options with targets that have been specified are explicitly represented in the capacity expansion and dispatch decisions. New generating technologies for fossil fuels, nuclear, and renewables compete directly in the decisions.

Renewable Fuels Module

The Renewable Fuels Module (RFM) includes submodules representing natural resource supply and technology input information for central-station, grid-connected electricity generation technologies, including biomass (wood, energy crops, and biomass co-firing), geothermal, landfill gas, solar thermal, solar photovoltaics, and wind energy. Conventional hydroelectricity is represented in the Electricity Market Module (EMM). Investment tax credits for renewable fuels are incorporated, as currently legislated in the Energy Policy Act of 1992.

Oil and Gas Supply Module

The Oil and Gas Supply Module models 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 gas recovery from coalbeds and low-permeability formations of sandstone and shale. This framework analyzes cash flow and profitability to compute investment and drilling for each of the supply sources, based on the prices for crude oil and natural gas, the domestic recoverable resource base, and the state of 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 to Canada and Mexico, and liquefied natural gas (LNG) imports and exports. Crude oil production quantities 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 natural gas 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 and storage capacity expansion requirements. Peak and off-peak periods are represented for natural gas transmission, and core and non-core 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, the availability and price of imported petroleum, and the domestic production of crude oil, natural gas liquids, and alcohol fuels. The module represents refining activities each of the five Petroleum Administration for Defense Districts (PADDs). The module uses the same crude oil types as the International Energy Module. It explicitly models the requirements of CAAA90 and the costs of automotive fuels, such as oxygenated and reformulated gasoline, and includes oxygenate production and blending for reformulated gasoline. *AEO2004* reflects State legislation that bans or limits the use of the gasoline blending component methyl tertiary butyl ether (MTBE) in the next several years in California, Colorado, Connecticut, Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, New York, Ohio, South Dakota, Washington, and Wisconsin.

The Federal oxygen requirement for reformulated gasoline in Federal nonattainment areas is assumed to remain intact. The "Tier 2" regulation that requires the nationwide phase-in of gasoline with a greatly reduced annual average sulfur content, between 2004 and 2007 and the diesel regulation that significantly limits the sulfur content of all highway diesel fuel produced after June 1, 2006 are represented in *AEO2004*. Costs of the regulation include capacity expansion for refinery-processing units based on a 10-percent hurdle rate and a 10-percent after-tax return on investment. End-use prices are based on the marginal costs of

production, plus markups representing product and distribution costs, and State and Federal taxes. Refinery capacity expansion may occur in all five refining regions.

Coal Market Module

The Coal Market Module (CMM) simulates mining, transportation, and pricing of coal, subject to the end-use demand for coal differentiated by physical characteristics, such as heat and sulfur content. The coal supply curves include a response to capacity utilization of mines, mining capacity, fuel costs, labor productivity, and factor input costs (mining equipment, mining labor and fuel requirements). Twelve coal types are represented—differentiated by coal rank, sulfur content, and mining process. Production and distribution are computed for 11 supply and 14 demand regions, using imputed coal transportation costs and trends in factor input costs. The CMM 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.

Cases for the *Annual Energy Outlook 2004*

The *AEO2004* presents detailed results for five cases which differ from each other due to fundamental assumptions concerning the domestic economy and world oil market conditions. Three alternative assumptions are specified for each of these two factors, with the reference case using the midlevel assumption for each.

- **Economic Growth** - In the *reference case*, real GDP grows at an average annual rate of 3.0 percent from 2002 through 2025, supported by a 2.3 percent per year growth in productivity in nonfarm business and a 1.1 percent per year growth in nonfarm employment. In the *high economic growth case*, real GDP is projected to increase by 3.5 percent per year, with productivity and nonfarm employment growing at 2.7 percent and 1.4 percent per year, respectively. In the *low economic growth case*, the average annual growth in GDP, productivity and nonfarm employment is 2.4, 1.8 and 0.9 percent, respectively.
- **World Oil Markets** - In the *reference case*, the average world oil price increases to \$27.00 per barrel (in real 2002 dollars) in 2025. Reflecting uncertainty in world markets, the price in 2025 reaches \$16.98 per barrel in the *low oil price case* and \$35.03 per barrel in the *high oil price case*.

In addition to these five cases, 26 additional cases presented in Table 1 explore the impacts of changing key assumptions on individual sectors.

Many of the side cases were designed to examine the impacts of varying key assumptions for individual modules or a subset of the NEMS modules, and thus the full market consequences, such as the consumption or price impacts, are not captured. In a fully integrated run, the impacts would tend to narrow the range of the differences from the reference case. For example, the best available technology side case in the residential demand assumes that all future equipment purchases are made from a selection of the most efficient technologies available in a particular year. In a fully integrated NEMS run, the lower resulting fuel consumption would have the effect of lowering the market prices of those fuels with the concomitant impact of increasing economic growth, thus stimulating some additional consumption. As another example, the higher electricity demand side case results in higher electricity prices due to the need to add additional capacity to the grid. If this was a fully integrated run, the demand for electricity would be reduced as a result of higher prices, thus moderating somewhat the higher demand. The results of single model or partially integrated cases should be considered the maximum range of the impacts that could occur with the assumptions defined for the case.

All projections are based on Federal, State, and local laws and regulations in effect on September 1, 2003 that have been specifically defined, including the additional fuels taxes in the Omnibus Budget Reconciliation Act of 1993, the CAAA90, the Energy Policy Act of 1992, the Outer Continental Shelf Deep Water Royalty Relief Act of 1995, the Federal Highway Bill of 1998, the Energy Policy Conservation Act of 1975, the National Energy Appliance Conservation Act of 1987, the Maritime Security Act of 2002, the new CAFE Standards for light trucks publishing by NATSA in 2003, EPA standards for gasoline and diesel fuel and heavy-duty vehicle emissions, and the energy-consuming equipment standards announced in 2001.

Table 1. Summary of AEO2004 Cases

Case name	Description	Integration mode
Reference	Baseline economic growth, world oil price, and technology assumptions	Fully integrated
Low Economic Growth	Gross domestic product grows at an average annual rate of 2.4 percent from 2002 through 2025, compared to the reference case growth of 3.0 percent	Fully integrated
High Economic Growth	Gross domestic product grows at an average annual rate of 3.5 percent from 2002 through 2025, compared to the reference case growth of 3.0 percent	Fully integrated
Low World Oil Price	World oil prices are \$19.04 per barrel in 2025, compared to \$26.57 per barrel in the reference case	Fully integrated
High World Oil Price	World oil prices are \$33.05 per barrel in 2025, compared to \$26.57 per barrel in the reference case	Fully integrated
Residential: 2004 Technology	Future equipment purchases based on equipment available in 2004. Existing building shell efficiencies fixed at 2004 levels	With commercial
Residential: High Technology	Earlier availability, lower costs, and higher efficiencies assumed for more advanced equipment. Heating shell efficiency increases by 13 percent from 2001 values by 2025.	With commercial
Residential: Best Available Technology	Future equipment purchases and new building shells based on most efficient technologies available. Heating shell efficiency increases by 18 percent from 2001 values by 2025	With commercial
Commercial: 2004 Technology	Future equipment purchases based on equipment available in 2004. Building shell efficiencies fixed at 2004 levels.	With residential
Commercial: High Technology	Earlier availability, lower costs, and higher efficiencies assumed for more advanced equipment. Heating shell efficiencies for new and existing buildings increase by 8.75 and 6.25 percent, respectively, from 1999 values by 2025.	With residential
Commercial: Best Available Technology	Future equipment purchases based on most efficient technologies available. Heating shell efficiencies for new and existing buildings increase by 10.5 and 7.5 percent, respectively, from 1999 values by 2025.	With residential
Industrial: 2004 Technology	Efficiency of plant and equipment fixed at 2004 levels.	Standalone
Industrial: High Technology	Earlier availability, lower costs, and higher efficiencies assumed for more advanced equipment	Standalone
Transportation: 2004 Technology	Efficiencies for new equipment in all modes of travel are fixed at 2004 levels	Standalone
Transportation: High Technology	Reduced costs and improved efficiencies are assumed for advanced technologies.	Standalone
Integrated 2004 Technology	Combination of the residential, commercial, industrial, and transportation 2004 technology cases, electricity low fossil technology case, and assumption of renewable technologies fixed at 2004 levels	Fully Integrated
Integrated High Technology	Combination of the residential, commercial, industrial, and transportation high technology cases, electricity high fossil technology case, high renewables case, and advanced nuclear cost case.	Fully Integrated

Table 1. Summary of AEO2003 Cases (Continued)

Cases	Description	Integration Mode
Electricity: Advanced Nuclear Cost	New nuclear capacity is assumed to have 10 percent lower capital and operating costs in 2025 than in the reference case	Fully integrated
Electricity: Nuclear AP1000 Case	New nuclear capacity is assumed to have lower capital costs, based on vendor goals for the AP1000 reactor	Fully Integrated
Electricity: Nuclear Vendor Estimate Case	New nuclear capacity is assumed to have lower capital costs, based on vendor goals for the AP1000 and CANDU reactors	Fully Integrated
Electricity: High Demand	Electricity demand increases at an annual rate of 2.5 percent, compared to 1.8 percent in the reference case	Partially Integrated
Electricity: Low Fossil Technology	New advanced fossil generating technologies are assumed not to improve over time from 2004	Partially Integrated
Electricity: High Fossil Technology	Costs and efficiencies for advanced fossil-fired generating technologies improve by 10 percent in 2025 from reference case values	Partially Integrated
Electricity: DOE Fossil Goals	Costs and/or efficiencies for advanced fossil-fired generating technologies improve from reference case values, based on Department goals	Partially Integrated
Renewables: Low Renewables	New renewable generating technologies are assumed not to improve over time from 2004	Fully Integrated
Renewables: High Renewables	Levelized cost of energy for nonhydropower renewable generating technologies declines by 10 percent in 2025 from reference case values	Fully Integrated
Renewables: DOE Goals	Lower costs and higher efficiencies for central-station renewable generating technologies and for distributed photovoltaics, approximating U.S. Department of Energy goals for 2025. Includes greater improvements in residential and commercial photovoltaic systems, more rapid improvement in recovery of industrial biomass byproducts, and more rapid improvement in cellulosic ethanol production technology.	Fully Integrated
Oil and Gas: Slow Technology	Cost, finding rate, and success rate parameters adjusted for 50-percent slower improvement than in the reference case	Fully integrated
Oil and Gas: Rapid Technology	Cost, finding rate, and success rate parameters adjusted for 50-percent more rapid improvement than in the reference case.	Fully integrated
Coal: Low Mining Cost	Productivity increases at an annual rate of 2.9 percent, compared to the reference case growth of 1.3 percent. Real wages and real mine equipment costs decrease by 0.5 percent annually, compared to constant real wages and equipment costs in the reference case.	Fully integrated
Coal: High Mining Cost	Productivity decreases at an annual rate of 0.6 percent, compared to the reference case growth of 1.3 percent. Real wages and real mine equipment costs increase by 0.5 percent annually, compared to constant real wages and equipment costs in the reference case.	Fully integrated

Emissions

Carbon dioxide emissions from energy use are dependent on the carbon dioxide content of the fossil fuel, the fraction of the fuel consumed in combustion, and the consumption of that fuel. The product of the carbon dioxide content at full combustion and the combustion fraction yields an adjusted carbon dioxide emission factor for each fossil fuel. The emissions factors are expressed in millions of metric tons carbon equivalent of carbon dioxide emitted per quadrillion Btu of energy use, or equivalently, in kilograms carbon equivalent of carbon dioxide per million Btu. The adjusted emissions factors are multiplied by the energy consumption of that fossil fuel to arrive at the carbon dioxide emissions projections.

For fuel uses of energy, the combustion fractions are assumed to be 0.99 for liquid fuels and 0.995 for gaseous fuels. The carbon dioxide 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. 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 are taken as zero, and no emission coefficient is reported. Renewable fuels include hydroelectric power, biomass, photovoltaic, geothermal, ethanol, landfill gas, solar thermal, and wind energy.

Table 2 presents the carbon dioxide coefficients at full combustion, the combustion fractions, and the adjusted carbon dioxide emission factors used for *AEO2004*.

Table 2. Carbon Dioxide Emission Factors
(Kilograms-carbon equivalent per million Btu)

Fuel Type	Carbon Dioxide Coefficient at Full Combustion	Combustion Fraction	Adjusted Emissions Factor
Petroleum			
Motor Gasoline	19.34	0.990	19.15
Liquefied Petroleum Gas			
Used as Fuel	17.18	0.995	17.09
Used as Feedstock	16.87	0.200	3.37
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 Feedstocks	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 Utility ¹	25.76	0.990	25.50
Natural Gas			
Used as Fuel	14.47	0.995	14.40
Used as Feedstocks	14.47	0.774	11.20

¹Emission factors for coal used for electricity generation are specified by coal supply region and types of coal, so the average carbon dioxide contents for coal varies throughout the forecast. The 2002 average is 25.50.

Source: Energy Information Administration, *Emissions of Greenhouse Gases in the United States 2002*, DOE/EIA-0573(2002), (Washington, DC, October 2003).

Notes and Sources

- [1] Energy Information Administration, Annual Energy Outlook 2004 (AEO2004), DOE/EIA-0383(2004), (Washington, DC, January 2004).
- [2] NEMS documentation reports are available on the EIA Homepage (<http://www.eia.doe.gov/bookshelf.html>).
- [3] Energy Information Administration, The National Energy Modeling System: An Overview 2003, DOE/EIA-0581(2003), (Washington, DC, March 2003).

